OCAS-DRI-DBS-19-26
NEW CAR ASSESSMENT PROGRAM
DYNAMIC BRAKE SUPPORT CONFIRMATION TEST

2019 Volvo XC40

DYNAMIC RESEARCH, INC.
355 Van Ness Avenue
Torrance, California 90501

16 May 2019

Final Report

Prepared Under Contract No.: DTNH22-14-D-00333

U. S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Office of Crash Avoidance Standards
1200 New Jersey Avenue, SE
West Building, 4th Floor (NRM-200)
Washington, DC 20590

Prepared for the Department of Transportation, National Highway Traffic Safety Administration, under Contract No. DTNH22-14-D-00333.

Prepared By: J. Lenkeit and A. Ricci

Program Manager Test Engineer

Date: 16 May 2019

<table>
<tr><td>1. Report No.

OCAS-DRI-DBS-19-26</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Final Report of Dynamic Brake Support Testing of a 2019 Volvo XC40.</td><td colspan="2">5. Report Date

16 May 2019</td></tr>
<tr><td colspan="2">6. Performing Organization Code

DRI</td></tr>
<tr><td colspan="2">7. Author(s)
J. Lenkeit, Program Manager
A. Ricci, Test Engineer</td><td colspan="2">8. Performing Organization Report No.

DRI-TM-18-149</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address

Dynamic Research, Inc.
355 Van Ness Ave, STE 200
Torrance, CA 90501</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
DTNH22-14-D-00333</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
U.S. Department of Transportation
National Highway Traffic Safety Administration
Office of Crash Avoidance Standards
1200 New Jersey Avenue, SE,
West Building, 4th Floor (NRM-200)
Washington, D.C. 20590</td><td colspan="2">13. Type of Report and Period Covered

Final Test Report
January - May 2019</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code

NRM-200</td></tr>
<tr><td colspan="4">15. Supplementary Notes</td></tr>
<tr><td colspan="4">16. Abstract
These tests were conducted on the subject 2019 Volvo XC40 in accordance with the specifications of the Office of Crash Avoidance Standards most current Test Procedure in docket NHTSA-2015-0006-0026; DYNAMIC BRAKE SUPPORT PERFORMANCE EVALUATION CONFIRMATION TEST FOR THE NEW CAR ASSESSMENT PROGRAM, October 2015. The vehicle passed the requirements of the test for all four DBS test scenarios.</td></tr>
<tr><td colspan="2">17. Key Words

Dynamic Brake Support,
DBS,
AEB,
New Car Assessment Program,
NCAP</td><td colspan="2">18. Distribution Statement
Copies of this report are available from the following:
NHTSA Technical Reference Division
National Highway Traffic Safety Administration
1200 New Jersey Avenue, SE
Washington, D.C. 20590</td></tr>
<tr><td>19. Security Classif. (of this report)

Unclassified</td><td>20. Security Classif. (of this page)

Unclassified</td><td>21. No. of Pages

164</td><td>22. Price</td></tr>
</table>

TABLE OF CONTENTS

Section I
OVERVIEW AND TEST SUMMARY

Dynamic Brake Support (DBS) systems are a subset of Automatic Emergency Braking (AEB) systems. DBS systems are designed to avoid or mitigate consequences of rear-end crashes by automatically applying supplemental braking on the subject vehicle when the system determines that the braking applied by the driver is insufficient to avoid a collision.

DBS systems intervene in driving situations where a rear-end collision is expected to be unavoidable unless additional braking is realized. Since DBS interventions are designed to occur late in the pre-crash timeline, and the driver has already initiated crash-avoidance braking, DBS systems are not required to alert the driver that a DBS intervention has occurred. In addition to sensors monitoring vehicle operating conditions, such as speed, brake application, etc., DBS systems employ RADAR, LIDAR, and/or vision-based sensors capable of detecting surrounding vehicles in traffic. Algorithms in the system's Central Processing Unit (CPU) use this information to continuously monitor the likelihood of a rear-end crash, and command additional braking as needed to avoid or mitigate such a crash.

The method prescribed by the National Highway Traffic Safety Administration (NHTSA) to evaluate DBS performance on the test track involves three longitudinal, rear-end type crash configurations and a false positive test. In the rear-end scenarios, a subject vehicle (SV) approaches a stopped, slower-moving, or decelerating principal other vehicle (POV) in the same lane of travel. For these tests, the POV is a strikeable object with the characteristics of a compact passenger car. The fourth scenario is used to evaluate the propensity of a DBS system to inappropriately activate in a non-critical driving scenario that does not present a safety risk to the SV occupant(s).

The purpose of the testing reported herein was to objectively quantify the performance of a Dynamic Brake Support system installed on a 2019 Volvo XC40. This test to assess Dynamic Brake Support systems is sponsored by the National Highway Traffic Safety Administration under Contract No. DTNH22-14-D-00333 with the New Car Assessment Program (NCAP).

Section II
DATA SHEETS

DYNAMIC BRAKE SUPPORT

DATA SHEET 1: TEST RESULTS

(Page 1 of 1)

2019 Volvo XC40

SUMMARY RESULTS

VIN: *YV4AC2HK3K20xxxx*

Test Date: *2/6/2019*

Test 1 - Subject Vehicle Encounters Stopped Principal Other Vehicle

SV 25 mph: *Pass*

Test 2 - Subject Vehicle Encounters Slower Principal Other Vehicle

SV 25 mph POV 10 mph: *Pass*

SV 45 mph POV 20 mph: *Pass*

Test 3 - Subject Vehicle Encounters Decelerating Principal Other Vehicle

SV 35 mph POV 35 mph: *Pass*

Test 4 - Subject Vehicle Encounters Steel Trench Plate

SV 25 mph: *Pass*

SV 45 mph: *Pass*

Overall: ***Pass***

Notes:

DYNAMIC BRAKE SUPPORT

DATA SHEET 2: VEHICLE DATA

(Page 1 of 2)

2019 Volvo XC40

TEST VEHICLE INFORMATION

VIN: *YV4AC2HK3K20xxxx*

Body Style: *SUV* Color: *Fusion Red Metallic*

Date Received: *1/21/2019* Odometer Reading: *72 mi*

Engine: *2 L Inline 4*

Transmission: *Automatic*

Final Drive: *FWD*

Is the vehicle equipped with:

ABS	**X**	Yes	____	No
Adaptive Cruise Control	**X**	Yes	____	No
Collision Mitigating Brake System	**X**	Yes	____	No

DATA FROM VEHICLE'S CERTIFICATON LABEL

Vehicle manufactured by: *Volvo Car Corporation*

Date of manufacture: *6/18*

DATA FROM TIRE PLACARD:

Tires size as stated on Tire Placard: Front: *235/55 R18*

Rear: *235/55 R18*

Recommended cold tire pressure: Front: *230 kPa (33 psi)*

Rear: *230 kPa (33 psi)*

<u>DYNAMIC BRAKE SUPPORT</u>

<u>DATA SHEET 2: VEHICLE DATA</u>

2019 Volvo XC40

<u>TIRES</u>

Tire manufacturer and model: *<u>Michelin Primacy</u>*

Front tire size: *<u>235/55 R18</u>*

Rear tire size: *<u>235/55 R18</u>*

<u>VEHICLE ACCEPTANCE</u>

Verify the following before accepting the vehicle:

__X__ All options listed on the "window sticker" are present on the test vehicle

__X__ Tires and wheel rims are the same as listed.

__X__ There are no dents or other interior or exterior flaws.

__X__ The vehicle has been properly prepared and is in running condition.

__X__ Verify that spare tire, jack, lug wrench, and tool kit (if applicable) is located in the vehicle cargo area.

DYNAMIC BRAKE SUPPORT

DATA SHEET 3: TEST CONDITIONS

(Page 1 of 2)

2019 Volvo XC40

GENERAL INFORMATION

Test date: *2/6/2019*

AMBIENT CONDITIONS

Air temperature: *5.0 C (41 F)*

Wind speed: *0.0 m/s (0.0 mph)*

X Windspeed ≤ 10 m/s (22 mph)

X Tests were not performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash.

X Tests were conducted during daylight hours with good atmospheric visibility (defined as an absence of fog and the ability to see clearly for more than 5000 meters). The tests were not conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal, and camera “washout” or system inoperability results.

VEHICLE PREPARATION

Verify the following:

All non consumable fluids at 100 % capacity : **X**

Fuel tank is full: **X**

Tire pressures are set to manufacturer's recommended cold tire pressure: **X**

Front: *230 kPa (33 psi)*

Rear: *230 kPa (33 psi)*

DYNAMIC BRAKE SUPPORT

DATA SHEET 3: TEST CONDITIONS

(Page 2 of 2)

2019 Volvo XC40

WEIGHT

Weight of vehicle as tested including driver and instrumentation

Left Front:	*533.9 kg (1177 lb)*	Right Front	*517.1 kg (1140 lb)*
Left Rear	*387.8 kg (855 lb)*	Right Rear	*375.1 kg (827 lb)*
		Total:	*1813.9 kg (3999 lb)*

DYNAMIC BRAKE SUPPORT SYSTEM

DATA SHEET 4:

DYNAMIC BRAKE SUPPORT SYSTEM OPERATION

2019 Volvo XC40

Name of the DBS option, option package, etc.

City Safety (standard)

System setting used for test (if applicable):

City Safety Warning set to normal.

Brake application mode used for test:

Hybrid control

What is the minimum vehicle speed at which the DBS system becomes active?

4 kph (2.5 mph)

What is the maximum vehicle speed at which the DBS system functions?

No Maximum

Does the vehicle system require an initialization sequence/procedure?

No initialization process required for the function to be active. However, it is recommended though that in addition to the procedure in CIB & DBS test protocols, the vehicle has been pre-conditioned with normal driving on public roads. (Preferably multiple driving cycles with a total of 60 miles.)

Will the system deactivate due to repeated AEB activations, impacts or near-misses?

No deactivation occurs. There is a three second time-out after each intervention, but after that the system is activated automatically again.

DYNAMIC BRAKE SUPPORT SYSTEM

DATA SHEET 4:

DYNAMIC BRAKE SUPPORT SYSTEM OPERATION

2019 Volvo XC40

How is the Forward Collision Warning presented to the driver?

(Check all that apply)

X Warning light

X Buzzer or audible alarm

___ Vibration

X Other

Describe the method by which the driver is alerted. For example, if the warning is a light, where is it located, its color, size, words or symbol, does it flash on and off, etc. If it is a sound, describe if it is a constant beep or a repeated beep. If it is a vibration, describe where it is felt (e.g., pedals, steering wheel), the dominant frequency (and possibly magnitude), the type of warning (light, audible, vibration, or combination) etc.

Audio: Repeated beep

Haptic: Short brake pulse

Is there a way to deactivate the system?

___ Yes

X No

If yes, please provide a full description including the switch location and method of operation, any associated instrument panel indicator, etc.

No, functionality is always on.

2019 Volvo XC40

Is the vehicle equipped with a control whose purpose is to adjust the range setting or otherwise influence the operation of DBS?

__X__ Yes

____ No

If yes, please provide a full description.

Using the steering wheel mounted controls and the vehicle display select:
-Settings
-My Car
-IntelliSafe

Under City Safety Warning, select Late, Normal or Early to set the desired warning distance.

(See Figures A16 and A17)

Are there other driving modes or conditions that render DBS inoperable or reduce its effectiveness?

__X__ Yes

____ No

If yes, please provide a full description.

City Safety functionality may be reduced in certain situations:

Surroundings

Low objects
Hanging objects, such as flags for overhanging loads or accessories such as auxiliary lights or front protective grids that extend beyond the height of the hood, may limit City Safety functionality.

Slippery road conditions
The extended braking distance on slippery roads may reduce City Safety's capacity to help avoid a collision. In these types of situations, the Anti-lock Braking System and Electronic Stability Control (ESC62) will help provide optimal braking power with maintained stability.

(Continued next page)

Backlighting
The visual warning signal in the windshield may be difficult to detect in bright sunlight, if there are reflections, or if the driver is wearing sunglasses or not looking straight ahead.

Heat
If the temperature in the passenger compartment is high due to e.g. bright sunlight, the visual warning signal in the windshield may be temporarily disabled.

Camera and radar sensor's field of vision
The camera's field of vision is limited and in certain situations, it may be unable to detect pedestrians, large animals, cyclists or vehicles, or it may detect them later than expected.

Vehicles that are dirty may be detected later than clean vehicles, and in dark conditions, motorcycles may be detected late or not at all.

Warnings and brake interventions can be triggered late or not at all if the traffic situation or external influences prevent the camera and radar unit from properly detecting pedestrians, cyclists, large animals or vehicles ahead of the vehicle.

To be able to detect vehicles at night, its front and rear lights must work and illuminate clearly.

The camera and radar unit have a limited range for pedestrians and cyclists – the system can provide effective warnings and brake interventions if the relative speed is lower than 50 km/h (30 mph). For stationary or slow-moving vehicles, warnings and brake interventions are effective at vehicle speeds of up to 70 km/h (43 mph). Speed reduction for large animals is less than 15 km/h (9 mph) and can be achieved at vehicle speeds over 70 km/h (43 mph). At lower speeds, the warning and brake intervention for large animals is less effective.

(Continued next page)

Warnings for stationary or slow-moving vehicles and large animals can be disengaged due to darkness or poor visibility.

Warnings and brake interventions for pedestrians and cyclists are disengaged at vehicle speeds over 80 km/h (50 mph).

Do not place, affix or mount anything on the inside or outside of the windshield, or in front of or around the camera and radar unit – this could disrupt camera-based functions.

Objects, snow, ice or dirt in the area of the camera sensor can reduce the function, disengage it completely or give an improper function response.

Notes:

Section III
TEST PROCEDURES

A. TEST PROCEDURE OVERVIEW

Four test scenarios were used, as follows:

Test 1. Subject Vehicle (SV) Encounters Stopped Principal Other Vehicle (POV)
Test 2. Subject Vehicle Encounters Slower Principal Other Vehicle
Test 3. Subject Vehicle Encounters Decelerating Principal Other Vehicle
Test 4. Subject Vehicle Encounters Steel Trench Plate

An overview of each of the test procedures follows.

1. TEST 1 – SUBJECT VEHICLE ENCOUNTERS STOPPED PRINCIPAL OTHER VEHICLE ON A STRAIGHT ROAD

This test evaluates the ability of the DBS system to detect and respond to a stopped lead vehicle in the immediate forward path of the SV, as depicted in Figure 1.

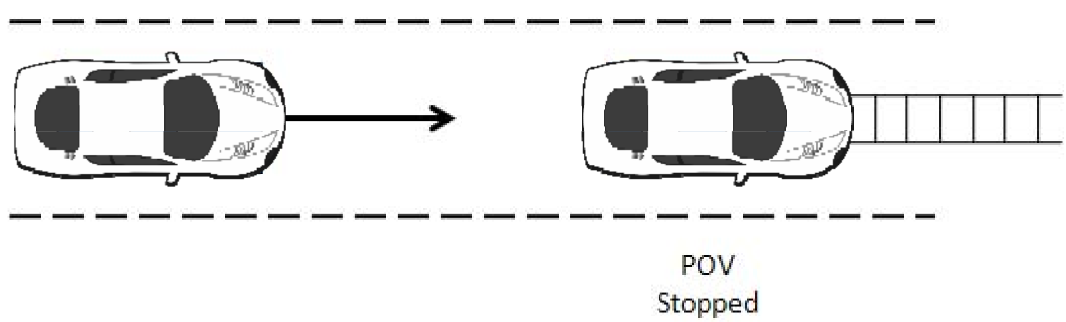


Figure 1. Depiction of Test 1

a. Procedure

The POV was parked in the center of a travel lane, with its longitudinal axis oriented parallel to the roadway edge and facing the same direction as the SV, so that the SV approaches the rear of the POV.

The SV ignition was cycled prior to each test run. The SV was driven at a nominal speed of 25 mph (40.2 kph) in the center of the lane of travel, toward the parked POV. The SV throttle pedal was released within 500 ms after t_{FCW}, i.e., within 500 ms of the FCW alert. The SV brakes were applied at TTC = 1.1 seconds (SV-to-POV distance of 40 ft (12 m)).

The test concluded when either:

- The SV came into contact with the POV or
- The SV came to a stop before making contact with the POV.

In addition to the general test validity criteria described below, for an individual test trial to be valid, the following was required throughout the test:

- The SV speed could not deviate from the nominal speed by more than 1.0 mph (1.6 kph) during an interval defined by a Time to Collision (TTC) = 5.1 seconds to t_{FCW}. For this test, TTC = 5.1 seconds is taken to occur at an SV-to-POV distance of 187 ft (57 m).

Table 1. Nominal Stopped POV DBS Test Choreography

Test Speeds		SV Speed Held Constant		SV Throttle Fully Released By		SV Brake Application Onset (for each application magnitude)	
SV	**POV**	**TTC (seconds)**	**SV-to-POV Headway**	**TTC (seconds)**	**SV-to-POV Headway**	**TTC (seconds)**	**SV-to-POV Headway**
25 mph (40.2 kph)	0	5.1 → t_{FCW}	187 ft (57 m) → t_{FCW}	Within 500 ms of FCW1 onset	Varies	1.1	40 ft (12 m)

b. Criteria

The performance requirement for this series of tests is that there be no SV-POV impact for at least five of the seven valid test trials.

2. TEST 2 – SUBJECT VEHICLE ENCOUNTERS SLOWER PRINCIPAL OTHER VEHICLE

This test evaluates the ability of the DBS system to detect and respond to a slower-moving lead vehicle traveling at a constant speed in the immediate forward path of the SV, as depicted in Figure 2.

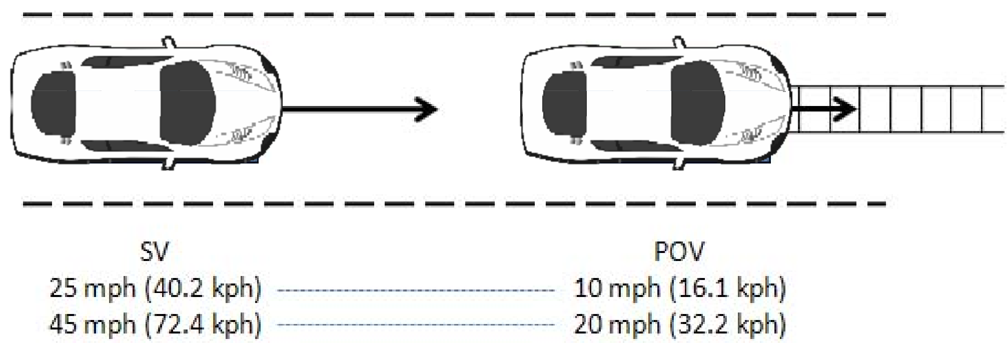


Figure 2. Depiction of Test 2

a. Procedure

The SV ignition was cycled prior to each test run. The tests were conducted two ways. In the first, the POV was driven at a constant 10.0 mph (16.1 kph) in the center of the lane of travel while the SV was driven at 25.0 mph (40.2 kph), in the center lane of travel, toward the slower-moving POV. In the second, the POV was driven at a constant 20.0 mph (32.2 kph) in the center of the lane of travel while the SV was driven at 45.0 mph (74.4 kph), in the center lane of travel, toward the slower-moving POV. In both cases, the SV throttle pedal was released within 500 ms after $t_{FCW,}$ i.e., within 500 ms of the FCW alert. The SV brakes were applied at TTC = 1.0 seconds, assumed to be SV-to-POV distance of 22 ft (7 m) for an SV speed of 25 mph and 37 ft (11 m) for an SV speed of 45 mph.

The test concluded when either:

- The SV came into contact with the POV or
- 1 second after the speed of the SV became less than or equal to that of the POV.

The SV driver then braked to a stop.

In addition to the general test validity criteria described below, for an individual test trial to be valid, the following was required throughout the test:

- The lateral distance between the centerline of the POV and the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The SV speed could not deviate more than ±1.0 mph (±1.6 kph) during an interval defined by TTC = 5.0 seconds to t_{FCW}.
- The POV speed could not deviate more than ±1.0 mph (±1.6 kph) during the validity period.

Table 2. Nominal Slower Moving POV DBS Test Choreography

Test Speeds		SV Speed Held Constant		SV Throttle Fully Released By		SV Brake Application Onset (for each application magnitude)	
SV	POV	TTC (seconds)	SV-to-POV Headway	TTC (seconds)	SV-to-POV Headway	TTC (seconds)	SV-to-POV Headway
25 mph (40 kph)	10 mph (16 kph)	5.0 → t_{FCW}	110 ft (34 m) → t_{FCW}	Within 500 ms of FCW1 onset	Varies	1.0	22 ft (7 m)
45 mph (72 kph)	20 mph (32 kph)	5.0 → t_{FCW}	183 ft (56 m) → t_{FCW}	Within 500 ms of FCW1 onset	Varies	1.0	37 ft (11 m)

b. Criteria

The performance requirement for this series of tests is that there be no SV-POV impact for at least five of the seven valid test trials.

3. TEST 3 – SUBJECT VEHICLE ENCOUNTERS DECELERATING PRINCIPAL OTHER VEHICLE

This test evaluates the ability of the DBS system to detect and respond to a lead vehicle slowing with a constant deceleration in the immediate forward path of the SV as depicted in Figure 3. Should the SV foundation brake system be unable to prevent an SV-to-POV impact for a given test condition, the DBS system should automatically provide supplementary braking capable of preventing an SV-to-POV collision.

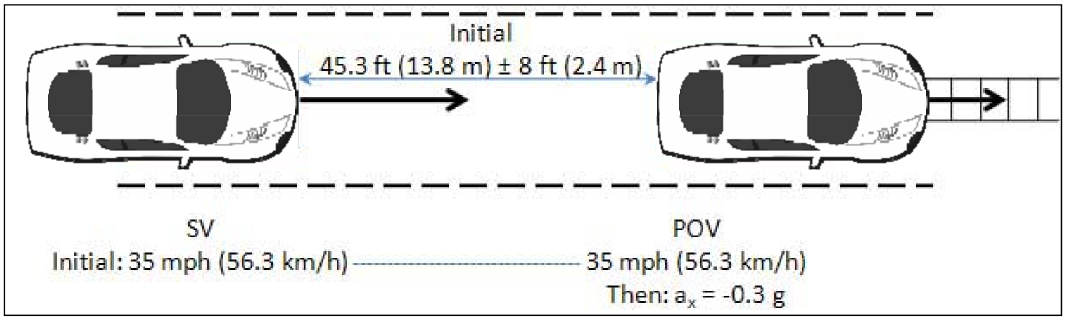


Figure 3. Depiction of Test 3 with POV Decelerating

a. Procedure

The SV ignition was cycled prior to each test run. For this scenario both the POV and SV were driven at a constant 35.0 mph (56.3 kph) in the center of the lane, with headway of 45 ft (14 m) ± 8 ft (2.4 m). Once these conditions were met, the POV tow vehicle brakes were applied to achieve 0.3 ± 0.03 g. The SV throttle pedal was released within 500 ms of $t_{FCW,}$ and the SV brakes were applied when TTC was 1.4 seconds (31.5 ft (9.6 m)).

The test concluded when either:

- The SV came into contact with the POV or
- 1 second after the velocity of the SV became less than or equal to that of the POV.

The SV driver then braked to a stop.

In addition to the general test validity criteria described below, for an individual test trial to be valid, the following was required throughout the test:

- The lateral distance between the centerline of the POV and the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The headway between the SV and POV must have been constant from the onset of the applicable validity period to the onset of POV braking.
- The SV and POV speed could not deviate more than ±1.0 mph (1.6 kph) during an interval defined by the onset of the validity period to the onset of POV braking.
- The average POV deceleration could not deviate by more than ±0.03 g from the nominal 0.3 g deceleration during the interval beginning at 1.5 seconds after the onset of POV braking and ending either 250 ms prior to the POV coming to a stop or the SV coming into contact with the POV.

Table 3. Nominal Decelerating POV DBS Test Choreography

Test Speeds		SV Speed Held Constant		SV Throttle Fully Released By		SV Brake Application Onset (for each application magnitude)	
SV	POV	TTC (seconds)	SV-to-POV Headway	TTC (seconds)	SV-to-POV Headway	TTC (seconds)	SV-to-POV Headway
35 mph (56 kph)	35 mph (56 kph)	3.0 seconds prior to POV braking → t_{FCW}	45 ft (14 m) → t_{FCW}	Within 500 ms of FCW1 onset	Varies	1.4	32 ft (10 m)

b. Criteria

The performance requirement for this series of tests is that no SV-POV contact occurs for at least five of the seven valid test trials.

4. TEST 4 – FALSE POSITIVE SUPPRESSION

The false positive suppression test series evaluates the ability of a DBS system to differentiate a steel trench plate (STP) from an object presenting a genuine safety risk to the SV. Although the STP is large and metallic, it is designed to be driven over without risk of injury to the driver or damage to the SV. Therefore, in this scenario, the automatic braking available from DBS is not necessary and should be suppressed. The test condition is nearly equivalent to that previously defined for Test 1, the stopped POV condition, but with an STP in the SV forward path in lieu of a POV.

a. Procedure

This test was conducted at two speeds, 25 mph (40.2 kph) and 45 mph (72.4 kph). The SV was driven directly towards, and over, the STP, which was positioned in the center of a travel lane, with its longest sides parallel to the road edge. The SV was driven at constant speed in the center of the lane toward the STP. If the SV did not present an FCW alert during the approach to the STP by TTC = 2.1 s, the SV driver initiated release of the throttle pedal at TTC = 2.1 s and the throttle pedal was fully released within 500 ms of TTC = 2.1 s. The SV brakes were applied at TTC of 1.1 seconds, assumed to be 40 ft (12.3 m) from the edge of the STP at 25 mph or 73 ft (22.1 m) at 45 mph. The test concluded when the front most part of the SV reached a vertical plane defined by the edge of the STP first encountered by the SV.

b. Criteria

In order to pass the False Positive test series, the magnitude of the SV deceleration reduction attributable to DBS intervention must have been less than or equal to 1.25 times the average of the deceleration experienced by the baseline command from the braking actuator for at least five of seven valid test trials.

B. GENERAL INFORMATION

1. t_{FCW}

The time at which the Forward Collision Warning (FCW) activation flag indicates that the system has issued an alert to the SV driver is designated as t_{FCW}. FCW alerts are typically haptic, visual, or audible, and the onset of the alert is determined by post-processing the test data.

For systems that implement audible or haptic alerts, part of the pre-test instrumentation verification process is to determine the tonal frequency of the audible warning or the vibration frequency of the tactile warning through use of the PSD (Power Spectral Density) function in Matlab. This is accomplished in order to identify the center frequency around which a band-pass filter is applied to subsequent audible or tactile warning data so that the beginning of such warnings can be programmatically determined. The bandpass filter used for these warning signal types is a phaseless, forward-reverse pass, elliptical (Cauer) digital filter, with filter parameters as listed in Table 4.

Table 4. Audible and Tactile Warning Filter Parameters

Warning Type	Filter Order	Peak-to-Peak Ripple	Minimum Stop Band Attenuation	Pass-Band Frequency Range
Audible	5^{th}	3 dB	60 dB	Identified Center Frequency ± 5%
Tactile	5^{th}	3 dB	60 dB	Identified Center Frequency ± 20%

2. General Validity Criteria

In addition to any validity criteria described above for the individual test scenarios, for an individual trial to be valid, it must have met the following criteria throughout the test:

- The SV driver seatbelt was latched.
- If any load had been placed on the SV front passenger seat (e.g., for instrumentation), the vehicle's front passenger seatbelt was latched.
- The SV was driven at the nominal speed in the center of the travel lane, toward the POV or STP.
- The driver used the least amount of steering input necessary to maintain SV position in the center of the travel lane during the validity period; use of abrupt steering inputs or corrections was avoided.
- The yaw rate of the SV did not exceed ±1.0 deg/s from the onset of the validity period to the instant SV deceleration exceeded 0.25 g.
- The SV driver did not apply any force to the brake pedal during the during the applicable validity period. All braking shall be performed by the programmable brake controller.
- The lateral distance between the centerline of the SV and the centerline of the POV or STP did not deviate more than ±1 ft (0.3 m) during the applicable validity period.

3. Validity Period

The valid test interval began:

Test 1: When the SV-to-POV TTC = 5.1 seconds

Test 2: When the SV-to-POV TTC = 5.0 seconds

Test 3: 3 seconds before the onset of POV braking

Test 4: 2 seconds prior to the SV throttle pedal being released

The valid test interval ended:

Test 1: When either of the following occurred:

- The SV came in contact with the POV (SV-to-POV contact was assessed by using GPS-based range data or by measurement of direct contact sensor output); or
- The SV came to a stop before making contact with the POV.

Tests 2: When either of the following occurred:

- The SV came into contact with the POV; or
- 1 second after the velocity of the SV became less than or equal to that of the POV.

Test 3: When either of the following occurred:

- The SV came in contact with the POV; or
- 1 second after minimum SV-to-POV range occurred.

Test 4: When the SV stopped.

4. Static Instrumentation Calibration

To assist in resolving uncertain test data, static calibration data was collected prior to each of the test series.

For Tests 1, 2, and 3, the SV, POV, and POV moving platform and tow vehicle were centered in the same travel lane with the same orientation (i.e., facing the same direction). For Test 4, the SV and STP were centered in the same travel lane.

For Tests 1, 2, and 3, the SV was positioned such that it just contacted a vertical plane defining the rearmost location of the POV. For Test 4, the front-most location of the SV was positioned such that it just reached a vertical plane defined by the leading edge of the STP first encountered by the SV (i.e., just before it is driven onto the STP). This is the "zero position."

The zero position was documented prior to, and immediately after, conduct of each test series.

If the zero position reported by the data acquisition system was found to differ by more than ±2 in (±5 cm) from that measured during collection of the pre-test static calibration data file, the pre-test longitudinal offset was adjusted to output zero and another pre-test static calibration data file was collected. If the zero position reported by the data acquisition system was found to differ by more than ±2 in (±5 cm) from that measured during collection of the post-test static calibration data file, the test trials performed between collection of that post-test static calibration data file and the last valid pre-test static calibration data file were repeated.

Static data files were collected prior to, and immediately after, conduct each of the test series. The pre-test static files were reviewed prior to test conduct to confirm that all data channels were operational and were properly configured.

5. Number of Trials

A target total of seven (7) valid trials were performed for each scenario. In cases where the test driver performed more than seven trials, the first seven trials satisfying all test tolerances were used to assess the SV performance.

6. Transmission

All trials were performed with SV automatic transmissions in ''Drive'' or with manual transmissions in the highest gear capable of sustaining the desired test speed.

Manual transmission clutches remained engaged during all maneuvers. The brake lights of the POV were not illuminated.

C. PRINCIPAL OTHER VEHICLE

DBS testing requires a POV that realistically represents typical vehicles, does not suffer damage or cause damage to a test vehicle in the event of collision, and can be accurately positioned and moved during the tests. The tests reported herein made use of the NHTSA developed Strikeable Surrogate Vehicle (SSV).

This SSV system was designed specifically for common rear-end crash scenarios which AEB systems address. The key elements of the SSV system are:

- POV element, whose requirements are to:
    - Provide an accurate representation of a real vehicle to DBS sensors, including cameras and radar.
    - Be resistant to damage and inflict little or no damage to the SV as a result of repeated SV-to-POV impacts.

- POV delivery system, whose requirements are to:
    - Accurately control the nominal POV speed up to 35 mph (56 kph).
    - Accurately control the lateral position of the POV within the travel lane.
    - Allow the POV to move away from the SV after an impact occurs.

The key components of the SSV system are:

- A POV shell which is a visually and dimensionally accurate representation of a passenger car.

- A slider and load frame assembly to which the shell is attached.

- A two-rail track on which the slider operates.

- A road-based lateral restraint track.

- A tow vehicle.

Operationally, the POV shell is attached to the slider and load frame which includes rollers that allows the entire assembly to move longitudinally along the guide rail. The guide rail is coupled to a tow vehicle and guided by the lateral restraint track secured to the test track surface. The rail includes a provision for restraining the shell and roller assembly in the rearward direction. In operation, the shell and roller assembly engages the rail assembly through detents to prevent relative motion during run-up to test speeds and minor deceleration of the tow vehicle. The combination of rearward stops and forward motion detents allows the test conditions such as relative POV-SV headway distance and speed etc to be achieved and adjusted as needed in the preliminary part of a test. If during the test, the SV strikes the rear of the POV shell, the detents are overcome and the entire shell/roller assembly moves, in a two-stage manner, forward along the rail, away from the SV. The forward end of the rail has a soft stop to restrain forward motion of the shell/roller assembly. After impacting the SSV, the SV driver uses the steering wheel to maintain SV position in the center of the travel lane, thereby straddling the two-rail track. The SV driver must manually apply the SV brakes after impact. The SSV system is shown in Figures A6 through A8 and a detailed description can be found in the NHTSA report: NHTSA’S STRIKEABLE SURROGATE VEHICLE PRELIMINARY DESIGN + OVERVIEW, May 2013.

D. FOUNDATION BRAKE SYSTEM CHARACTERIZATION

Data collected and analyzed from a series of pre-test braking runs were used to objectively quantify the response of the vehicle’s foundation brake system without the contribution of DBS. The results of these analyses were used to determine the brake pedal input magnitudes needed for the main tests.

This characterization was accomplished by recording longitudinal acceleration and brake pedal force and travel data for a variety of braking runs. For three initial brake characterization runs, the vehicle was driven at 45 mph, and the brakes were applied at a rate of 1 inch/sec up to the brake input level needed for at least 0.7 g. Linear regressions were performed on the data from each run to determine the linear vehicle deceleration response as a function of both applied brake pedal force and brake pedal travel. The brake input force or displacement level needed to achieve a vehicle deceleration of 0.4 g was determined from the average of the three runs. Using the 0.4 g brake input force or displacement level found from the three initial runs, subsequent runs were performed at 25 mph, 35 mph, and 45 mph, with the brakes applied at a rate of 10 inch/sec to the determined 0.4 g brake input force or displacement level. For each of the three test speeds, if the average calculated deceleration level was found to be within 0.4 ± 0.025 g, the resulting force or displacement was recorded and used. If the average calculated deceleration level exceeded this tolerance, the brake input force or displacement levels were adjusted and retested until the desired magnitude was realized. Prior to each braking event, the brake pad temperatures were required to be in the range of 149° - 212°F.

E. BRAKE CONTROL

1. Subject Vehicle programmable brake controller

To achieve accurate, repeatable, and reproducible SV brake pedal inputs, a programmable brake controller was used for all brake applications. The controller has the capability to operate in one of two user-selectable, closed-loop, control modes:

- Constant pedal displacement. By maintaining constant actuator stroke, the position of the vehicle's brake pedal remains fixed for the duration of the input. To achieve this, the brake controller modulates application force.

- Hybrid control. Hybrid control uses position-based control to command the initial brake application rate and actuator position, then changes to force-based control to command a reduction of applied force to a predetermined force. This force is maintained until the end of the braking maneuver by allowing the brake controller to modulate actuator displacement.

2. Subject Vehicle brake parameters

- Each test run began with the brake pedal in its natural resting position, with no preload or position offset.

- The onset of the brake application was considered to occur when the brake actuator had applied 2.5 lbf (11 N) of force to the brake pedal.

- The magnitude of the brake application was that needed to produce 0.4 g deceleration, as determined in the foundation brake characterization.

- The SV brake application rate was between 9 to 11 in/s (229 to 279 mm/s), where the application rate is defined as the slope of a linear regression line applied to brake pedal position data over a range from 25% to 75% of the commanded input magnitude.

3. POV Automatic Braking System

The POV was equipped with an automatic braking system, which was used in Test Type 3. The braking system consisted of the following components:

- Electronically controlled linear actuator, mounted on the seat rail and attached to the brake pedal. The actuator can be programmed for control of stroke and rate.

- PC module programmed for control of the stroke and rate of the linear actuator.

- Switch to activate actuator.

F. INSTRUMENTATION

Table 5 lists the sensors, signal conditioning, and data acquisition equipment used for these tests.

TABLE 5. TEST INSTRUMENTATION AND EQUIPMENT

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Tire Pressure Gauge	Vehicle Tire Pressure	0-100 psi 0-690 kPa	< 1% error between 20 and	Omega DPG8001	17042707002	By: DRI Date: 6/21/2018 Due: 6/21/2019
Platform Scales	Vehicle Total, Wheel, and Axle Load	1200 lb/platform 5338 N/	0.5% of applied load	Intercomp SWI	1110M206352	By: DRI Date: 1/3/2019 Due: 1/3/2020
Linear (string) encoder	Throttle pedal travel	10 in 254 mm	0.1 in 2.54 mm	UniMeasure LX-EP	43020490	By: DRI Date: 5/1/2018 Due: 5/1/2019
Load Cell	Force applied to brake pedal					By: DRI
		0 - 250 lb 0 -1112 N	0.1% FS	Honeywell 41A	1464391	Date: 8/28/2018 Due: 8/28/2019
		0-250 lb 1112 N	0.05% FS	Stellar Technology PNC700	1607338	Date: 8/28/2018 Due: 8/28/2019
Differential Global Positioning System	Position, Velocity	Latitude: ±90 deg Longitude: ±180 deg Altitude: 0-18 km Velocity: 0-1000 knots	Horizontal Position: ±1 cm Vertical Position: ±2 cm Velocity: 0.05 kph	Trimble GPS Receiver, 5700 (base station and in-vehicle)	00440100989	NA

TABLE 5. TEST INSTRUMENTATION AND EQUIPMENT (continued)

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Multi-Axis Inertial Sensing System	Position; Longitudinal, Lateral, and Vertical Accels; Lateral, Longitudinal and Vertical Velocities; Roll, Pitch, Yaw Rates; Roll, Pitch, Yaw Angles	Accels ± 10g, Angular Rat	Accels .01g, Angular Rate	Oxford Inertial +		By: Oxford Technical Solutions
					2182	Date: 10/16/2017 Due: 10/16/2019
					2176	Date: 4/11/2018 Due: 4/11/2020
Real-Time Calculation of Position and Velocity Relative to Lane Markings (LDW) and POV (FCW)	Distance and Velocity to lane markings (LDW) and POV (FCW)	Lateral Lane Dist: ±30 m Lateral Lane Velocity: ±20 m/sec Longitudinal Range to POV: ±200 m Longitudinal Range Rate: ±50 m/sec	Lateral Distance to Lane Marking: ±2 cm Lateral Velocity to Lane Marking: ±0.02m/sec Longitudinal Range: ±3 cm Longitudinal Range Rate: ±0.02 m/sec	Oxford Technical Solutions (OXTS), RT-Range	97	NA
Microphone	Sound (to measure time at alert)	Frequency Response: 80 Hz – 20 kHz	Signal-to-noise: 64 dB, 1 kHz at 1 Pa	Audio-Technica AT899	NA	NA
Light Sensor	Light intensity (to measure time at alert)	Spectral Bandwidth: 440-800 nm	Rise time < 10 msec	DRI designed and developed Light Sensor	NA	NA
Accelerometer	Acceleration (to measure time at alert)	±5g	≤ 3% of full range	Silicon Designs, 2210-005	NA	NA

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Coordinate Measurement Machine	Inertial Sensing System Coordinates	0-8 ft 0-2.4 m	±.0020 in. ±.051 mm (Single point articulation accuracy)	Faro Arm, Fusion	UO8-05-08-06636	By: DRI Date: 1/2/2019 Due: 1/2/2020

Type	Description	Mfr, Model	Serial Number
Data Acquisition System	Data acquisition is achieved using a dSPACE MicroAutoBox II. Data from the Oxford IMU, including Longitudinal, Lateral, and Vertical Acceleration, Roll, Yaw, and Pitch Rate, Forward and Lateral Velocity, Roll and Pitch Angle are sent over Ethernet to the MicroAutoBox. The Oxford IMUs are calibrated per the manufacturer's recommended schedule (listed above).	D-Space Micro-Autobox II 1401/1513	
		Base Board	549068
		I/O Board	588523

APPENDIX A

Photographs

LIST OF FIGURES

Figure A1. Front View of Subject Vehicle

Figure A2. Rear View of Subject Vehicle

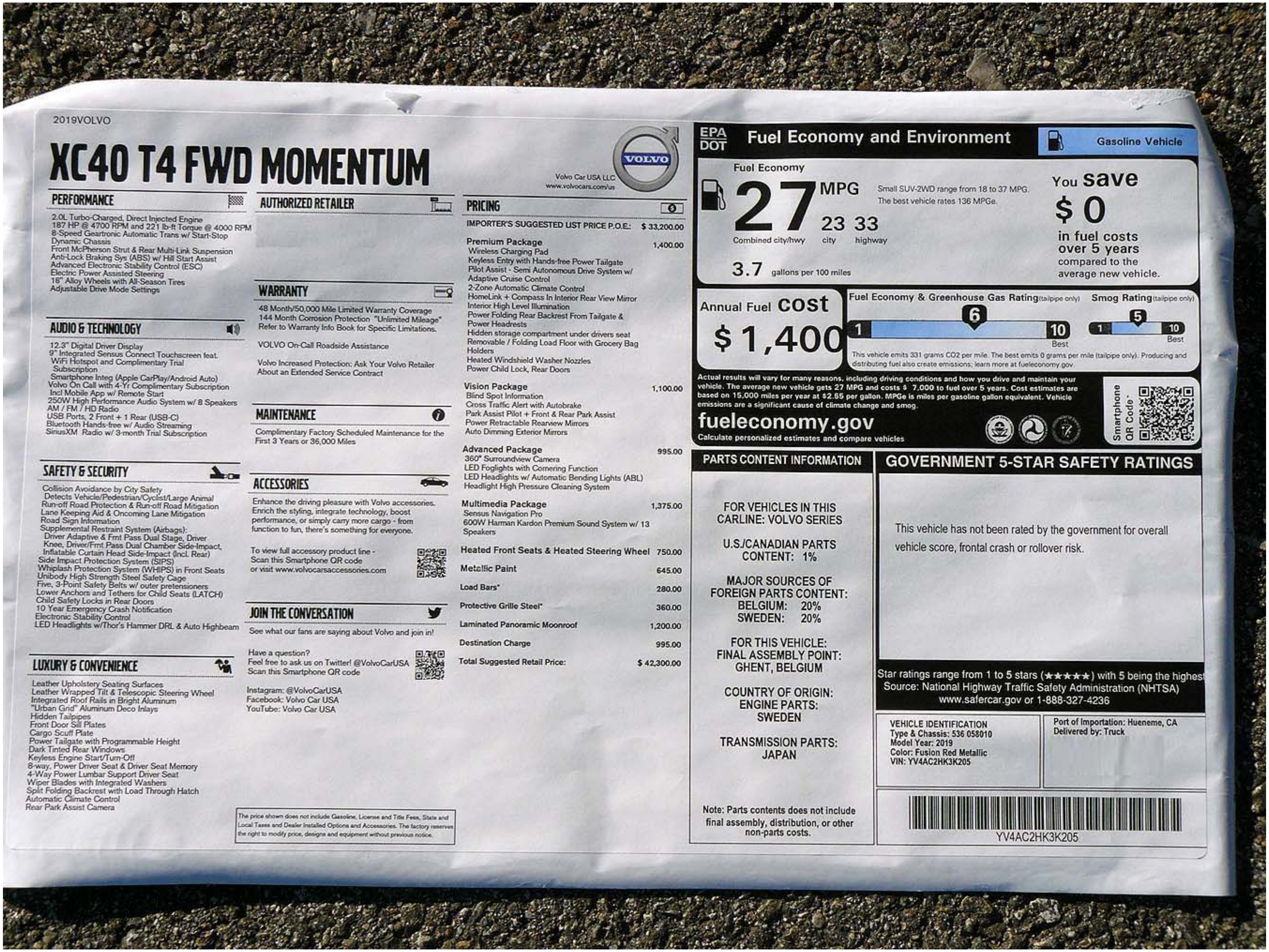


Figure A3. Window Sticker (Monroney Label)

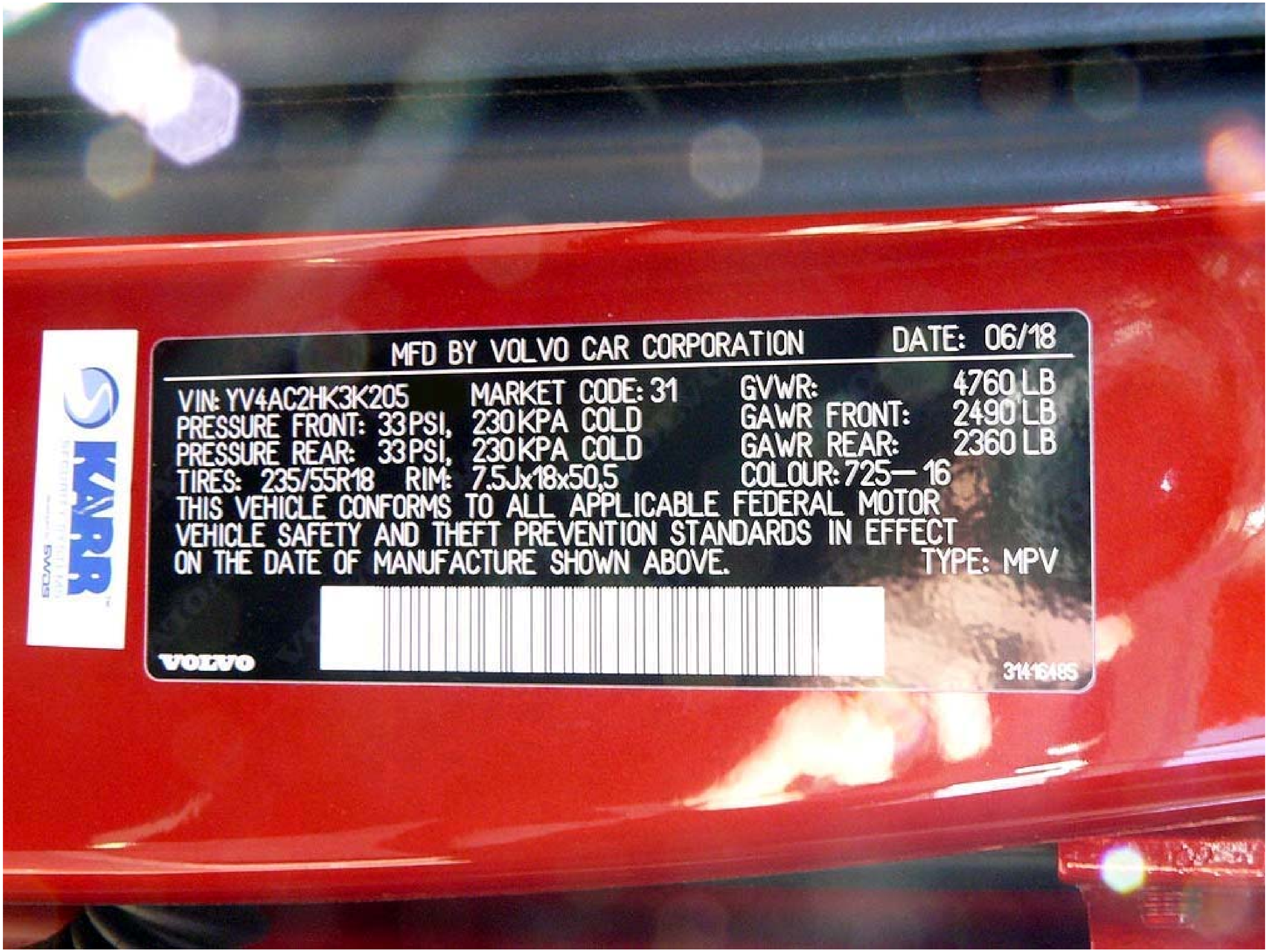


Figure A4. Vehicle Certification Label

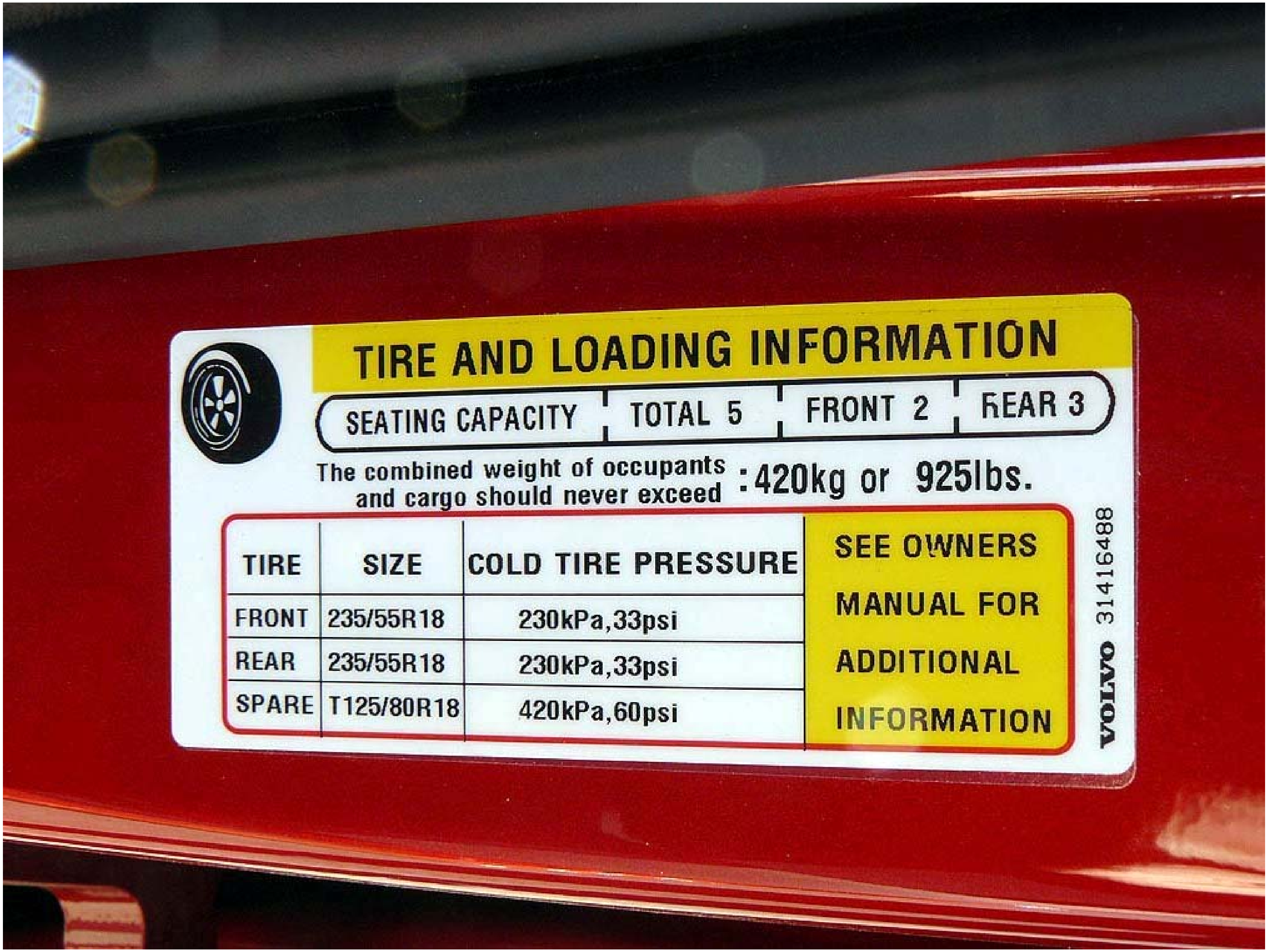


Figure A5. Tire Placard

Figure A6. Rear View of Principal Other Vehicle (SSV)

Figure A7. Load Frame/Slider of SSV

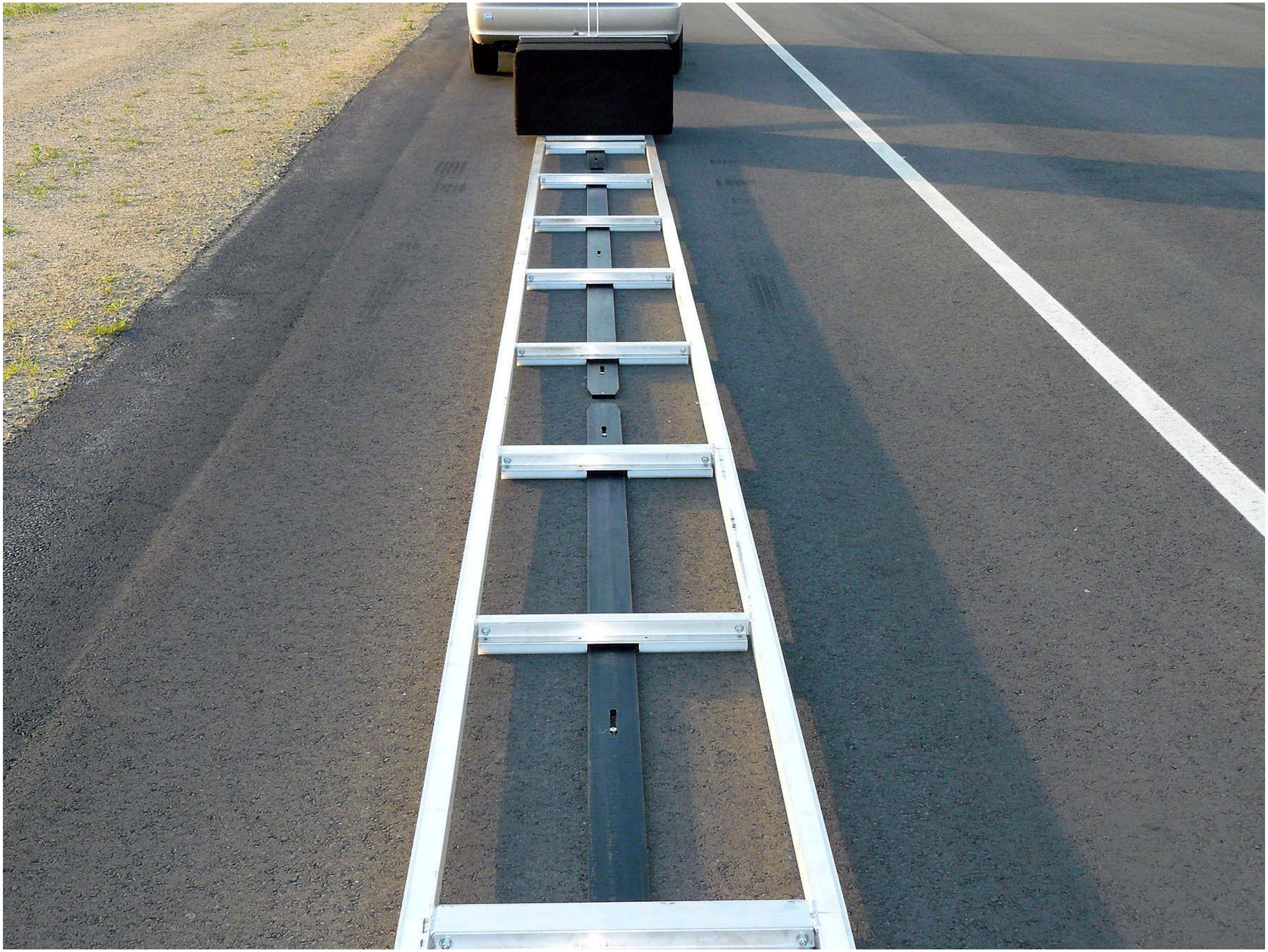


Figure A8. Two-Rail Track and Road-Based Lateral Restraint Track

Figure A9. Steel Trench Plate

Figure A10. DGPS and Inertial Measurement Unit nstalled in Subject Vehicle

Figure A11. Sensor for Detecting Auditory Alert

Figure A12. Computer and Brake Actuator Installed in Subject Vehicle

Figure A13. Brake Actuator Installed in POV System

Figure A14. AEB Setup Menus

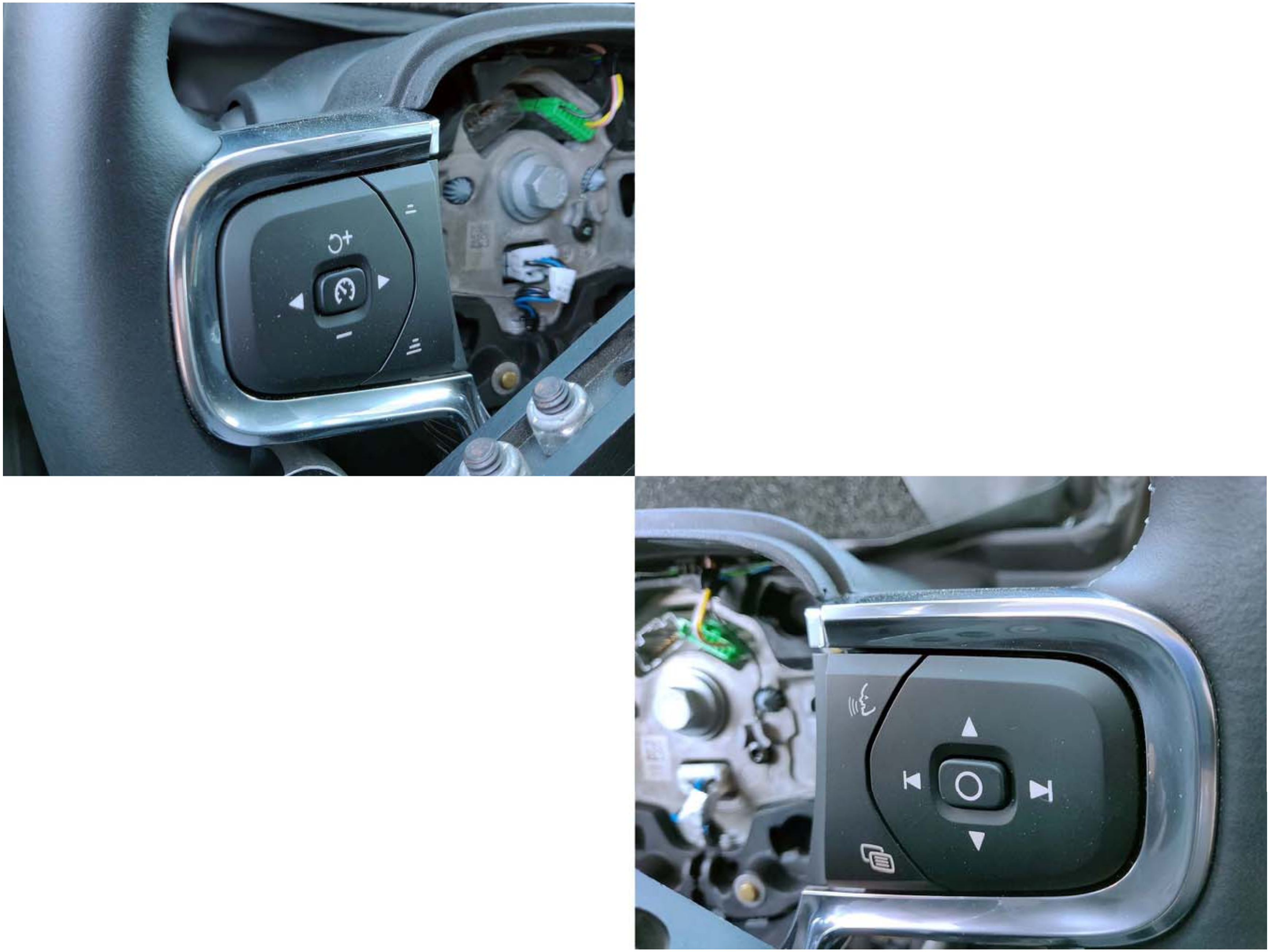


Figure A15. Steering Wheel Mounted Control Buttons for Changing Parameters

APPENDIX B

Excerpts from Owner's Manual

◀◀ goal. In addition to continuous environmental refinement of conventional gasoline-powered internal combustion engines, Volvo is actively looking at advanced technology alternative-fuel vehicles.

When you drive a Volvo, you become our partner in the work to lessen the vehicle's impact on the environment. To reduce your vehicle's environmental impact, you can:

- Maintain proper air pressure in your tires. Tests have shown decreased fuel economy with improperly inflated tires.
- Follow the recommended maintenance schedule in your Warranty and Service Records Information booklet.
- Drive at a constant speed whenever possible.
- See a trained and qualified Volvo service technician as soon as possible for inspection if the check engine (malfunction indicator) light illuminates, or stays on after the vehicle has started.
- Properly dispose of any vehicle-related waste such as used motor oil, used batteries, brake pads, etc.
- When cleaning your vehicle, please use genuine Volvo car care products. All Volvo car care products are formulated to be environmentally friendly.

Related information

- Economical driving (p. 415)
- Starting and stopping preconditioning* (p. 210)
- The Owner's Manual and the environment (p. 24)
- Air quality (p. 187)

IntelliSafe - driver support

IntelliSafe is Volvo Cars' philosophy regarding vehicle safety. IntelliSafe consists of a number of systems, both standard and optional, that are designed to help make driving safer, prevent accidents and protect passengers and other road users.

Support

IntelliSafe includes driver support functions such as Adaptive cruise control* which helps the driver to maintain an even speed combined with a preselected time interval to the vehicle ahead.

Pilot Assist[2] helps the driver keep the vehicle in the current traffic lane by providing steering assistance and maintaining an even speed and a set time interval to the vehicle ahead.

Park Assist Pilot* helps the driver pull into and out of parking spaces.

Other examples of systems that can help the driver are the Active main beam, Cross Traffic Alert (CTA)* and Blind Spot Information (BLIS)* systems.

Prevention

City Safety is a function intended to help prevent accidents. The function can help prevent or mitigate a collision with pedestrians, cyclists, large animals or other vehicles. Light, sound and pulsations in the brake pedal are provided to alert of a

[2] Depending on market, this function can be either standard or optional.

* Option/accessory.

possible collision and help the driver act in time to prevent it. If the driver does not react to the warning and the risk of collision is determined to be imminent, City Safety can automatically apply the brakes.

Lane assistance (LKA) is another example of a function that can help prevent accidents by helping the driver - on expressways and similar larger roads - to reduce the risk of the car accidentally leaving its own lane.

The function **Steering aid during increased collision risk** can help the driver reduce the risk of the car leaving its lane unintentionally and/or colliding with another vehicle or obstacle by actively steering the car back into its lane and/or swerving.

Protection

To help protect the driver and passengers, the vehicle is equipped with seat belt tensioners that pull the seat belts taut in collisions and other critical situations. The vehicle also has airbags, inflatable curtains and the Whiplash Protection System (WHIPS), which helps prevent whiplash injuries.

Related information

- Driver support systems (p. 252)
- Active high beam (p. 145)
- Safety (p. 42)
- Seat belts (p. 47)
- Airbags (p. 52)
- Whiplash Protection System (p. 46)

Warning symbols in the instrument panel

The warning symbols alert the driver that an important function is activated or that a serious fault or error has occurred.

Symbol	Meaning
	**WARNING** The red warning symbol illuminates to indicate that a fault has been detected that could affect safety and/or driveability. An explanatory message will be simultaneously displayed in the instrument panel. The warning symbol may also illuminate in combination with other symbols.
	**Seat belt reminder** This symbol will glow steadily or flash if the driver or front seat passenger has not fastened their seat belt or if anyone in the rear seat has removed their seat belt.
	**Airbags** If this symbol remains illuminated or comes on while driving, a fault has been detected in one of the vehicle's safety systems. Read the message in the instrument panel. Volvo recommends contacting an authorized Volvo workshop.
 A  B	**Fault in brake system** If this symbol illuminates, the brake fluid level may be too low. Contact your nearest authorized workshop to have the brake fluid level checked and adjusted.
 A  B	**Parking brake on** This symbol glows steadily when the parking brake is applied. A flashing symbol indicates that a fault has occurred. Read the message in the instrument panel.
	**Low oil pressure** If this symbol illuminates while driving, the engine oil level is too low. Stop the engine immediately and check the engine oil level. Add oil if necessary. If the symbol illuminates and the oil level is normal, contact a workshop. Volvo recommends contacting an authorized Volvo workshop.
	**Generator not charging** This symbol illuminates during driving if a fault is detected in the electrical system. Contact a workshop. Volvo recommends contacting an authorized Volvo workshop.
	**Collision risk** City Safety warns the driver if there is a risk of a collision with another vehicle, pedestrian, cyclist or large animal.

A Canadian models.
B US models.

Related information

- Indicator symbols in the instrument panel (p. 88)
- Instrument panel (p. 80)

The previous illustration[54] shows that Pilot Assist is set to maintain a speed of 110 km/h (68 mph) and that there is no target vehicle ahead to follow.

Pilot Assist will provide steering assistance because it can detect the lane's side marking lines.

Related information

- Pilot Assist (p. 287)

Radar sensor

The radar sensor is used by several driver support systems to detect other vehicles.

Note: This illustration is general and details may vary depending on model.

The radar sensor is used by the following functions:

- Distance Alert*
- Adaptive Cruise Control*
- Lane Keeping Aid
- Pilot Assist*
- City Safety

Any modifications to the radar sensor may make its use illegal.

Related information

- Radar sensor limitations (p. 303)
- Recommended maintenance for the radar sensor (p. 306)
- Radar sensor type approval (p. 306)

54 Note: This illustration is general and details may vary depending on model.

Canada:
This Category II radiocommunication device complies with Industry Canada Standard RSS-310.

This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions:

(1) this device may not cause interference, and

(2) this device must accept any interference, including interference that may cause undesired operation of the device.

Ce dispositif de radiocommunication de catégorie II respecte la norme CNR-310 d'Industrie Canada.

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes:

(1) l'appareil ne doit pas produire de brouillage, et

(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Related information

- Radar sensor (p. 302)

Camera

The camera is used by several driver support systems to e.g. detect lane marker lines or road signs.

Note: This illustration is general and details may vary depending on model.

The camera is used by the following functions:

- Adaptive Cruise Control*
- Pilot Assist*
- Lane Keeping Aid*
- Steering assistance at risk of collision
- City Safety
- Driver Alert Control*
- Road Sign Information*
- Active high beams*

Related information

- Camera limitations (p. 308)
- Recommended maintenance for the camera/radar sensor (p. 311)

Recommended maintenance for the camera/radar sensor

In order for the camera/radar sensor to function properly, the area of the windshield in front of the unit must be kept free of dirt, ice, snow, etc. and should be washed regularly with water and car washing detergent.

NOTE

Dirt, ice and snow covering the camera and radar unit reduce their function and can make measurement impossible.

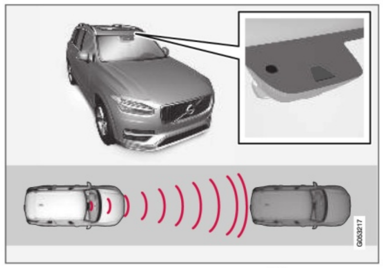
It could cause functions to be reduced, deactivated completely or produce an incorrect function response.

Related information

- Camera (p. 307)

City Safety™

City Safety can alert the driver with light, sound and pulsations in the brake pedal to help the driver detect pedestrians, cyclists, large animals and vehicles that appear suddenly – the vehicle will then attempt to automatically brake if the driver does not act within a reasonable amount of time.



Location of the camera and radar sensor[60].

City Safety can help prevent a collision or lower the vehicle's speed at the point of impact.

City Safety is an aid intended to assist the driver if a collision with a pedestrian, large animal, cyclist or vehicle is imminent.

City Safety can help the driver avoid a collision when e.g. driving in stop-and-go traffic, when changes in the traffic ahead and driver distraction could lead to an incident.

The function assists the driver by automatically applying the brakes if there is an imminent risk of a collision and the driver does not react in time by braking and/or steering away.

City Safety activates a brief, forceful braking in an attempt to stop your vehicle immediately behind the vehicle or object ahead.

City Safety is activated in situations in which the driver should have applied the brakes much earlier, which means that the system will not be able to assist the driver in all situations.

City Safety is designed to be activated as late as possible to help avoid unnecessary intervention.

Normally, the occupants of the vehicle will not be aware of City Safety except when the system intervenes when a collision is imminent.

60 Note: This illustration is general and details may vary depending on model.

⚠ **WARNING**

- The City Safety function is supplementary driver support intended to help improve driving safety – it cannot handle all situations in all traffic, weather and road conditions.
- The City Safety auto-brake function can prevent a collision or reduce collision speed, but to ensure full brake performance the driver should always depress the brake pedal – even when the car auto-brakes.
- The warning is only activated if there is a high risk of collision – you must therefore never wait for a collision warning or for City Safety to intervene.
- Warnings and brake interventions for pedestrians and cyclists are disengaged at vehicle speeds over 80 km/h (50 mph).
- City Safety does not activate auto-braking intervention during heavy acceleration.
- City Safety is not a substitute for the driver's attention and judgment. The driver is always responsible for ensuring the vehicle is driven in a safe manner, at the appropriate speed, with an appropriate distance to other vehicles, and in accordance with current traffic rules and regulations.
- The driver is advised to read all sections in the Owner's Manual that relate to City Safety to learn about factors such as its limitations and what the driver should be aware of before using the system (see the list of links for all subsections).

Related information

- City Safety parameters and sub-functions (p. 312)
- Setting a warning distance for City Safety (p. 314)
- Detecting obstacles with City Safety (p. 315)
- City Safety in crossing traffic (p. 317)
- Limitations of City Safety in crossing traffic (p. 318)
- City Safety and delayed evasive maneuvers (p. 319)
- City Safety braking for oncoming vehicles* (p. 320)
- City Safety limitations (p. 321)
- City Safety messages (p. 323)

City Safety parameters and sub-functions

City Safety can help avoid a collision with a vehicle, cyclist or large animal ahead by reducing the vehicle's speed using its automatic braking function.

If the difference in speed is greater than the speeds specified below, the City Safety auto-brake function cannot prevent a collision, but it can help mitigate its effects.

Vehicles

City Safety can help prevent a collision with a vehicle ahead by reducing your vehicle's speed by up to 60 km/h (37 mph).

Cyclists

City Safety can help prevent a collision with a cyclist ahead by reducing your vehicle's speed by up to 50 km/h (30 mph).

Pedestrians

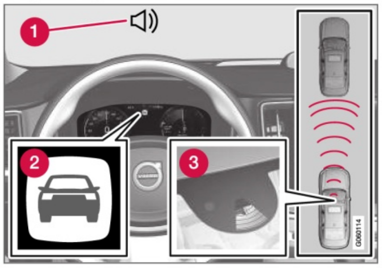
City Safety can help prevent a collision with a pedestrian ahead by reducing your vehicle's speed by up to 45 km/h (28 mph).

* Option/accessory.

Large animals
If there is a risk of colliding with a large animal, City Safety can help reduce your vehicle's speed by up to 15 km/h (9 mph).

The braking function for large animals is primarily intended to mitigate the force of a collision at higher speeds. Braking is most effective at speeds above 70 km/h (43 mph) and less effective at lower speeds.

City Safety sub-functions



Function overview[61].

1. Acoustic collision warning signal
2. Collision warning symbol
3. Camera/radar sensor distance monitoring

City Safety carries out three steps in the following order:

1. Collision warning
2. Brake assistance
3. Auto-brake

Descriptions of what happens in these three steps are provided below.

1 - Collision warning
The driver is first alerted to the risk of an imminent collision.

City Safety can detect pedestrians, cyclists or vehicles that are stationary, are moving in the same direction as your vehicle and are ahead of your vehicle. City Safety can also detect pedestrians, cyclists or large animals that are crossing the road in front of your vehicle.

If there is a risk of a collision with a pedestrian, large animal, cyclist or another vehicle, or with a vehicle described in the section "City Safety in crossing traffic", the driver will be alerted with light, sound and pulsations in the brake pedal. At lower speeds, during hard braking or if the accelerator pedal is pressed, the brake pedal pulsation warning will not be given. The intensity of the brake pedal pulsations varies according to the vehicle's speed.

2 - Brake assistance
If the risk of a collision increases after the collision warning, brake support will be activated.

If the system determines that the pressure the driver is exerting on the brake pedal is insufficient to prevent the collision, brake support will increase pressure.

[61] Note: This illustration is general and details may vary depending on model.

◀◀ **3 - Auto-brake**
The automatic braking function is activated at the last moment.

If the driver has not taken evasive action by this stage and a collision is imminent, the automatic braking function will be triggered. This occurs whether or not the driver is pressing the brake pedal. Full braking force will be applied to reduce the speed at impact or reduced braking effect will be applied if this is sufficient to avoid the collision.

The seat belt tensioners may be activated along with the automatic braking function. See "Seat belt tensioners" for more information.

In certain situations, auto-braking may begin with a limited braking force before applying full braking force.

If City Safety has prevented a collision, the vehicle will be kept at a standstill until the driver takes action. If the vehicle has slowed to avoid colliding with a slower-moving vehicle ahead, your speed will be reduced to that vehicle's speed.

Auto-braking can always be cancelled if the driver presses hard on the accelerator pedal.

> **NOTE**
> When City Safety activates the brakes, the brake lights come on.

When City Safety applies the brakes, a text message will appear in the instrument panel to notify the driver that the function is/was activated.

> **WARNING**
> City Safety may not be used to change how the driver operates the vehicle. The driver must not only rely on City Safety to brake the vehicle.

Related information

- City Safety™ (p. 311)

Setting a warning distance for City Safety

City Safety is always active, but the function's warning distance can be adjusted.

> **NOTE**
> The City Safety function cannot be deactivated. It is activated automatically each time the engine/electric motor is started.

The alert distance determines the sensitivity of the system and regulates the distance at which the light, sound and brake pulsations will be activated.

To select warning distance:

1. Select **Settings** ➔ **My Car** ➔ **IntelliSafe** in the center display's Top view.
2. Under **City Safety Warning**, tap **Late**, **Normal** or **Early** to set the desired warning distance.

If the driver feels that the **Early** setting is giving too many warnings or finds them irritating, the **Normal** or **Late** warning distance settings can be selected instead.

If the driver feels that the warnings are too frequent and distracting, the warning distance can be reduced. This will reduce the total number of warnings, but it will also result in City Safety providing warnings at a later stage.

The **Late** warning distance setting should therefore only be used in exceptional cases, such as when a more dynamic driving style is preferred.

WARNING

- No automatic system can guarantee 100% correct function in all situations. You should therefore never test use of City Safety in the direction of people, animals or vehicles – this could lead to severe damage, serious personal injury or even death.
- City Safety warns the driver if there is a risk of collision, but the function cannot reduce the driver's reaction time.
- Even if the warning distance has been set to **Early**, warnings may be perceived as late in certain situations – e.g. when there are large speed differences or if the vehicle ahead suddenly brakes heavily.
- With the warning distance set to **Early**, warnings come further in advance. This may cause the warnings to come more frequently than with warning distance **Normal**, but is recommended since it can make City Safety more effective.

NOTE

The warning with direction indicators for Rear Collision Warning is deactivated if the collision warning distance in the City Safety function is set to the lowest level "**Late**".

The seat belt tensioning and braking functions remain active.

Related information

- City Safety™ (p. 311)

Detecting obstacles with City Safety

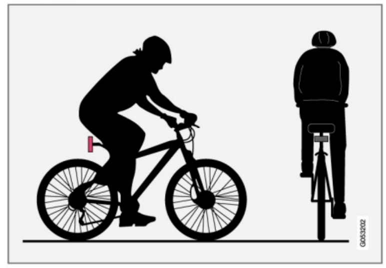
City Safety can help detect vehicles, cyclists, large animals and pedestrians.

Vehicles

City Safety detects most types of vehicles that are either stationary, moving in the same direction as your vehicle or those described in "City Safety in crossing traffic" and City Safety braking for oncoming vehicles".

For City Safety to be able to detect a vehicle in the dark, its headlights and taillights must be on and clearly visible.

Cyclists



Optimal examples of what City Safety would interpret to be a cyclist: clear body and bicycle shapes.

For optimal performance, the system's function for cyclist detection needs the clearest possible information about the contours of the bicycle and

◀◀ of the cyclist's head, arm, shoulders, legs, torso and lower body in combination with normal human movements.

If large portions of the cyclist's body or the bicycle itself are not visible to the function's camera, it will not be able to detect a cyclist.

The system can only detect adult cyclists riding on bicycles intended for adults.

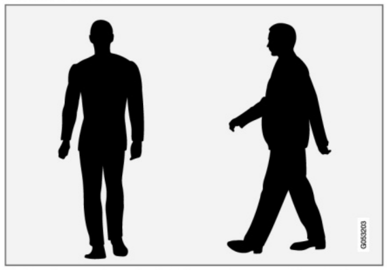
⚠ WARNING

City Safety is supplementary driver support, but it cannot detect all cyclists in all situations and, for example, cannot see:

- partially obscured cyclists.
- cyclists if the background contrast of the cyclist is poor - warning and brake interventions may then be late or not occur at all.
- cyclists in clothing that hides their body contour.
- bikes loaded with large objects.

The driver is always responsible for ensuring that the vehicle is driven correctly and with a safety distance suitable for the speed.

Pedestrians



Optimal examples of what the system considers to be a pedestrian: clear body contours.

For optimal performance, the system's function for pedestrian detection needs the clearest possible information about body and bicycle contours. This entails being able to detect the contours of the pedestrian's head, arm, shoulders, legs, torso and lower body in combination with normal human movements.

In order to detect a pedestrian, there must be a contrast to the background, which could depend on clothing, weather conditions, etc. If there is little contrast, the person may be detected late or not at all, which may result in a delayed reaction from the system or no reaction at all.

City Safety can detect pedestrians even in dark conditions if they are illuminated by the vehicle's headlights.

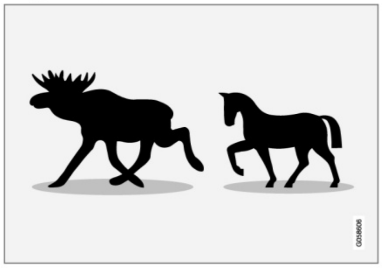
⚠ WARNING

City Safety is supplementary driver support, but it cannot detect all pedestrians in all situations and, for example, cannot see:

- partially obscured pedestrians, people in clothing that hides their body contour or pedestrians shorter than 80 cm (32 in.).
- pedestrians if the background contrast of the pedestrians is poor - warning and brake interventions may then be late or not occur at all.
- pedestrians who are carrying large objects.

The driver is always responsible for ensuring that the vehicle is driven correctly and with a safety distance suitable for the speed.

Large animals



Optimal examples of what City Safety would interpret as a large animal: stationary or moving slowly and with clear body contours.

For optimal performance, the system's function for detecting large animals (e.g. moose, horses, etc.) needs the clearest possible information about body contours. This entails being able to detect the animal straight from the side in combination with normal movements for that animal.

If parts of the animal's body are not visible to the function's camera, the system will not be able to detect the animal.

City Safety can detect large animals even in dark conditions if they are illuminated by the vehicle's headlights.

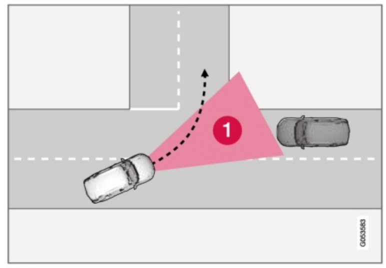
> **⚠ WARNING**
>
> City Safety is supplementary driver support, but it cannot detect all large animals in all situations and, for example, cannot see:
>
> - partially obscured larger animals.
> - larger animals seen from the front or from behind.
> - running or fast moving larger animals.
> - larger animals if the contrast of the animal's background is poor - warning and brake interventions may then occur late or not at all.
> - smaller animals such as cats and dogs.
>
> The driver is always responsible for ensuring that the vehicle is driven correctly and with a safety distance suitable for the speed.

Related information

- City Safety™ (p. 311)
- City Safety in crossing traffic (p. 317)
- City Safety braking for oncoming vehicles* (p. 320)

City Safety in crossing traffic

City Safety can assist the driver when turning in the path of an oncoming vehicle in an intersection.



1: Sector in which City Safety can detect an oncoming vehicle in crossing traffic.

In order for City Safety to detect an oncoming vehicle in situations where there is a risk of a collision, that vehicle must be within the sector in which City Safety can analyze the situation.

The following criteria must also be met:

- your vehicle's speed must be at least 4 km/h (3 mph)
- your vehicle must be making a left turn
- the oncoming vehicle's headlights must be on

▸▸

◀◀

⚠ WARNING

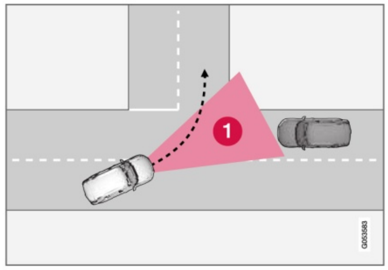
- The "City Safety in crossing traffic" function is supplementary driver support intended to improve driving safety – it cannot handle all situations in all traffic, weather and road conditions.
- Warnings and brake interventions due to a collision risk with an oncoming vehicle often come very late.
- Never wait for a collision warning or for City Safety to intervene.
- City Safety is not a substitute for the driver's attention and judgment. The driver is always responsible for ensuring the vehicle is driven in a safe manner, at the appropriate speed, with an appropriate distance to other vehicles, and in accordance with current traffic rules and regulations.

Related information

- City Safety™ (p. 311)

Limitations of City Safety in crossing traffic

In certain situations, it may be difficult for City Safety to help the driver avoid a collision with crossing traffic.



For example:

- on slippery roads when Electronic Stability Control (ESC) is actively operating
- if an approaching vehicle is detected at a late stage
- if the oncoming vehicle is partially obstructed by another vehicle or object
- if the oncoming vehicle's headlights are off
- if the oncoming vehicle is moving erratically and e.g. suddenly changes lanes at a late stage.

ⓘ NOTE

The function uses the vehicle's combined camera and radar unit, which has certain general limitations; see sections "Camera limitations" and "Radar sensor limitations".

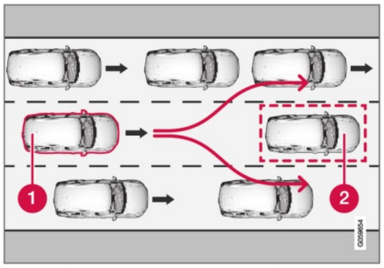
Related information

- City Safety™ (p. 311)
- City Safety limitations (p. 321)
- City Safety in crossing traffic (p. 317)
- Camera limitations (p. 308)
- Radar sensor limitations (p. 303)

City Safety and delayed evasive maneuvers

City Safety can assist the driver by automatically braking the vehicle when it is not possible to avoid a collision by steering alone.

City Safety assists the driver by periodically attempting to predict possible "escape routes" to the sides of the vehicle in the event a slow-moving or stationary vehicle were to be detected at a late stage.



Your vehicle (1) cannot detect any potential escape routes for veering away from the vehicle ahead (2) and may therefore apply the brakes at an earlier stage.

1. Own vehicle
2. Slow-moving/stationary vehicles

City Safety will not intervene to automatically apply the brakes if it is possible for the driver to avoid a collision by steering the vehicle.

However, if City Safety determines that an evasive maneuver would not be possible due to traffic in the adjacent lane(s), the function can assist the driver by automatically starting to apply the brakes at an earlier stage.

WARNING

- The possibility of City Safety predicting a certain situation is supplementary driver support intended to improve driving safety – it cannot handle all situations in all traffic, weather and road conditions.
- City Safety is not a substitute for the driver's attention and judgment. The driver is always responsible for ensuring the vehicle is driven in a safe manner, at the appropriate speed, with an appropriate distance to other vehicles, and in accordance with current traffic rules and regulations.

Limitations of City Safety during evasive maneuvers

NOTE

The function uses the vehicle's combined camera and radar unit, which has certain general limitations; see sections "Camera limitations" and "Radar sensor limitations".

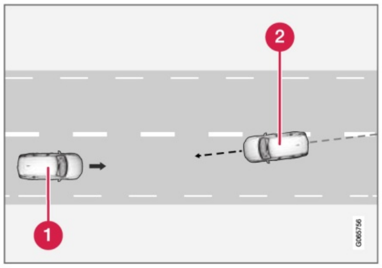
Related information

- City Safety™ (p. 311)
- Camera limitations (p. 308)
- Radar sensor limitations (p. 303)

City Safety braking for oncoming vehicles*

City Safety can help you apply the brakes for an oncoming vehicle in your lane.

If an oncoming vehicle veers into your lane and a collision is unavoidable, City Safety can help reduce your vehicle's speed to attempt to mitigate the force of the collision.



1 Own vehicle

2 Oncoming vehicles

The following criteria must be met for the function to work:

- your vehicle's speed must be above 4 km/h (3 mph)
- the road must be straight
- your lane must have clear side lane markings
- your vehicle must be positioned straight in your lane
- the oncoming vehicle must be positioned within your vehicle's lane markings
- the oncoming vehicle's headlights must be on
- the function can only handle "front-to-front" collisions
- the function can only detect vehicles with four wheels
- the function requires functioning **Electric Seat Belt Tensioners*** (see section "Seat belt tensioners").

NOTE

The function uses the vehicle's combined camera and radar unit, which has certain general limitations; see sections "Camera limitations" and "Radar sensor limitations".

WARNING

- The "City Safety braking for oncoming vehicles" function is supplementary driver support intended to help improve driving safety – it cannot handle all situations in all traffic, weather and road conditions.
- Warnings and brake interventions due to an imminent collision with an oncoming vehicle always come very late.
- Never wait for a collision warning or for City Safety to intervene. If you notice any hazard or other potentially dangerous situation, always fully apply the brakes.
- City Safety is not a substitute for the driver's attention and judgment. The driver is always responsible for ensuring the vehicle is driven in a safe manner, at the appropriate speed, with an appropriate distance to other vehicles, and in accordance with current traffic rules and regulations.

Related information

- City Safety™ (p. 311)
- City Safety limitations (p. 321)
- Camera limitations (p. 308)
- Radar sensor limitations (p. 303)
- Seat belt tensioners (p. 50)

* Option/accessory.

City Safety limitations

City Safety functionality may be reduced in certain situations.

Surroundings

Low objects
Hanging objects, such as flags for overhanging loads or accessories such as auxiliary lights or front protective grids that extend beyond the height of the hood, may limit City Safety functionality.

Slippery road conditions
The extended braking distance on slippery roads may reduce City Safety's capacity to help avoid a collision. In these types of situations, the Anti-lock Braking System and Electronic Stability Control (ESC[62]) will help provide optimal braking power with maintained stability.

Backlighting
The visual warning signal in the windshield may be difficult to detect in bright sunlight, if there are reflections, or if the driver is wearing sunglasses or not looking straight ahead.

Heat
If the temperature in the passenger compartment is high due to e.g. bright sunlight, the visual warning signal in the windshield may be temporarily disabled.

Camera and radar sensor's field of vision
The camera's field of vision is limited and in certain situations, it may be unable to detect pedestrians, large animals, cyclists or vehicles, or it may detect them later than expected.

Vehicles that are dirty may be detected later than clean vehicles, and in dark conditions, motorcycles may be detected late or not at all.

If a text message displayed in the instrument panel indicates that the camera/radar sensor is obstructed, it may be difficult for City Safety to detect pedestrians, large animals, cyclists, vehicles or lane markings in front of the vehicle. City Safety functionality may therefore be reduced.

Text messages may not be displayed for all situations in which the windshield sensors are blocked. The driver must therefore always keep the windshield in front of the camera/radar sensor clean.

CAUTION

Maintenance and replacement of City Safety components may only be performed by a workshop – an authorized Volvo workshop is recommended.

Driver intervention

Backing up
City Safety is temporarily deactivated when the vehicle is backing up.

Low speed
City Safety is not activated at very low speeds under 4 km/h (3 mph). The system will therefore not intervene in situations in which your vehicle is approaching another vehicle very slowly, such as when parking.

Active driver
Action by the driver always has priority. City Safety will therefore not react or will react at a later stage with a warning or intervention in situations in which the driver is clearly steering and operating the accelerator pedal, even if a collision is unavoidable.

An active and aware driving style may therefore delay collision warnings and intervention in order to minimize unnecessary warnings.

62 Electronic Stability Control

Other limitations

WARNING

- Warnings and brake interventions can be triggered late or not at all if the traffic situation or external influences prevent the camera and radar unit from properly detecting pedestrians, cyclists, large animals or vehicles ahead of the vehicle.
- To be able to detect vehicles at night, its front and rear lights must work and illuminate clearly.
- The camera and radar unit have a limited range for pedestrians and cyclists – the system can provide effective warnings and brake interventions if the relative speed is lower than 50 km/h (30 mph). For stationary or slow-moving vehicles, warnings and brake interventions are effective at vehicle speeds of up to 70 km/h (43 mph). Speed reduction for large animals is less than 15 km/h (9 mph) and can be achieved at vehicle speeds over 70 km/h (43 mph). At lower speeds, the warning and brake intervention for large animals is less effective.
- Warnings for stationary or slow-moving vehicles and large animals can be disengaged due to darkness or poor visibility.
- Warnings and brake interventions for pedestrians and cyclists are disengaged at vehicle speeds over 80 km/h (50 mph).
- Do not place, affix or mount anything on the inside or outside of the windshield, or in front of or around the camera and radar unit – this could disrupt camera-based functions.
- Objects, snow, ice or dirt in the area of the camera sensor can reduce the function, disengage it completely or give an improper function response.

NOTE

The function uses the vehicle's combined camera and radar unit, which has certain general limitations; see sections "Camera limitations" and "Radar sensor limitations".

Market limitations

City Safety is not available in all countries. If City Safety is not shown in the center display's **Settings** menu, your vehicle is not equipped with this function.

In the center display's Top view, tap:

- **Settings ➔ My Car ➔ IntelliSafe**

Related information

- City Safety™ (p. 311)
- Camera limitations (p. 308)
- Radar sensor limitations (p. 303)

City Safety messages

A number of messages related to City Safety may be displayed in the instrument panel.

Some examples of symbols and messages are shown in the table below.

Message	Meaning
City Safety **Automatic intervention**	When City Safety is braking or has activated the automatic braking function, one or more symbols may illuminate in the instrument panel and a text message may be displayed.
City Safety **Reduced functionality Service required**	The system is not functioning as intended. Contact a workshop – an authorized Volvo workshop is recommended.

A text message can be erased by briefly pressing the O button in the center of the right-side steering wheel keypad.

If the message persists: Contact a workshop – an authorized Volvo workshop is recommended.

Related information

- City Safety™ (p. 311)

Rear Collision Warning

The Rear Collision Warning (RCW) function can help the driver avoid rear-end collisions from vehicles approaching from behind.

RCW is automatically activated each time the engine is started.

RCW can warn the driver of a potential collision with vehicles approaching from behind by rapidly flashing the turn signals.

If, at a speed below 30 km/h (20 mph), the RCW function detects that the car is in danger of being hit from behind, the seatbelt tensioners may tension the front seatbelts and activate the Whiplash Protection System safety system.

Immediately before a collision from behind, RCW may also activate the foot brake in order to reduce the forward acceleration of the car during the collision. However, the brakes will only be applied if your vehicle is stationary. The brakes will be immediately released if the accelerator pedal is depressed.

Related information

- Rear Collision Warning limitations (p. 324)
- Whiplash Protection System (p. 46)

Rear Collision Warning limitations

In some situations, it may be difficult for RCW to warn the driver of a collision risk.

This may be the case if:

- the vehicle approaching from the rear is detected at a late stage
- the vehicle approaching from the rear changes lanes at a late stage
- the vehicle approaching from the rear is moving at a speed above 80 km/h (50 mph)
- a trailer, bicycle holder or similar is connected to the vehicle's electrical system - the RCW function will then be automatically deactivated.

NOTE

In certain markets RCW does **not** warn with the direction indicators due to local traffic regulations – in such cases, that part of the function is deactivated.

NOTE

The warning with direction indicators for Rear Collision Warning is deactivated if the collision warning distance in the City Safety function is set to the lowest level "**Late**".

The seat belt tensioning and braking functions remain active.

Related information

- Rear Collision Warning (p. 324)

APPENDIX C

Run Log

Subject Vehicle: **2019 Volvo XC40** Test Date: 2/6/2019

Principal Other Vehicle: SSV

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
1-16	Brake characterization and confirmation						See Appendix D
17	Static Run						
18	**Stopped POV**	Y	1.37	15.03	1.08	Pass	
19		Y	2.11	13.33	1.04	Pass	
20		Y	2.10	14.25	1.07	Pass	
21		Y	2.08	13.62	1.02	Pass	
22		Y	2.07	11.92	1.04	Pass	
23		Y	2.04	7.83	0.99	Pass	
24		Y	2.09	10.10	0.99	Pass	
25	Static Run						
26	**Slower POV, 25 vs 10**	Y	1.53	5.81	0.59	Pass	
27		Y	1.54	6.70	0.68	Pass	
28		Y	1.68	4.25	0.51	Pass	
29		Y	1.63	7.79	0.98	Pass	
30		Y	1.61	3.80	0.50	Pass	
31		Y	1.58	7.67	0.96	Pass	
32		Y	1.63	5.98	1.01	Pass	
33	Static run						

Subject Vehicle: **2019 Volvo XC40**

Test Date: 2/6/2019

Principal Other Vehicle: SSV

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
34	**Slower POV, 45 vs 20**	Y	2.19	14.51	1.10	Pass	
35		Y	2.27	14.21	1.03	Pass	
36		Y	2.25	13.94	1.11	Pass	
37		Y	2.28	12.03	1.06	Pass	
38		Y	2.22	12.73	1.08	Pass	
39		Y	2.25	12.80	1.07	Pass	
40		Y	2.39	11.88	1.08	Pass	
41	Static run						
42	**Braking POV, 35**	N					Late Brake Force, intercept to 0.47"
43		N					Early Brake Release
44		Y	1.74	3.48	0.59	Pass	
45		Y	1.82	5.29	0.58	Pass	
46		N					POV Speed
47		N					Post Processor Error
48		Y	1.75	4.89	0.57	Pass	
49		Y	1.80	5.40	0.57	Pass	
50		Y	1.83	6.86	0.62	Pass	
51		N					POV Speed
52		Y	1.71	5.63	0.58	Pass	
53		Y	1.83	5.53	0.58	Pass	

Subject Vehicle: **2019 Volvo XC40**

Test Date: 2/6/2019

Principal Other Vehicle: SSV

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
54	Static run						
55	STP - Static run						
56	**Baseline, 25**	Y			0.39		
57		Y			0.39		
58		Y			0.40		
59		Y			0.40		
60		Y			0.40		
61		Y			0.40		
62		Y			0.40		
63	STP - Static run						
64	**Baseline, 45**	Y			0.46		
65		Y			0.47		
66		Y			0.50		
67		Y			0.50		
68		Y			0.50		
69		Y			0.50		
70		Y			0.49		
71	STP - Static run						

Subject Vehicle: **2019 Volvo XC40** Test Date: 2/6/2019

Principal Other Vehicle: SSV

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
72	STP - Static run						
73	**STP False Positive, 25**	Y			0.48	Pass	
74		Y			0.47	Pass	
75		Y			0.45	Pass	
76		Y			0.44	Pass	
77		Y			0.43	Pass	
78		Y			0.42	Pass	
79		N					Throttle
80		Y			0.43	Pass	
81	STP - Static run						
82	**STP False Positive, 45**	Y			0.40	Pass	
83		Y			0.60	Pass	
84		Y			0.54	Pass	
85		Y			0.54	Pass	
86		N					Throttle
87		Y			0.52	Pass	
88		Y			0.55	Pass	
89		N					Throttle
90		N					Brake Actuator Malfunction
91		Y			0.50	Pass	

Subject Vehicle: **2019 Volvo XC40**

Test Date: 2/6/2019

Principal Other Vehicle: SSV

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
92	STP - Static run						

APPENDIX D

Brake Characterization

Subject Vehicle: **2019 Volvo XC40** Test Date: 2/6/2019

DBS Initial Brake Characterization				
Run Number	**Stroke at 0.4 g (in)**	**Force at 0.4 g (lb)**	**Slope**	**Intercept**
1	1.068997	15.9063	1.254416	0.207719
2	1.175604	15.9722	1.205489	0.27105
3	1.145065	15.75761	1.155806	0.21957

DBS Brake Characterization Confirmation								
Run	**DBS Mode**	**Speed**	**Valid Run**	**Average Decel. (g)**	**0.4 g Stroke Value (in)**	**0.4 g Force Value (lb)**	**Stroke/Force Calculator (in)**	**Notes**
4	**Displacement**	35	N					Brake Application Rate
5			N	0.370	1.13	15.88	1.22	Decel Too Low
6			N	0.440	1.20	15.88	1.09	Decel Too High
7			Y	0.414	1.16	15.88	1.12	
8		25	Y	0.397	1.16	15.88	1.17	
9		45	Y	0.408	1.16	15.88	1.14	

DBS Brake Characterization Confirmation								
Run	**DBS Mode**	**Speed**	**Valid Run**	**Average Decel. (g)**	**0.4 g Stroke Value (in)**	**0.4 g Force Value (lb)**	**Stroke/Force Calculator (in)**	**Notes**
10	**Hybrid**	35	N	0.517	1.16	15.88	12.29	Decel Too High
11			N	0.426	1.16	13.00	12.21	Decel Too High
12			Y	0.423	1.16	12.50	11.82	
13		25	N	0.438	1.16	12.50	11.42	Decel Too High
14			Y	0.411	1.16	12.00	11.68	
15		45	N	0.369	1.16	12.00	13.01	
16			Y	0.412	1.16	12.50	12.14	

Appendix E

TIME HISTORY PLOTS

LIST OF FIGURES

Description of Time History Plots

A set of time history plots is provided for each valid run in the test series. Each set of plots comprises time varying data from both the Subject Vehicle (SV) and the Principal Other Vehicle (POV), as well as pass/fail envelopes and thresholds. The following is a description of data types shown in the time history plots, as well as a description of the color code indicating to which vehicle the data pertain.

Time History Plot Description

Each time history plot consists of data relevant to the test type under consideration, and therefore the data channels plotted vary according to test type. The test types (shown in the plot titles) include:

- Stopped POV (SV at 25 mph)
- Slower POV, 25/10 (SV at 25 mph, POV at 10 mph)
- Slower POV, 45/20 (SV at 45 mph, POV at 20 mph)
- Braking POV 35 mph (Both vehicles at 35 mph with 13.8 m gap, POV brakes at 0.3 g)
- False Positive Baseline 25 mph (Baseline run at 25 mph)
- False Positive Baseline 45 mph (Baseline run at 45 mph)
- False Positive STP 25 mph (Steel trench plate run over at 25 mph)
- False Positive STP 45 mph (Steel trench plate run over at 45 mph)
- DBS Brake Characterization, Initial
- DBS Brake Characterization Determination

Time history figures include the following sub-plots:

- FCW Warning – displays the Forward Collision Warning alert (which can be audible, visual, or haptic). Depending on the type of FCW alert or instrumentation used to measure the alert, this can be any combination of the following:
    - Filtered, rectified, and normalized sound signal. The vertical scale is 0 to 1.
    - Filtered, rectified, and normalized acceleration (i.e., haptic alert, such as steering wheel vibration). The vertical scale is 0 to 1.
    - Normalized light sensor signal. The vertical scale is 0 to 1.

As only the audible or haptic alert is perceptible by the driver during a test run, the earliest of either of these alerts is used to define the onset of the FCW alert. A vertical black bar on the plot indicates the TTC (sec) at the first moment of the warning issued by the FCW system. The FCW TTC is displayed to the right of the subplot in green.

- Headway (ft) – longitudinal separation between the frontmost point of the Subject Vehicle and the rearmost point of the Strikeable Surrogate Vehicle (SSV) towed by the Principal Other Vehicle. The minimum headway during the run is displayed to the right of the subplot.

- SV/POV Speed (mph) – speed of the Subject Vehicle and the Principal Other Vehicle (if any). For DBS tests, in the case of an impact, the speed reduction experienced by the Subject Vehicle up until the moment of impact is displayed to the right of the subplot.

- Yaw Rate (deg/sec) – yaw rate of the Subject Vehicle and Principal Other Vehicle (if any).

- Lateral Offset (ft) – lateral offset within the lane of the Subject Vehicle to the center of the lane of travel. Note that for tests involving the Strikeable Surrogate Vehicle (SSV), the associated lateral restraint track is defined to be the center of the lane of travel. If testing is done with a different POV which does not have a lateral restraint track, lateral offset is defined to be the lateral offset between the SV and POV.

- Ax (g) – longitudinal acceleration of the Subject Vehicle and Principal Other Vehicle (if any). The peak value of Ax for the SV is shown on the subplot.

- Pedal Position (in) – position of the accelerator pedal and brake pedal.

- Brake Force (lb) – force on the brake pedal as applied by the DBS controller. The TTC at the onset of the brake by the DBS controller is shown on the subplot. Additionally, the average force at the brake pedal while the DBS controller is active is displayed.

Note that the minimum (worst) GPS fix type is displayed in the lower right corner of each page. The only valid fix type is RTK fixed (displayed in green). If the fix type during any portion of the test was anything other than RTK fixed, then “RTK Fixed OR LESS!!” is displayed in red.

Envelopes and Thresholds

Some of the time history plot figures contain either green or yellow envelopes and/or black threshold lines. These envelopes and thresholds are used to programmatically and visually determine the validity of a given test run. Envelope and threshold exceedances are indicated with either red shading or red asterisks, and red text is placed to the right side of the plot indicating the type of exceedance. Such exceedances indicate either that the test was invalid or that the requirements of the test were not met (i.e., failure of the AEB system).

For plots with green envelopes, in order for the test to be valid, the time-varying data must not exceed the envelope boundaries at any time within the envelope. Exceedances of a green envelope are indicated by red shading in the area between the measured time-varying data and the envelope boundaries.

For plots with yellow envelopes, in order for the test to be valid, the time-varying data must not exceed the envelope at the beginning (left edge of the boundary) and/or end (right edge), but may exceed the boundary during the time between the left and right edges. Exceedances at the left or right extent of a yellow envelope are indicated by red asterisks.

For the headway plot, a dashed black threshold line indicating a relative headway of zero is given. If no impact occurs, a green circle is displayed at the moment of minimum distance. If impact occurs, a red asterisk is displayed at the moment of impact.

For the plot indicating the Ax, if the scenario is an AEB brake to stop scenario, a vertical dashed black line is displayed for all plots indicating the moment of first POV braking. The yellow envelope in this case is relevant to the POV braking only. The left edge of the envelope is at 1.5 seconds after the first POV braking. A solid black threshold line extends horizontally 0.5 seconds to the left of the envelope. This threshold line represents the time during which the Ax of the Principal Other Vehicle must first achieve 0.27g (the upper edge of the envelope). A green circle or red asterisk is displayed at the moment the POV brake level achieves 0.27g. A green circle indicates that the test was valid (the threshold was crossed during the appropriate interval) and a red asterisk indicates that the test was invalid (the threshold was crossed out of the appropriate interval).

For the pedal position plot, a thick black bar appears on the brake pedal position data over the DBS controller brake onset period to signify the time over which the brake application rate is determined. The calculated brake application rate is also displayed on the figure.

For the brake force plot, a dashed black threshold line indicating a brake force of 2.5 lbs is given. For the time period where the DBS controller is active, the brake force at the pedal must not fall below this 2.5 lb threshold. Exceedances of this threshold are indicated by red shading in the area between the measured time-varying data and the dashed threshold line. The yellow envelope in this case is used only to visualize the target average brake force necessary for the test to be valid.

Color Codes

Color codes have been adopted to easily identify which data correspond to which vehicle, as well as to indicate the types of envelopes and thresholds used in the plots.

Color codes can be broken into four categories:

1. Time-varying data
2. Validation envelopes and thresholds
3. Individual data points
4. Text

1. Time-varying data color codes:
    - Blue = Subject Vehicle data
    - Magenta = Principal Other Vehicle data
    - Brown = Relative data between SV and POV (i.e., TTC, lateral offset and headway distance)

2. Validation envelope and threshold color codes:
    - Green envelope = time varying data must be within the envelope at all times in order to be valid
    - Yellow envelope = time varying data must be within limits at left and/or right ends
    - Black threshold (Solid) = time varying data must cross this threshold in the time period shown in order to be valid

- Black threshold (Dashed) = for reference only – this can include warning level thresholds, TTC thresholds, and acceleration thresholds

3. Individual data point color codes:
   - Green circle = passing or valid value at a given moment in time
   - Red asterisk = failing or invalid value at a given moment in time

4. Text color codes:
   - Green = passing or valid value
   - Red = failing or invalid value

Examples of valid or passing time history plots for each test type (including passing, failing, and invalid runs) are shown in Figure E1 through E12. Figures E1 through E8 show passing runs for each of the 8 test types. Figure E9 shows an example of a passing brake characterization run. Figures E10 and E11 show examples of invalid runs. Figure E12 shows an example of a valid test that failed the DBS requirements.

Time history data plots for the tests of the vehicle under consideration herein are provided beginning with Figure E13.

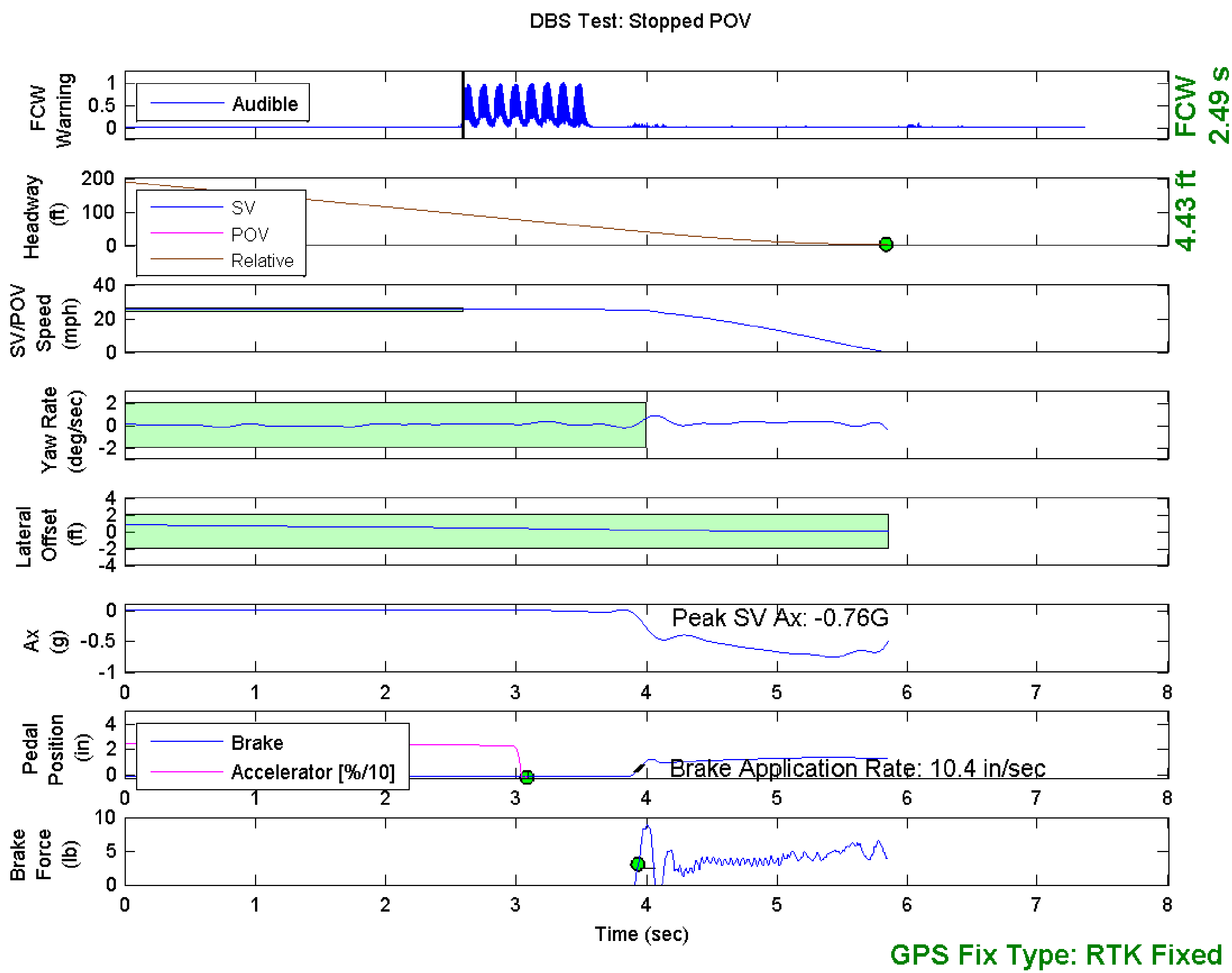


Figure E1. Example Time History for Stopped POV, Passing

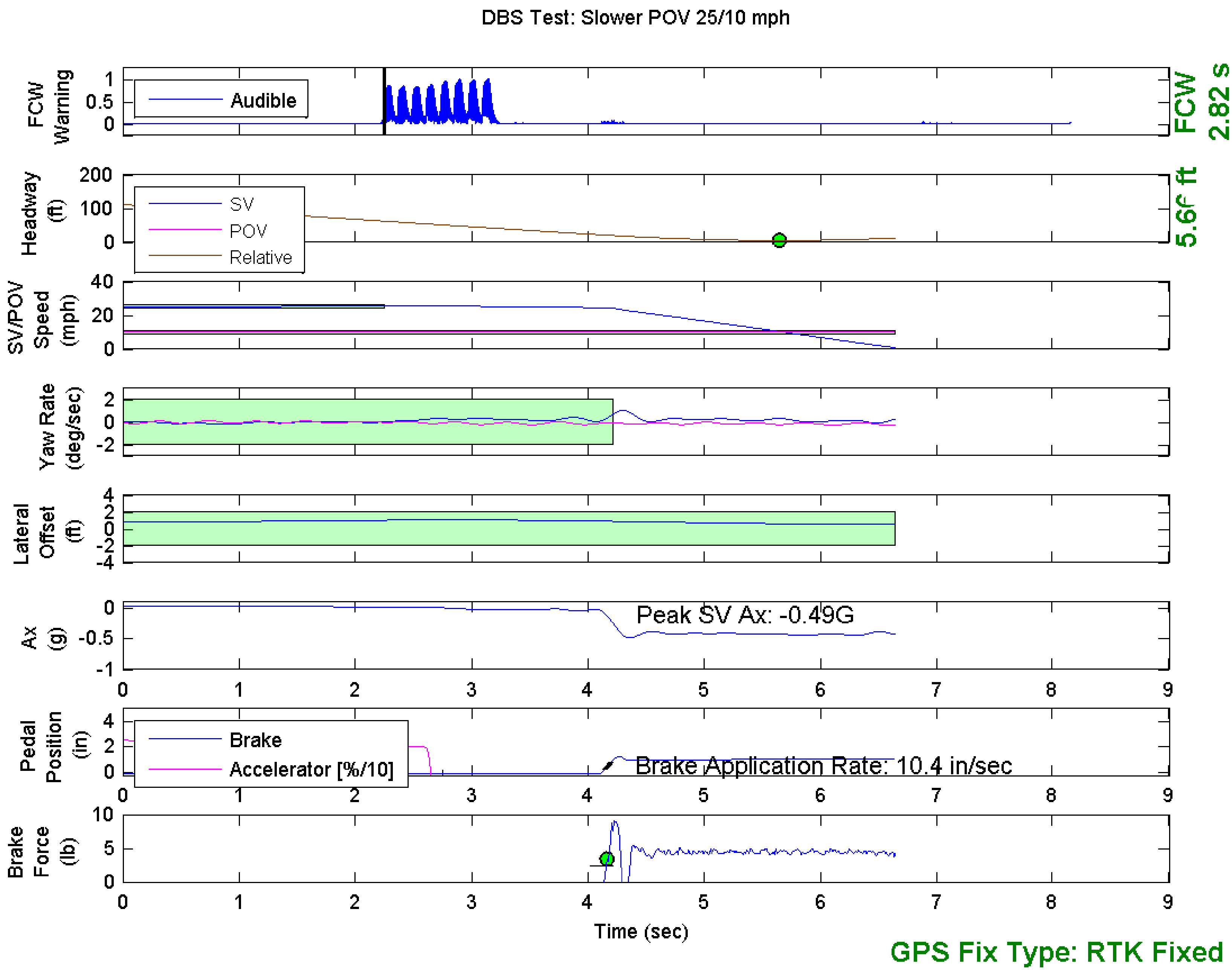


Figure E2. Example Time History for Slower POV 25 vs. 10, Passing

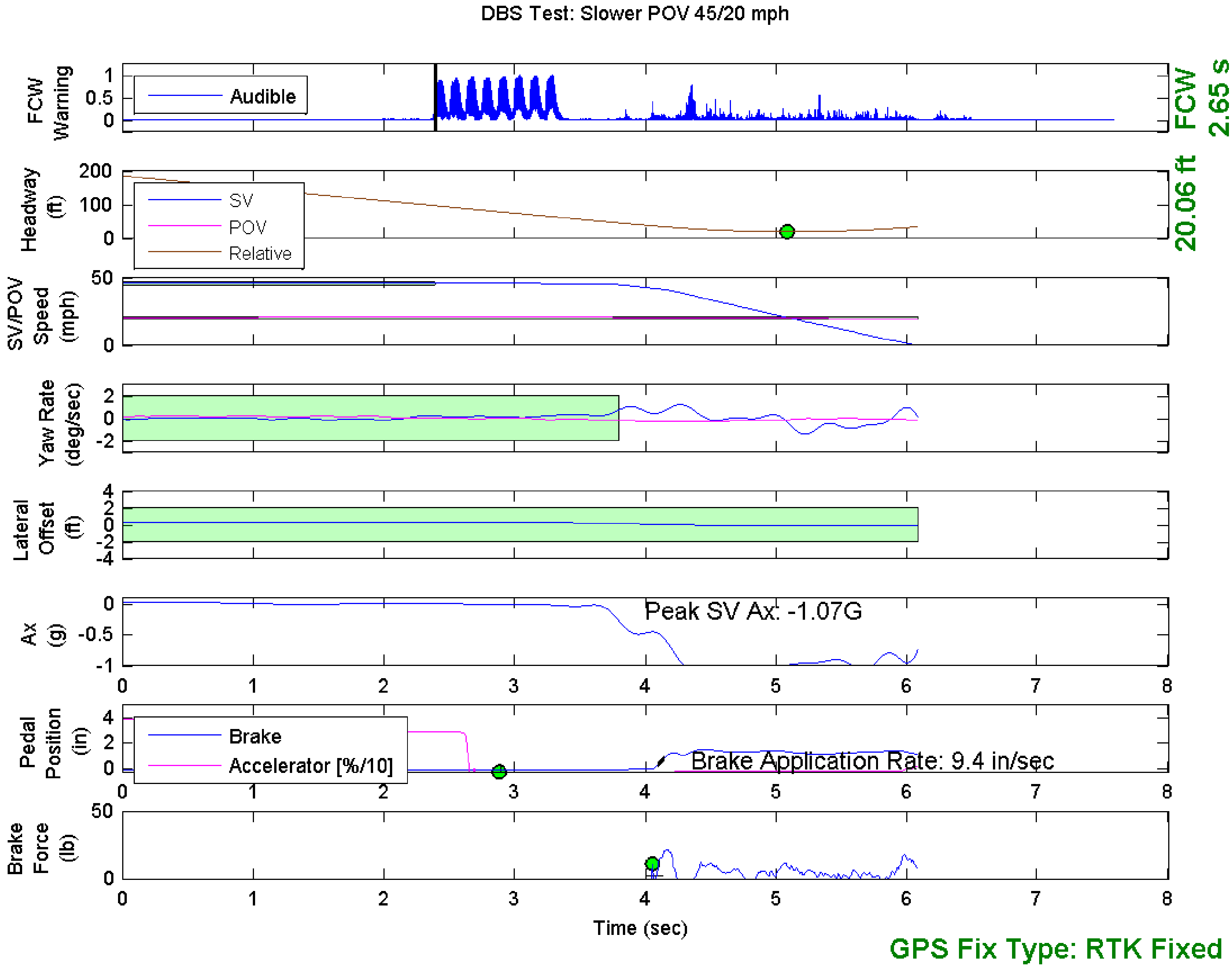


Figure E3. Example Time History for Slower POV 45 vs. 20, Passing

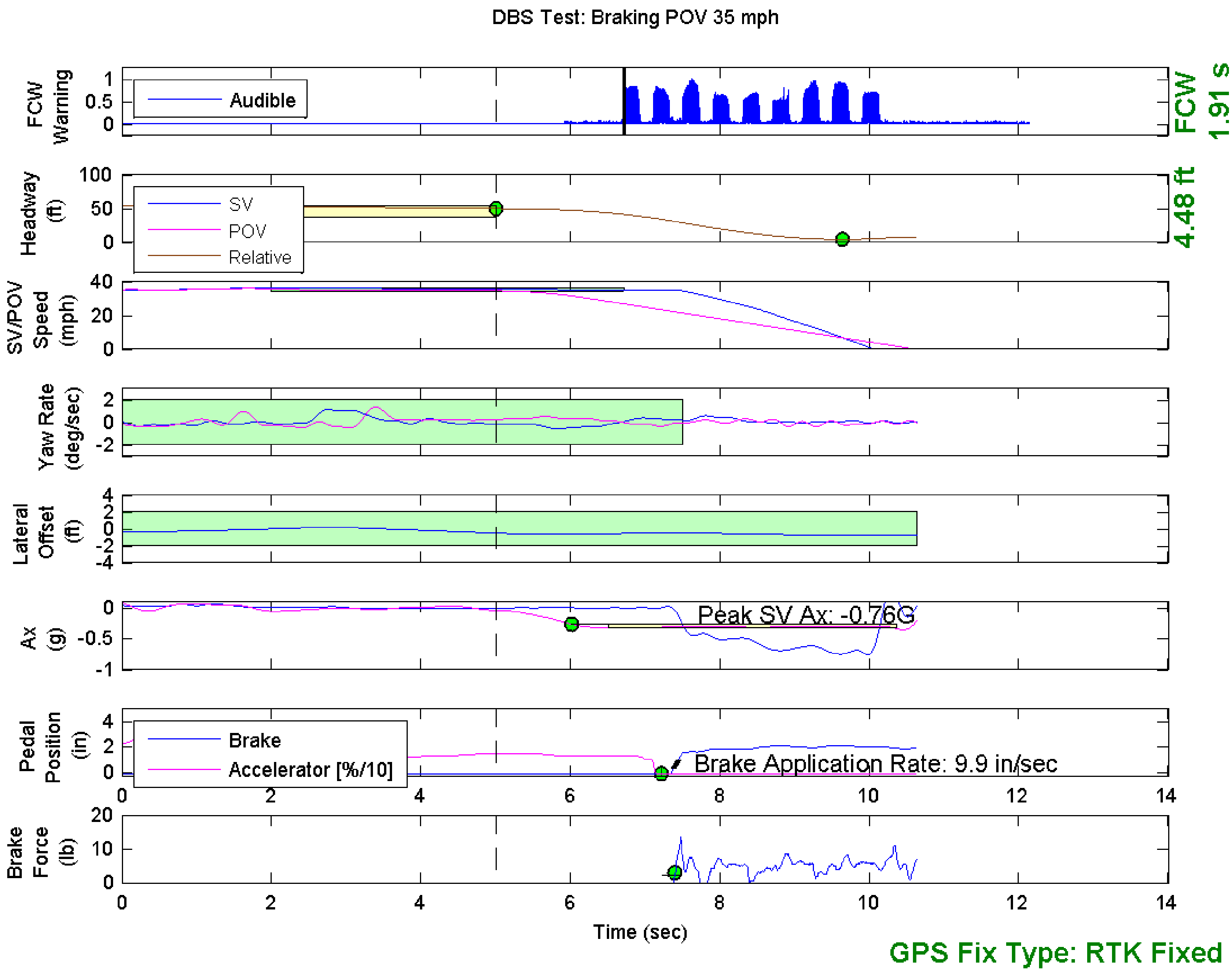


Figure E4. Example Time History for Braking POV 35, Passing

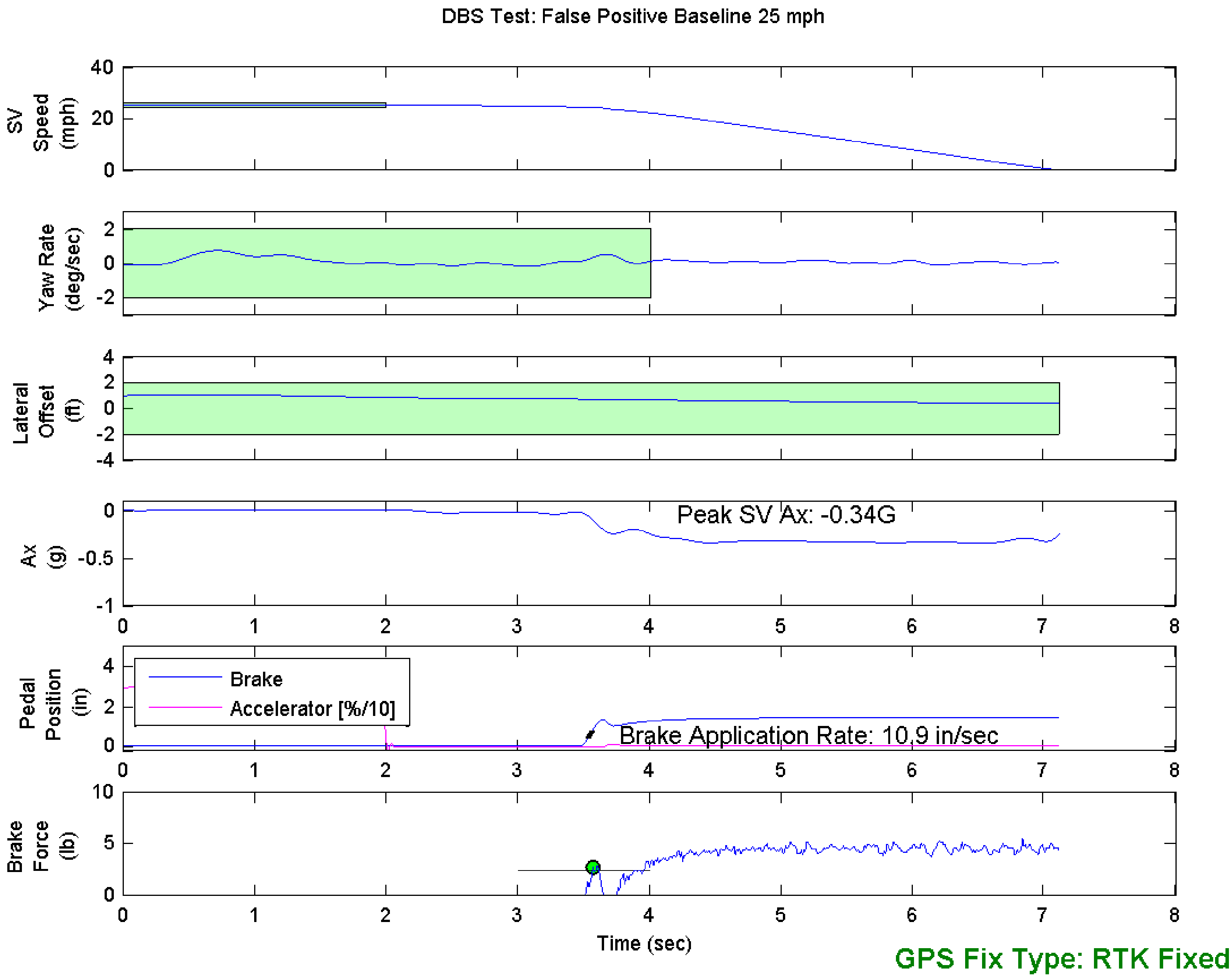


Figure E5. Example Time History for False Positive Baseline 25, Passing

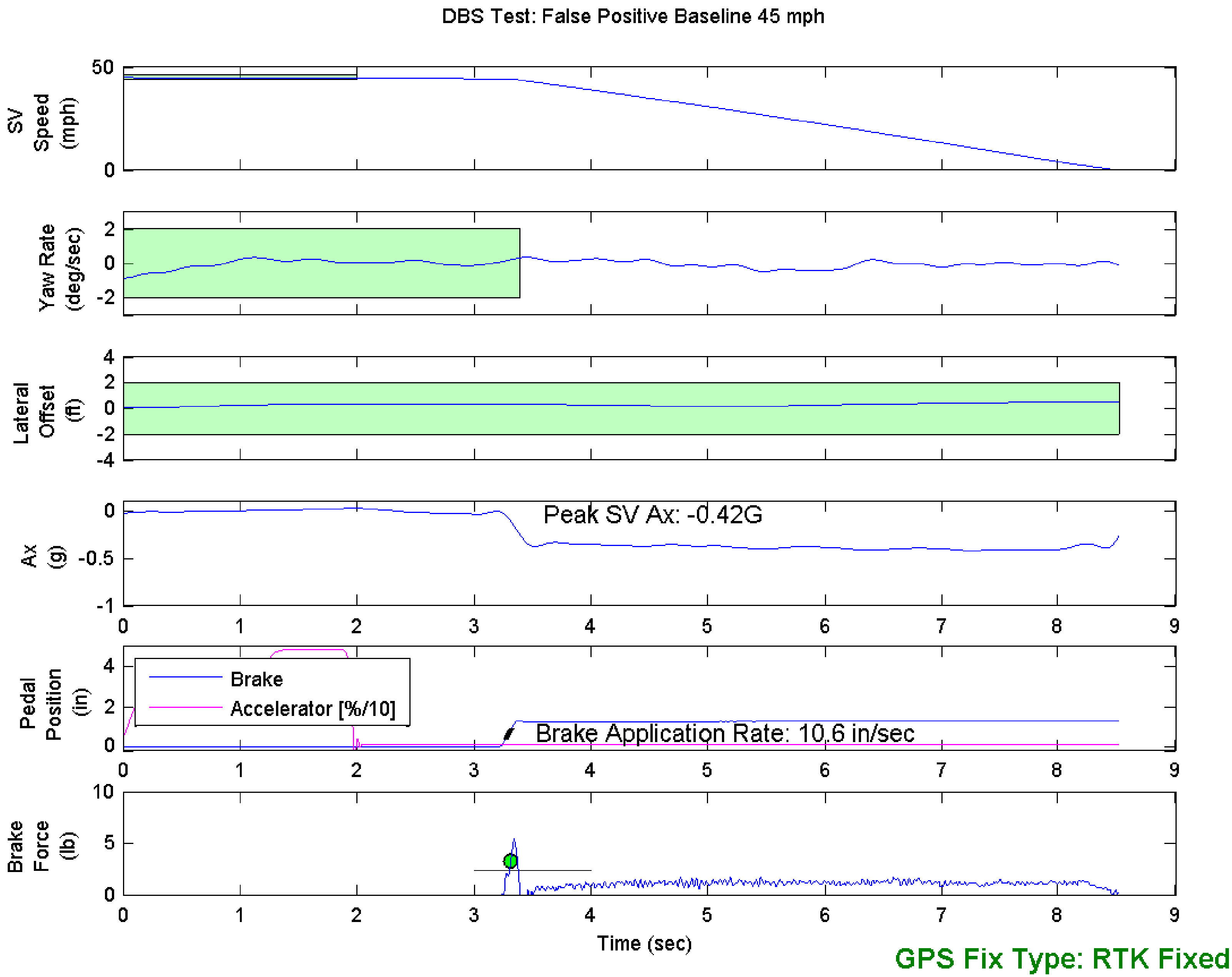


Figure E6. Example Time History for False Positive Baseline 45, Passing

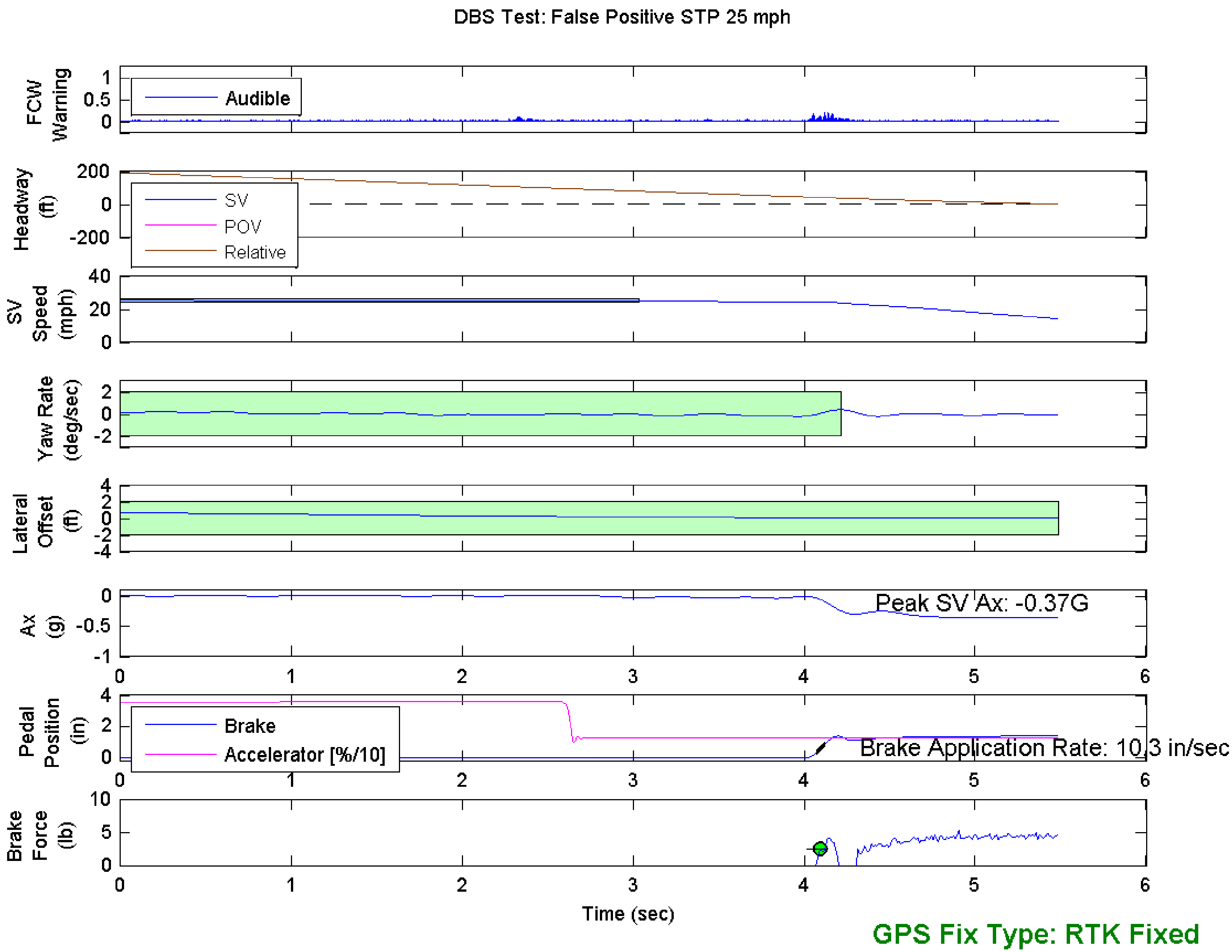


Figure E7. Example Time History for False Positive Steel Plate 25, Passing

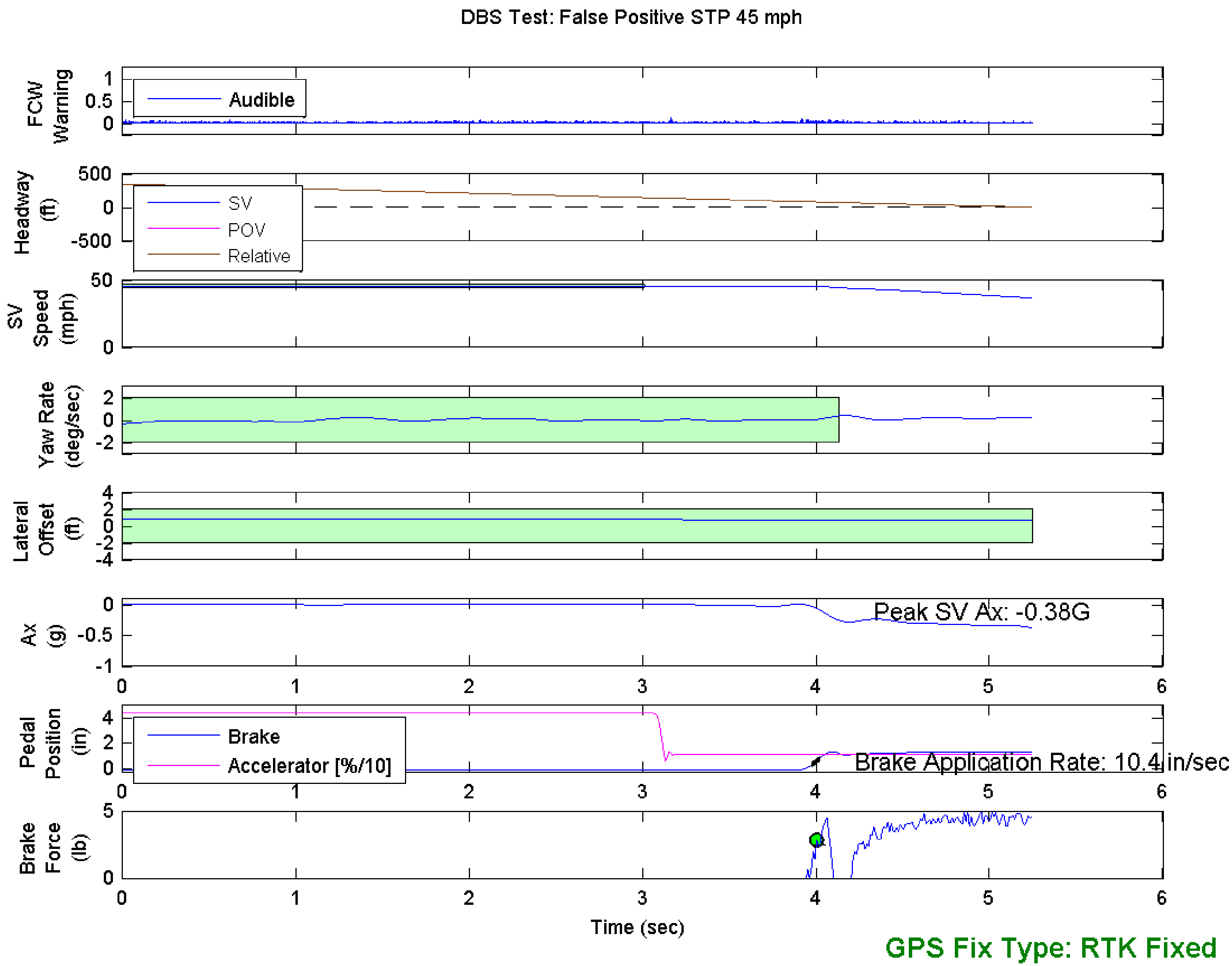


Figure E8. Example Time History for False Positive Steel Plate 45, Passing

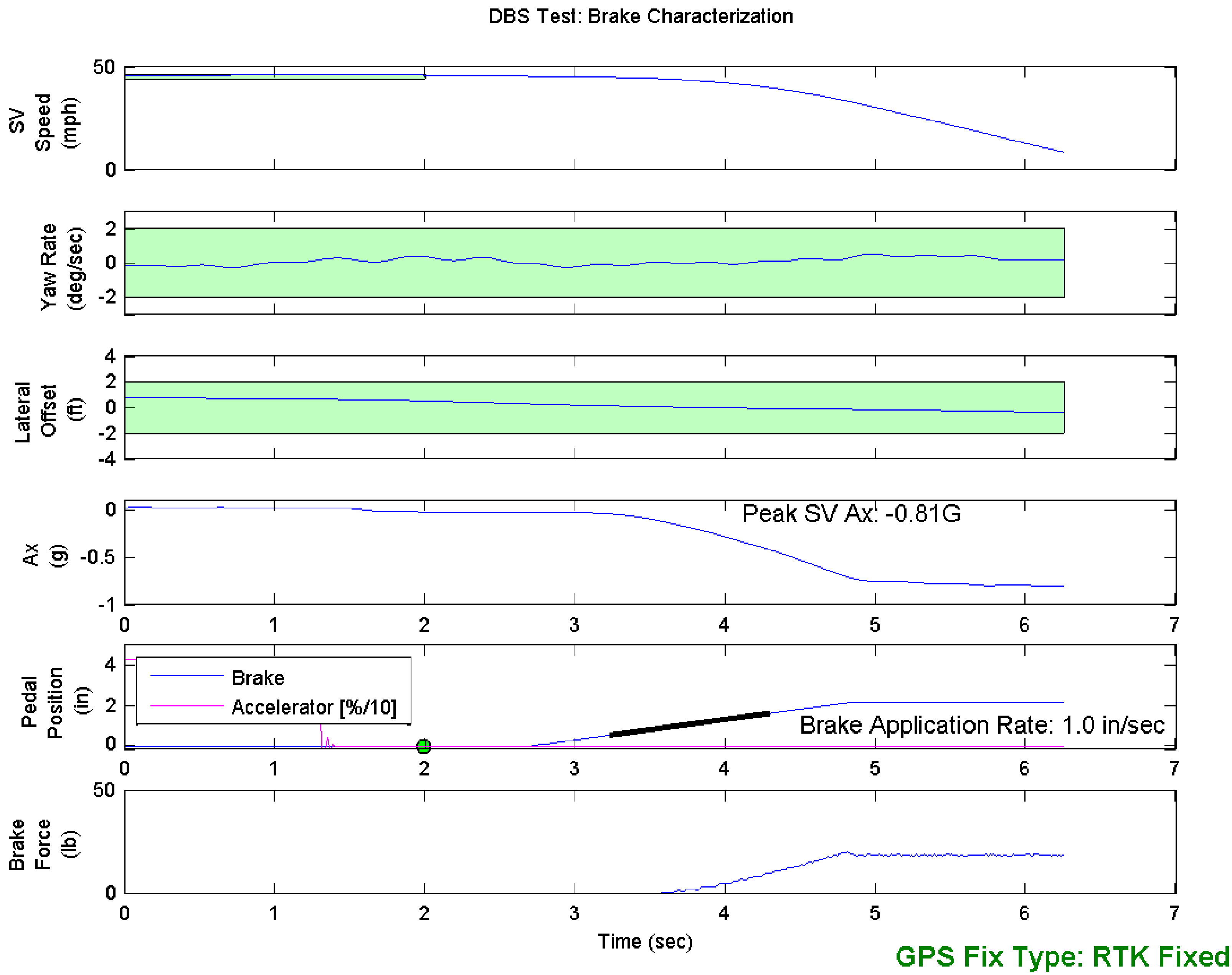


Figure E9. Example Time History for DBS Brake Characterization, Passing

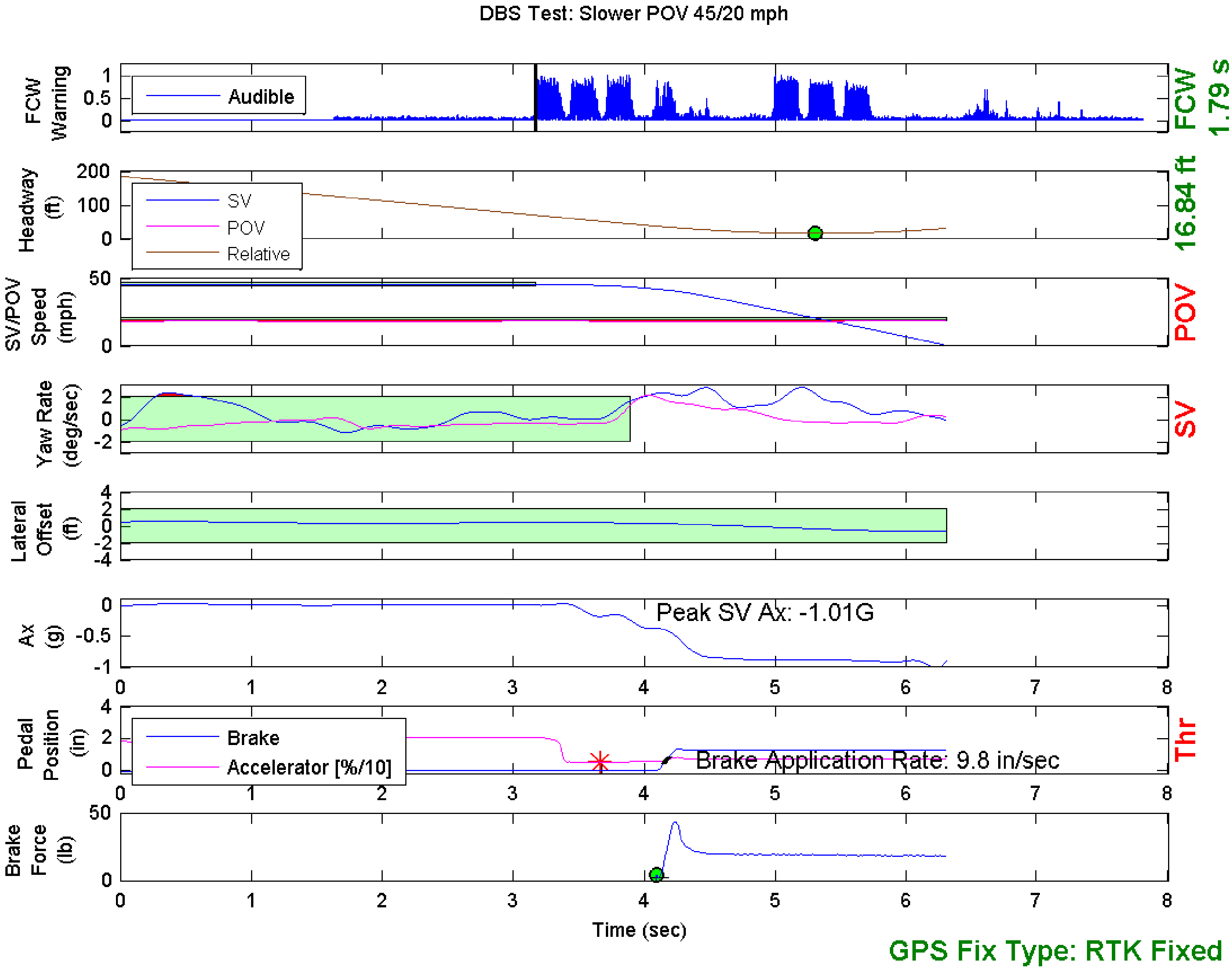


Figure E10. Example Time History Displaying Various Invalid Criteria

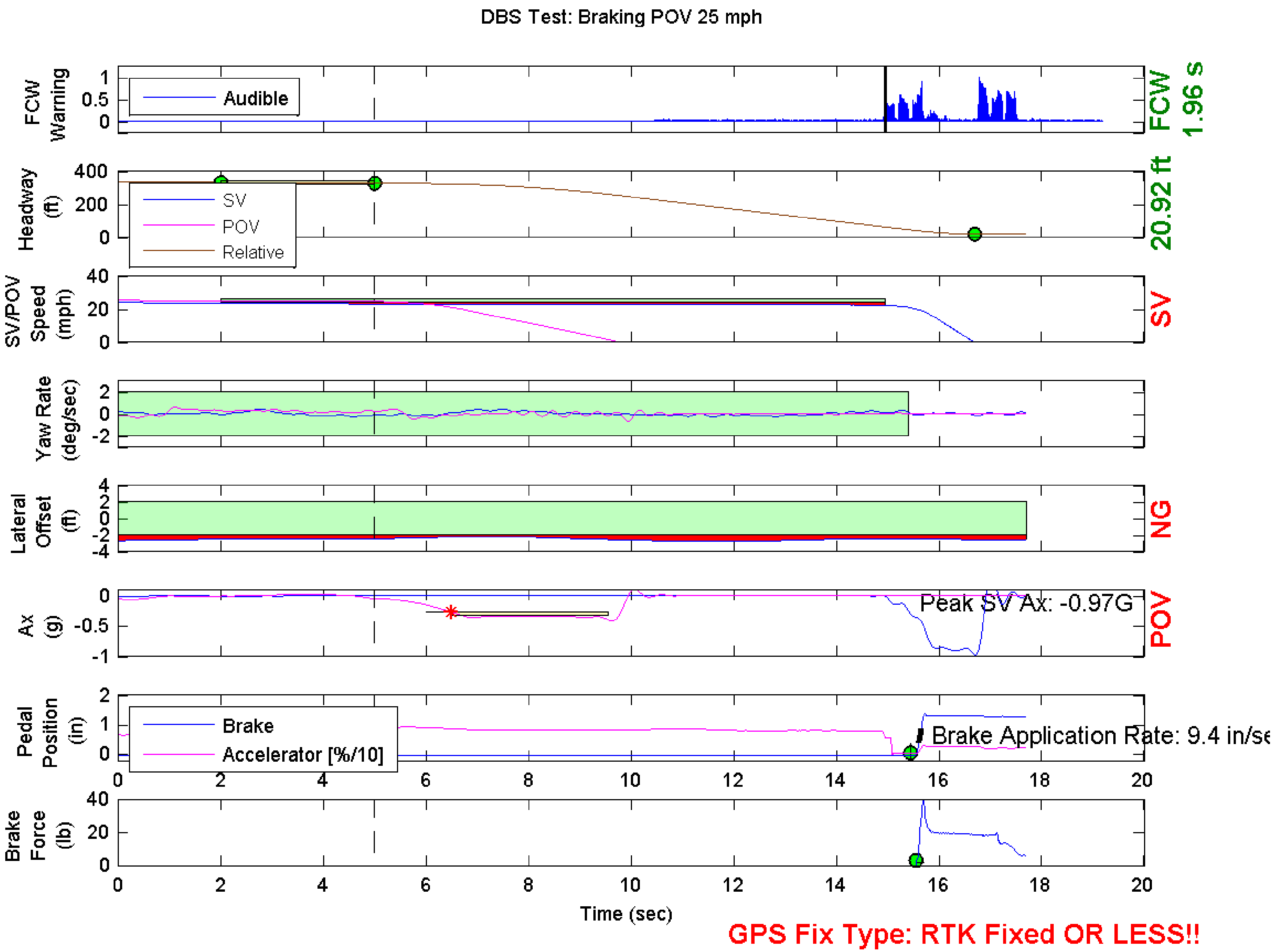


Figure E11. Example Time History Displaying Various Invalid Criteria

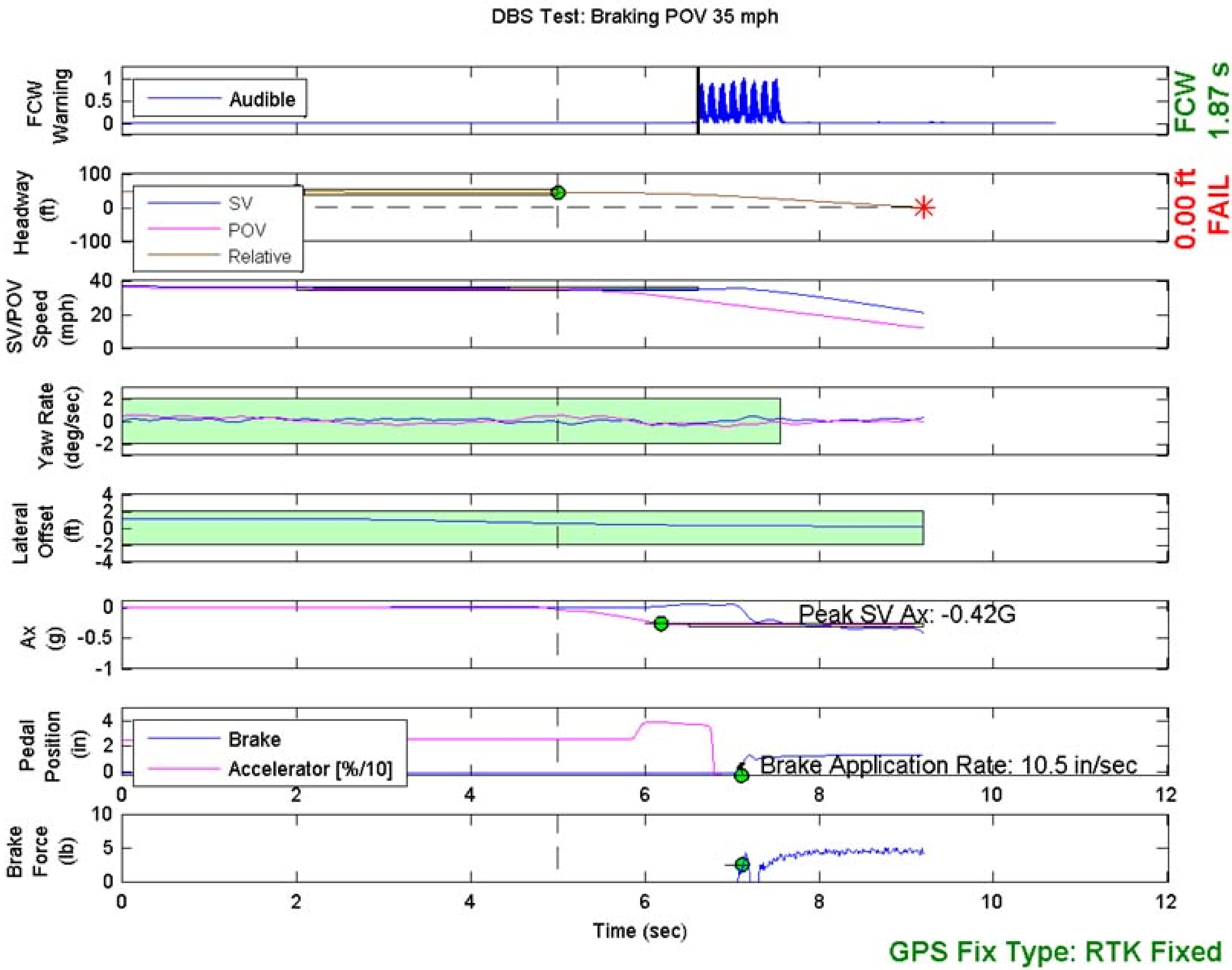


Figure E12. Example Time History for a Failed Run

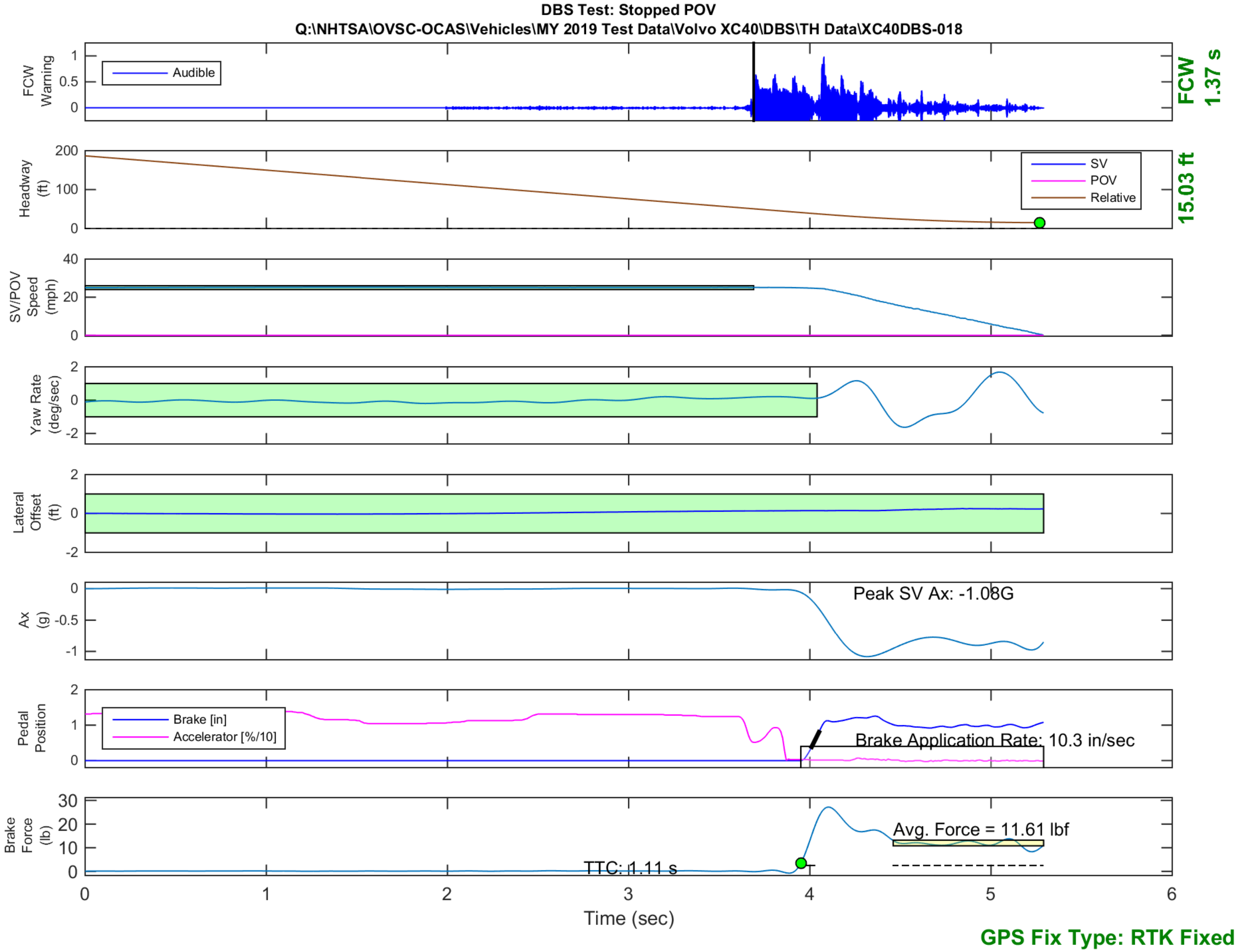


Figure E13. Time History for DBS Run 18, SV Encounters Stopped POV

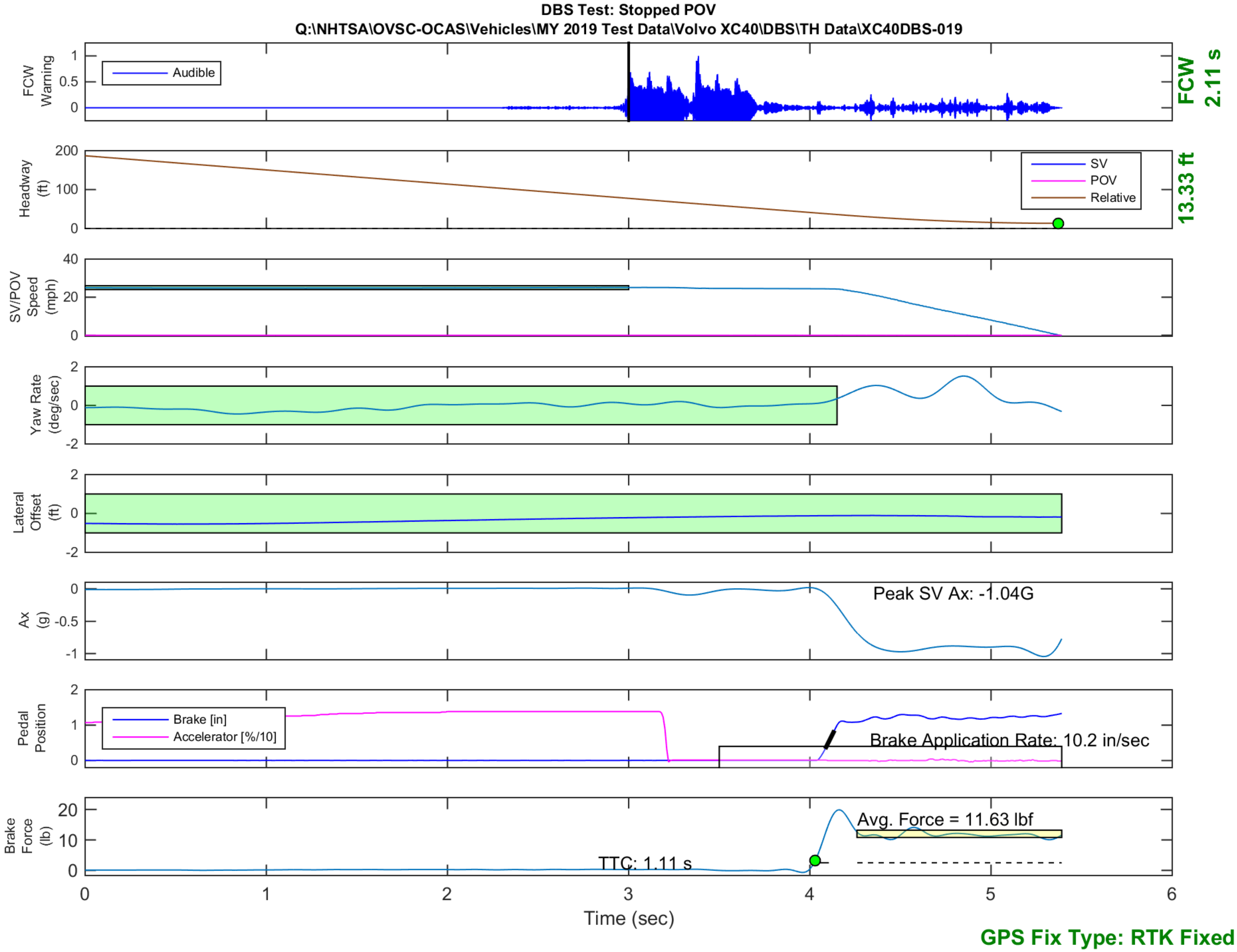


Figure E14. Time History for DBS Run 19, SV Encounters Stopped POV

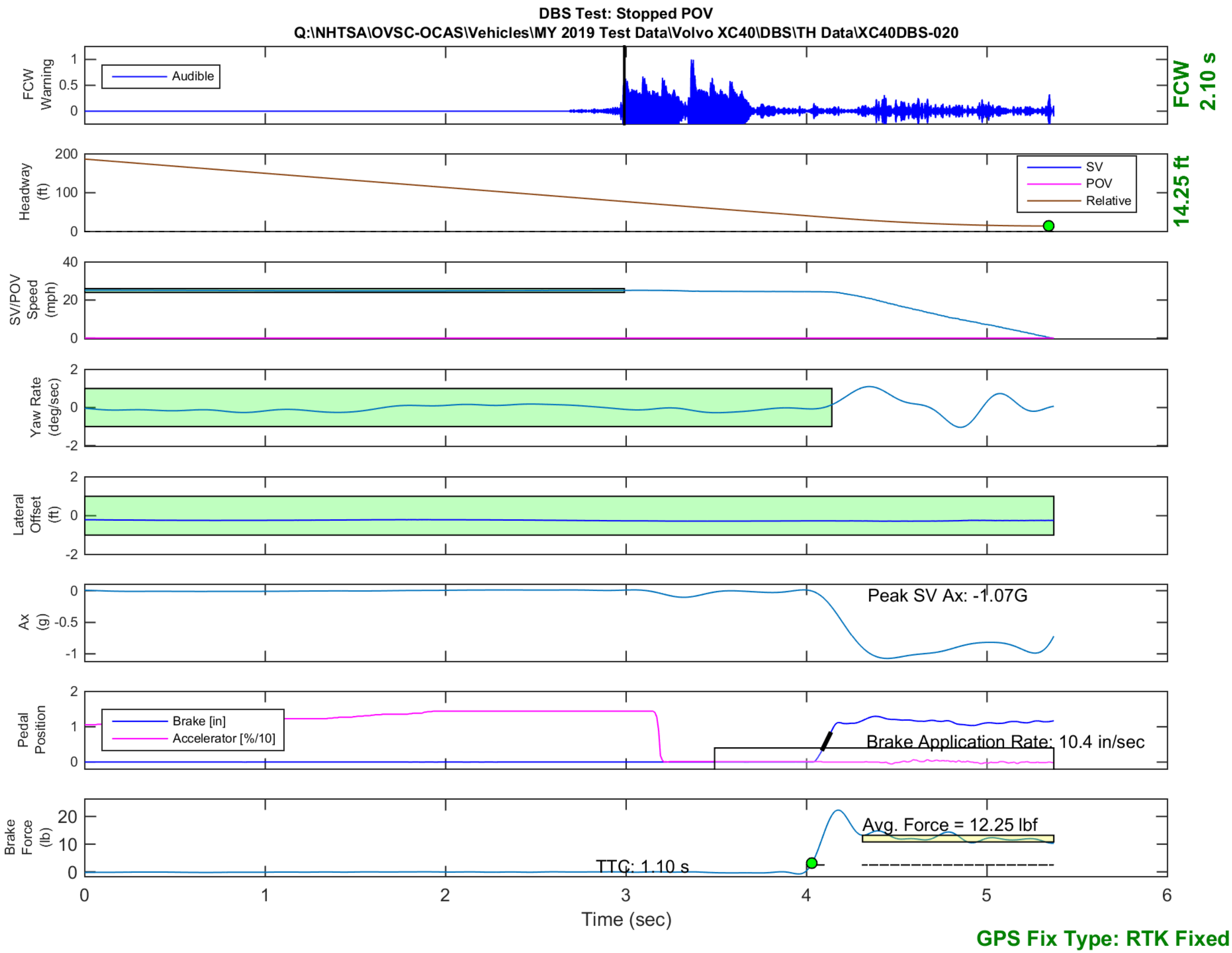


Figure E15. Time History for DBS Run 20, SV Encounters Stopped POV

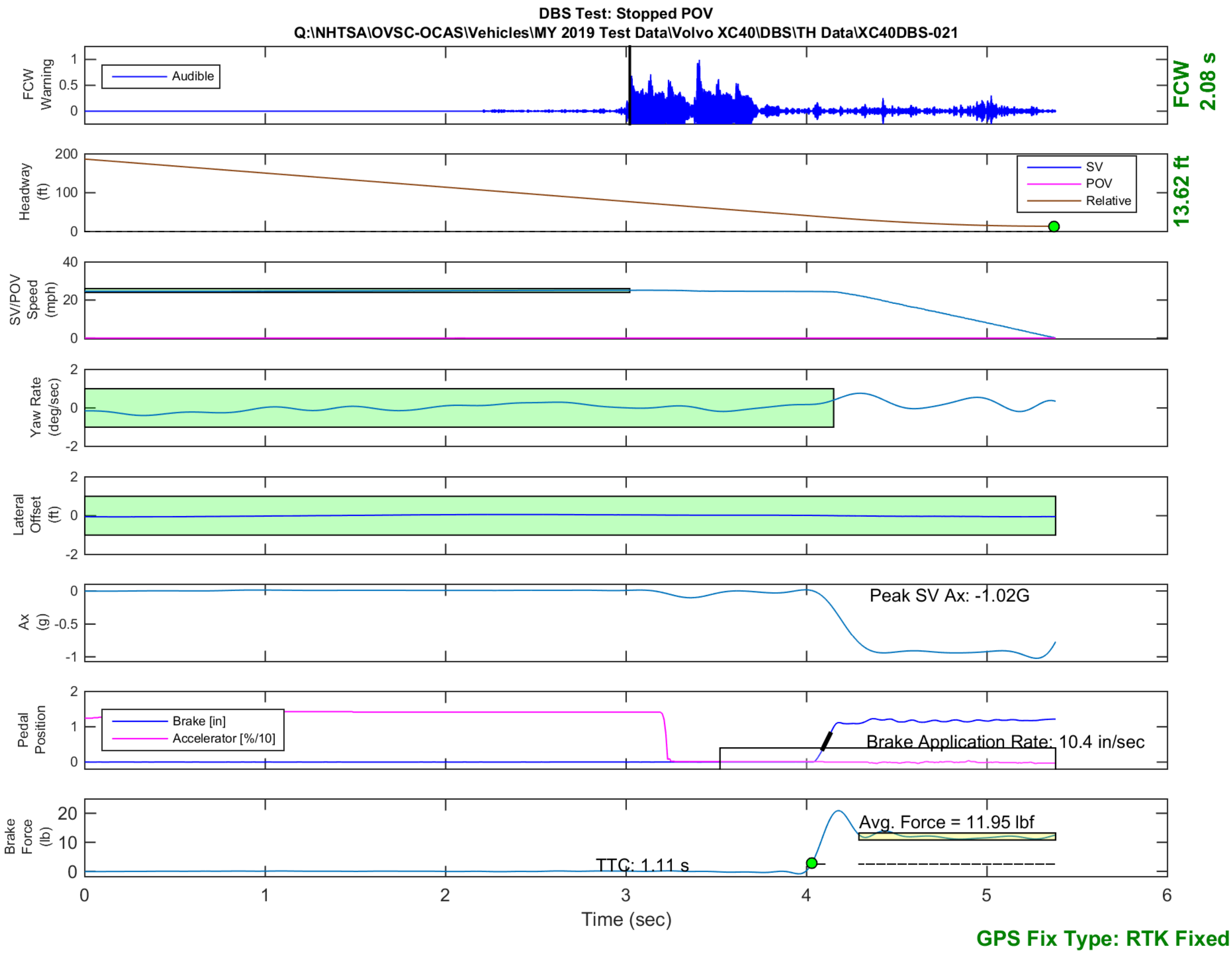


Figure E16. Time History for DBS Run 21, SV Encounters Stopped POV

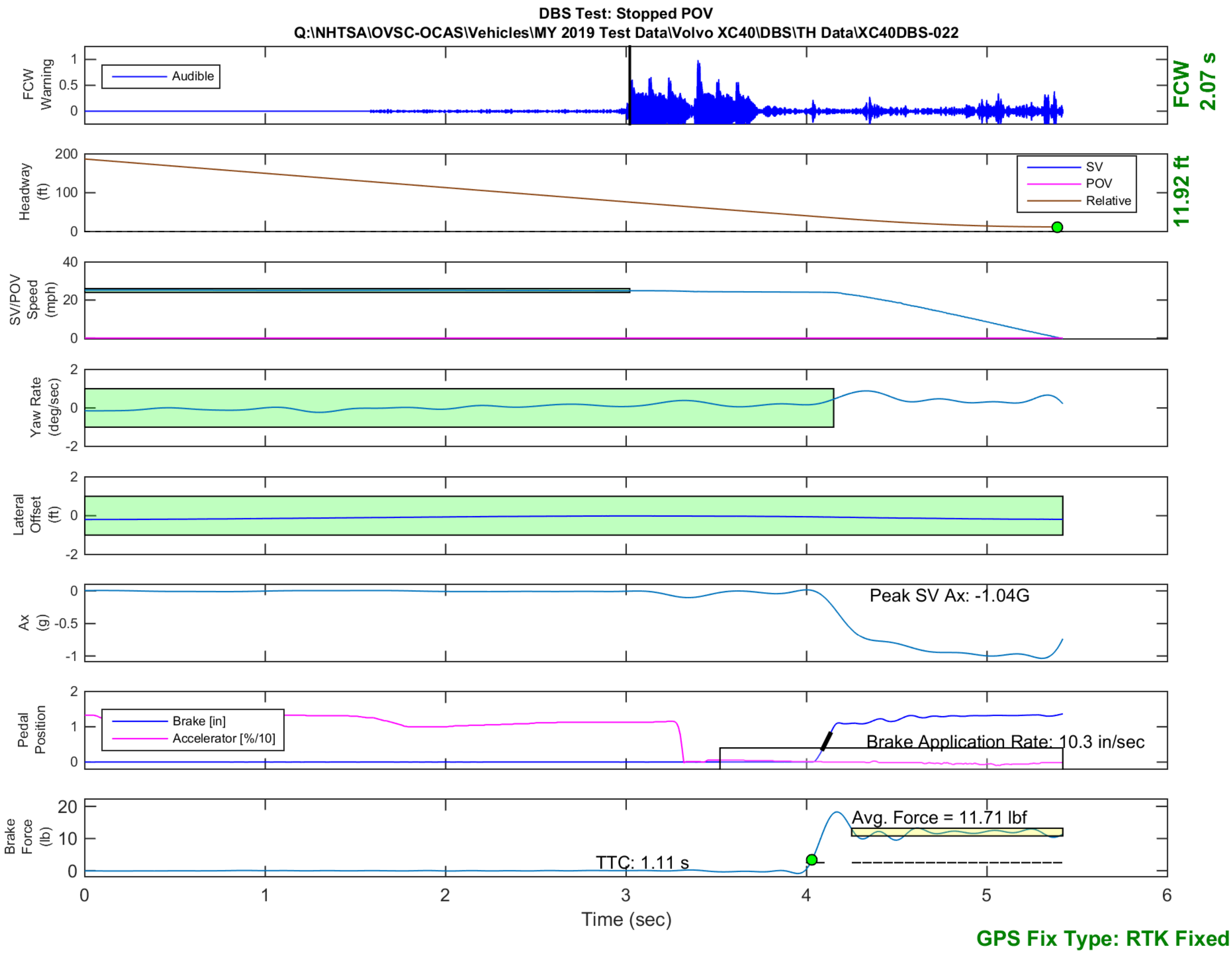


Figure E17. Time History for DBS Run 22, SV Encounters Stopped POV

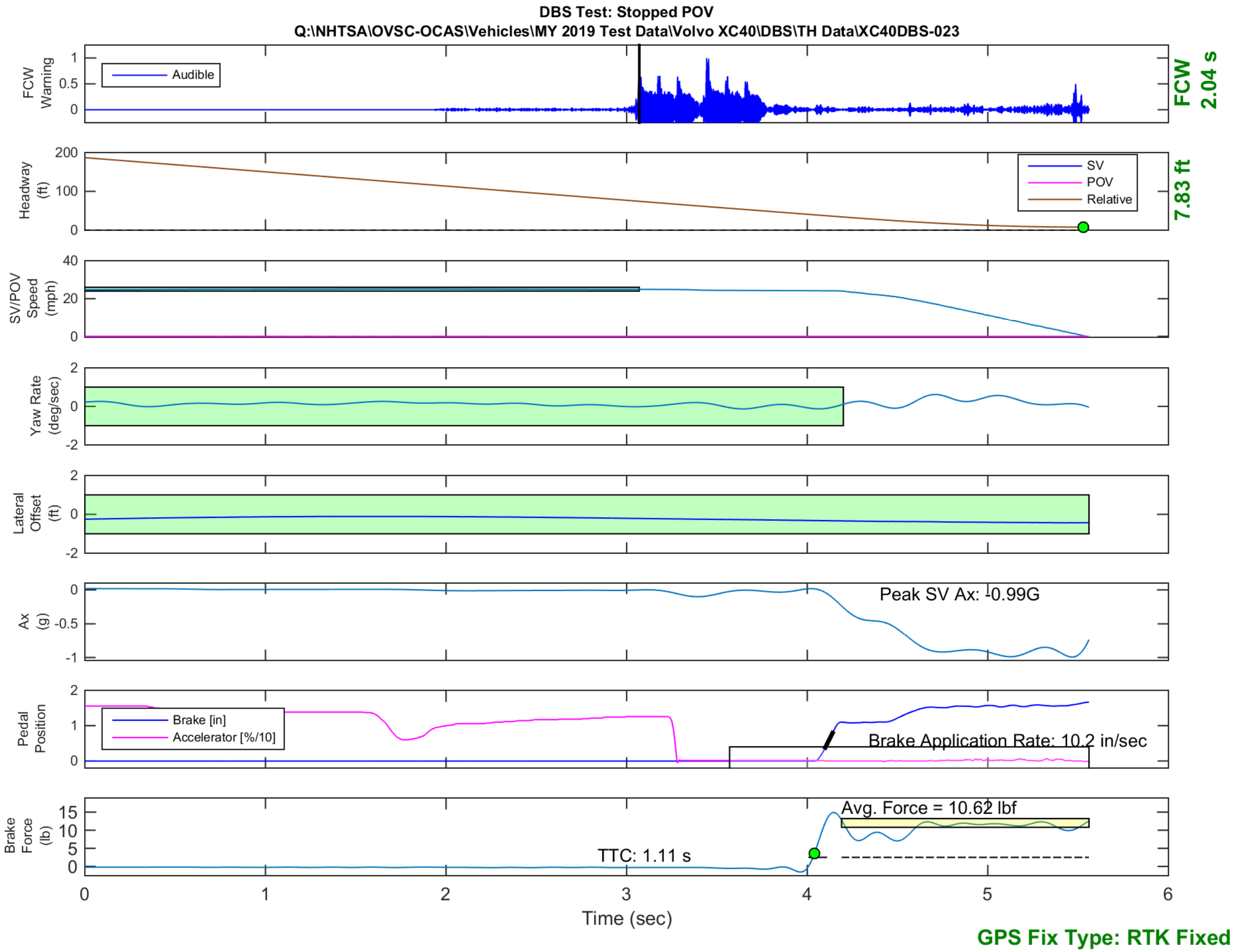


Figure E18. Time History for DBS Run 23, SV Encounters Stopped POV

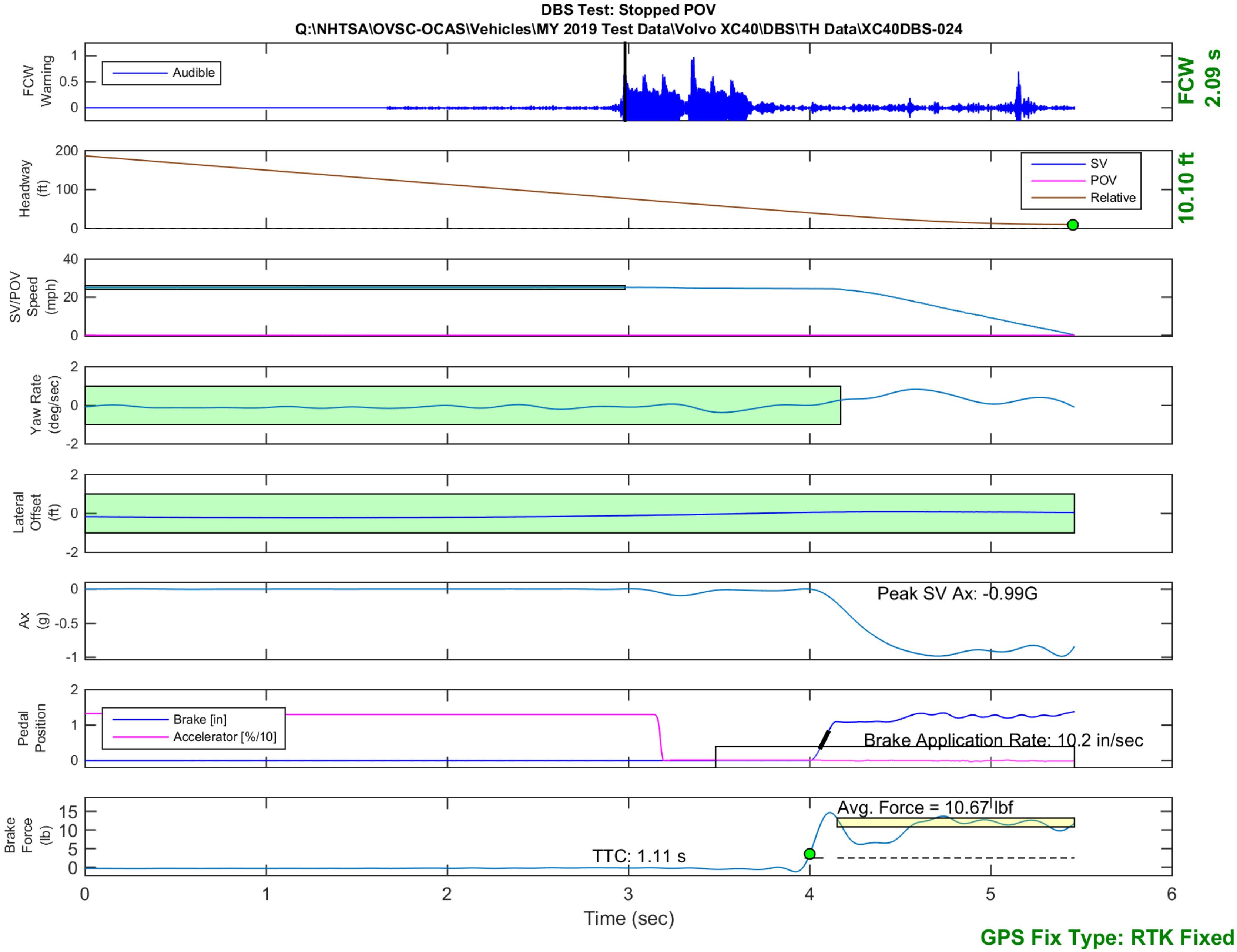


Figure E19. Time History for DBS Run 24, SV Encounters Stopped POV

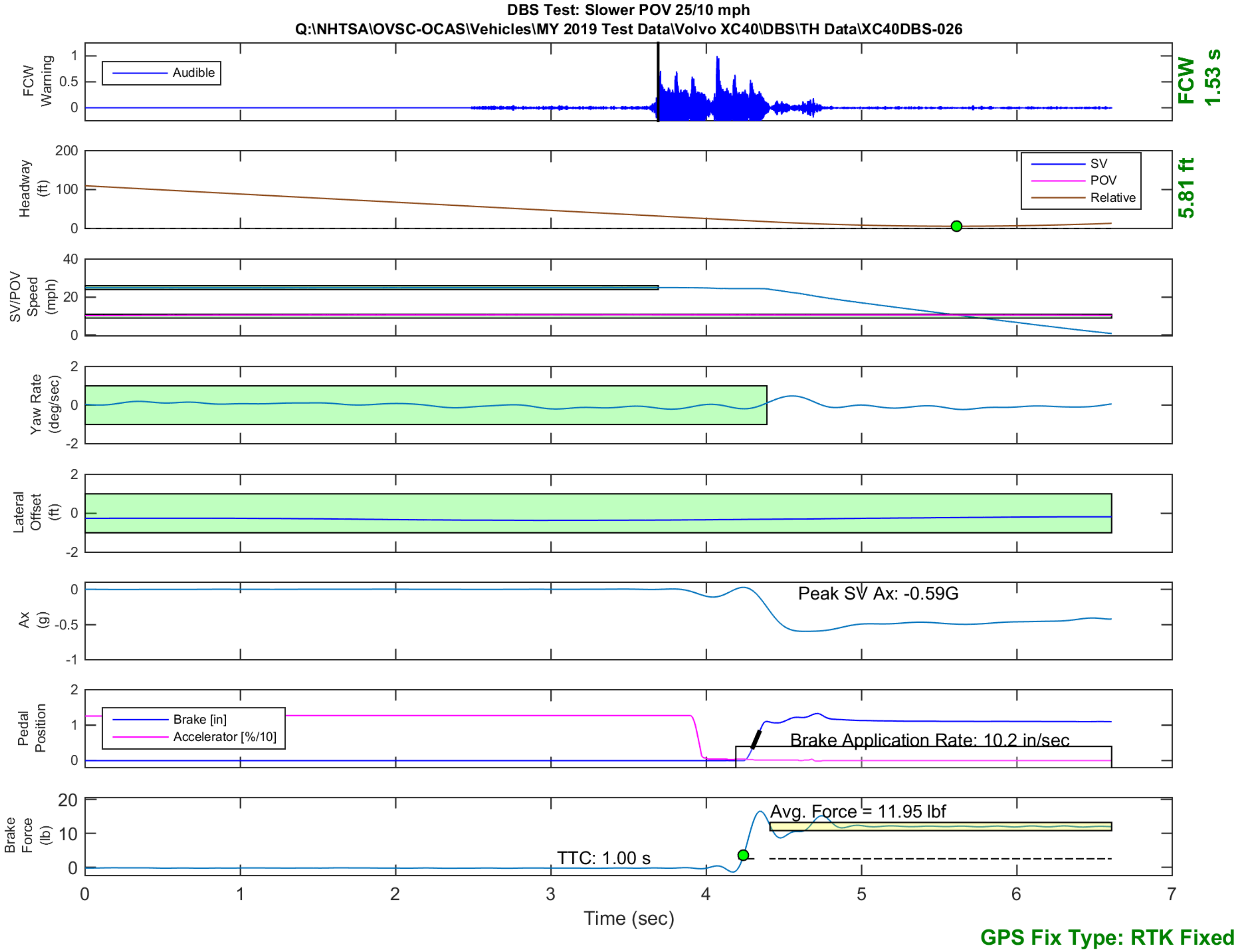


Figure E20. Time History for DBS Run 26, SV Encounters Slower POV, SV 25 mph, POV 10 mph

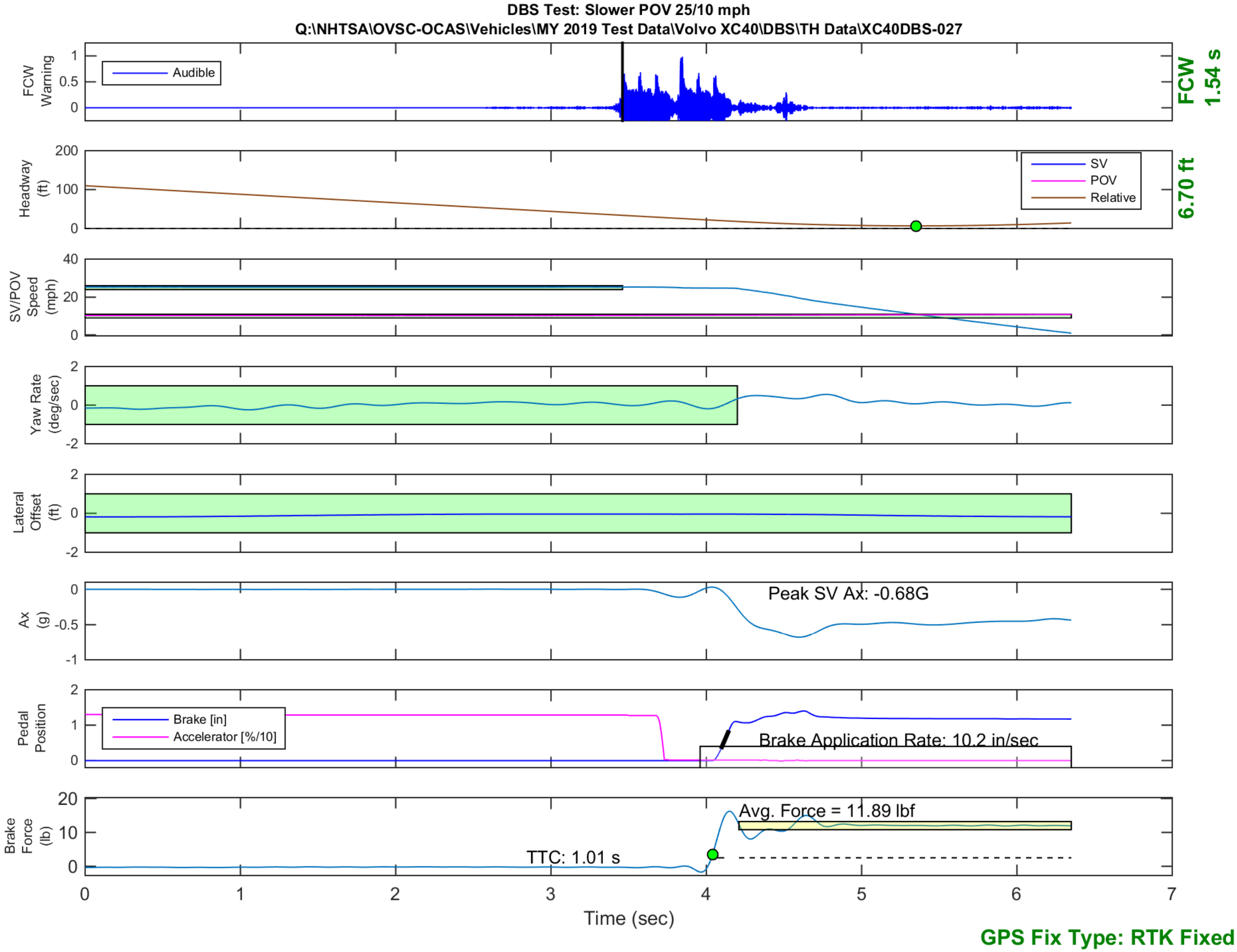


Figure E21. Time History for DBS Run 27, SV Encounters Slower POV, SV 25 mph, POV 10 mph

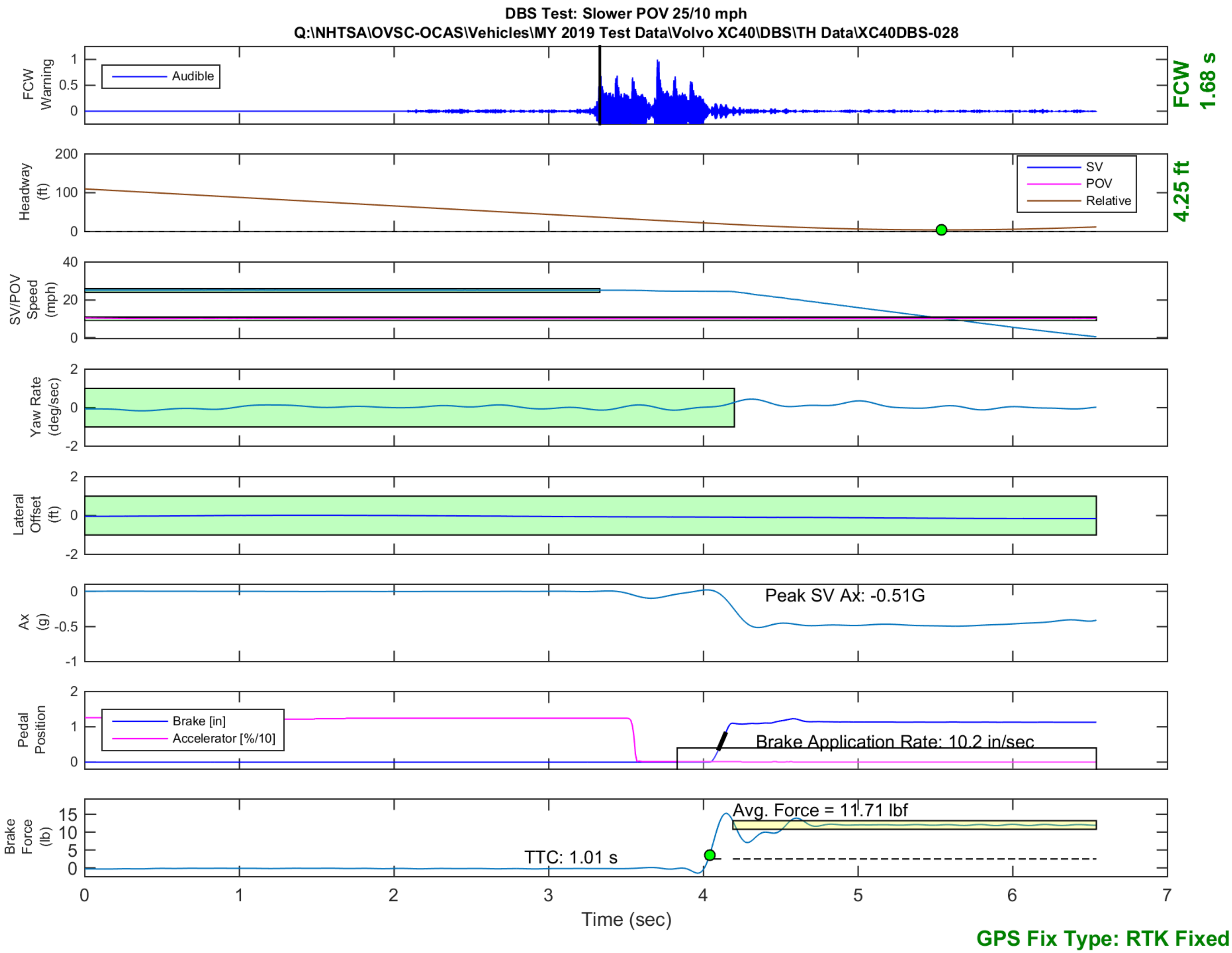


Figure E22. Time History for DBS Run 28, SV Encounters Slower POV, SV 25 mph, POV 10 mph

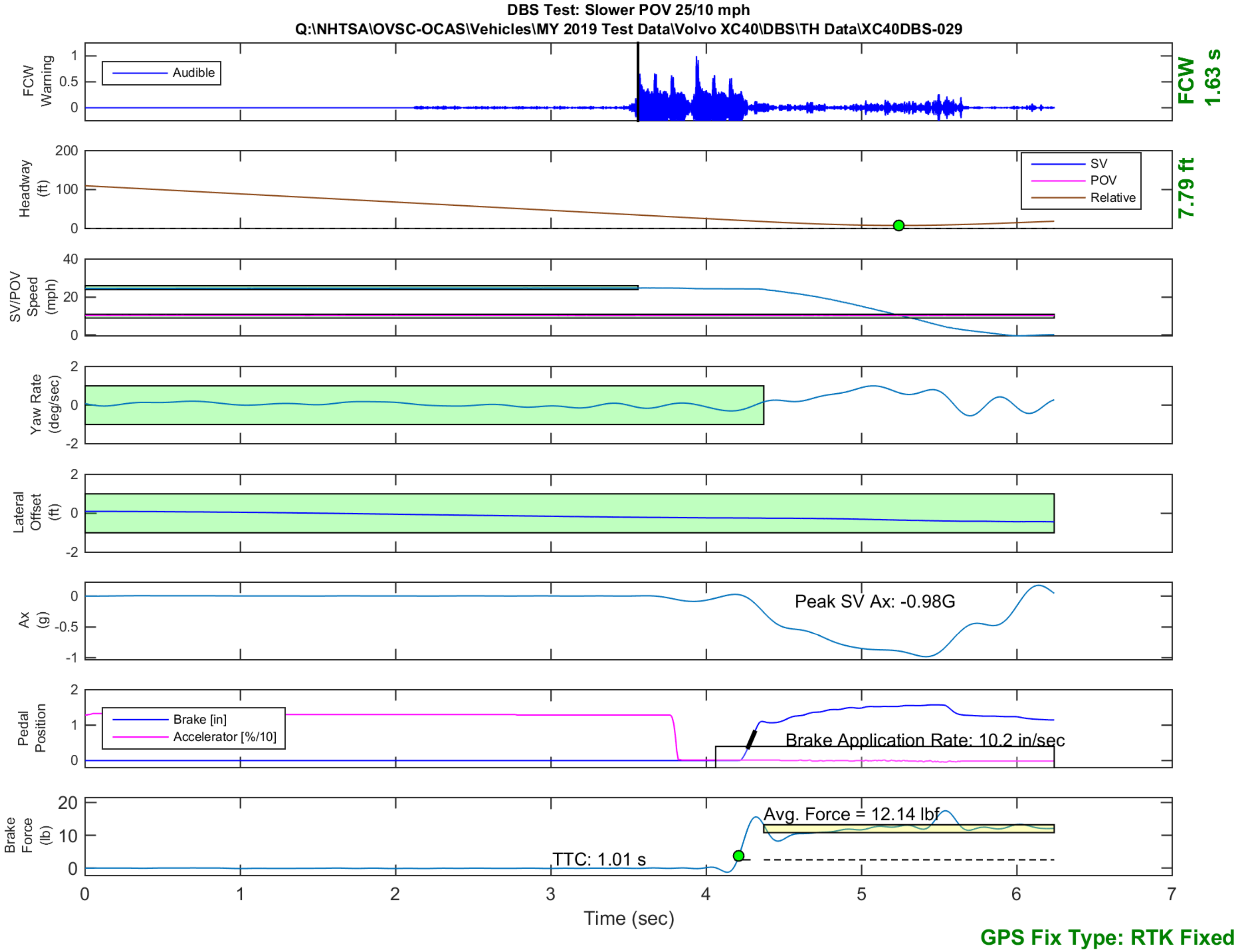


Figure E23. Time History for DBS Run 29, SV Encounters Slower POV, SV 25 mph, POV 10 mph

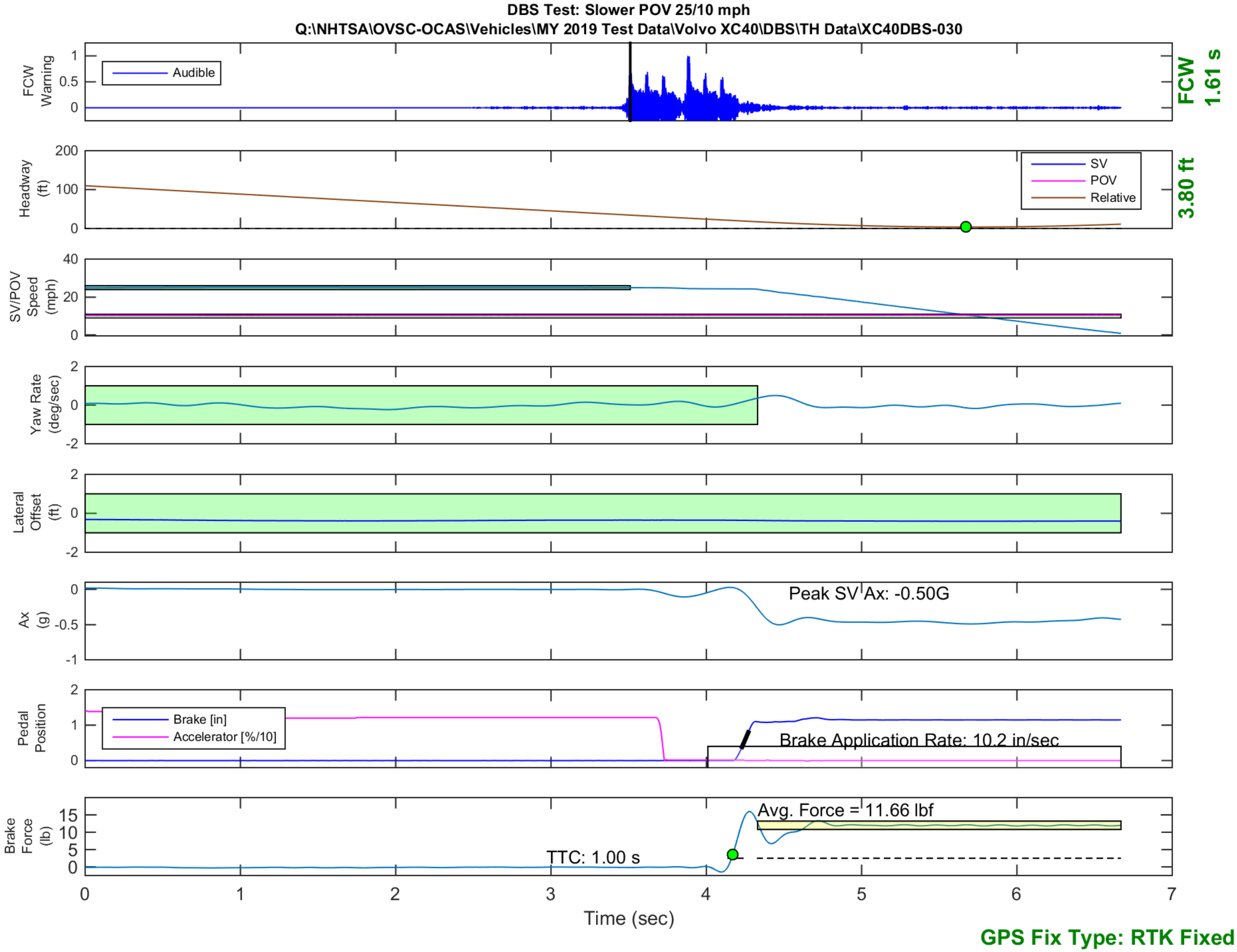


Figure E24. Time History for DBS Run 30, SV Encounters Slower POV, SV 25 mph, POV 10 mph

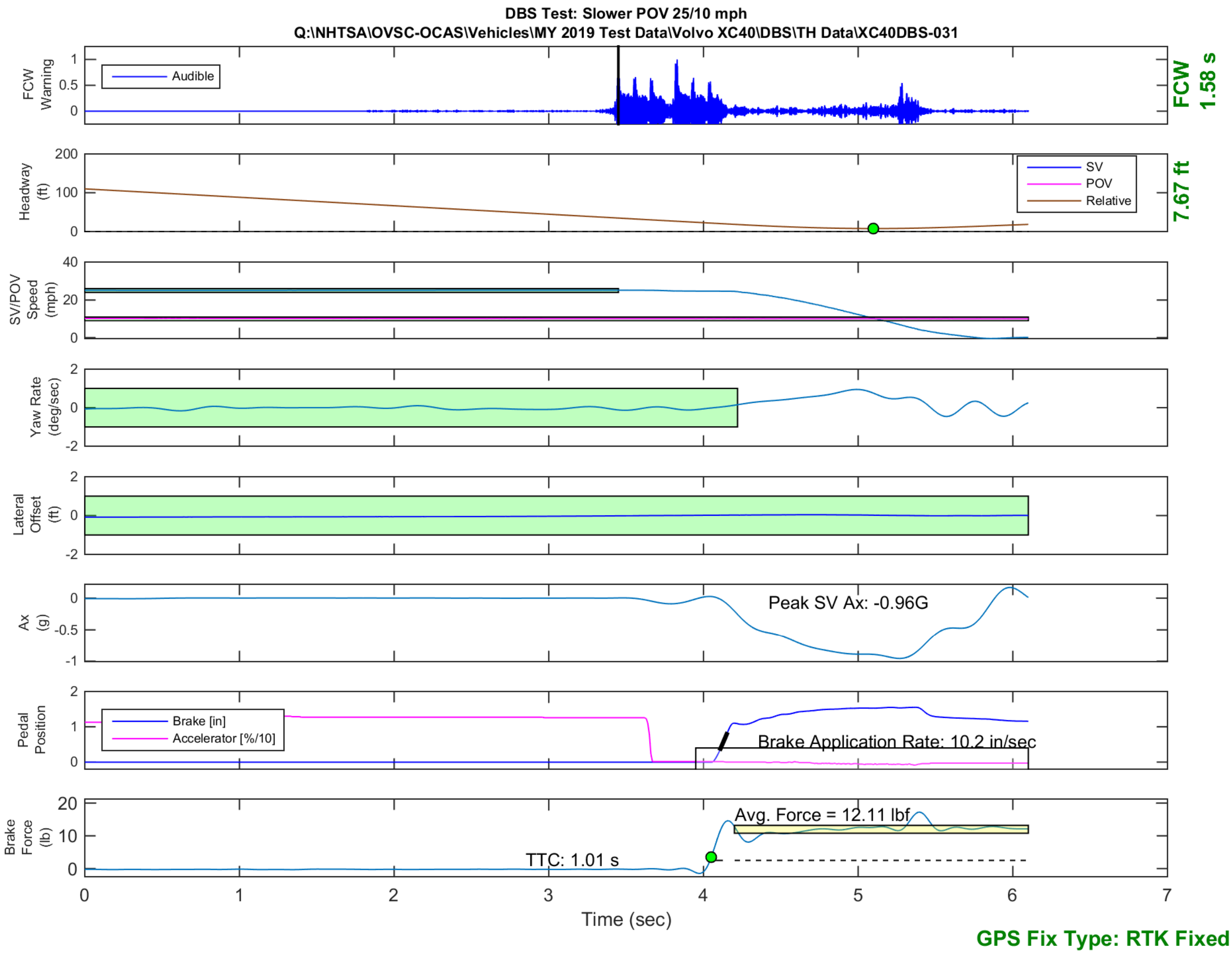


Figure E25. Time History for DBS Run 31, SV Encounters Slower POV, SV 25 mph, POV 10 mph

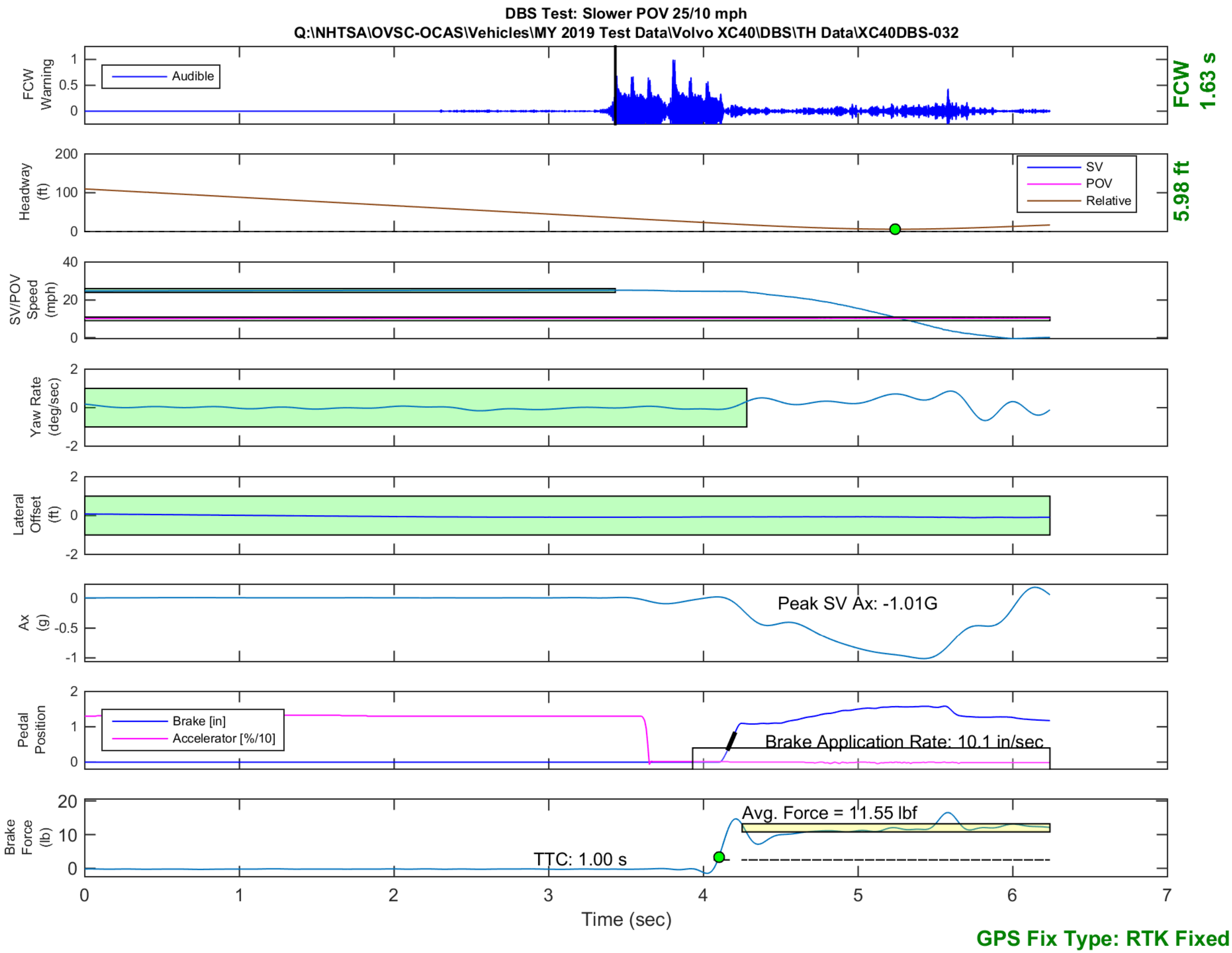


Figure E26. Time History for DBS Run 32, SV Encounters Slower POV, SV 25 mph, POV 10 mph

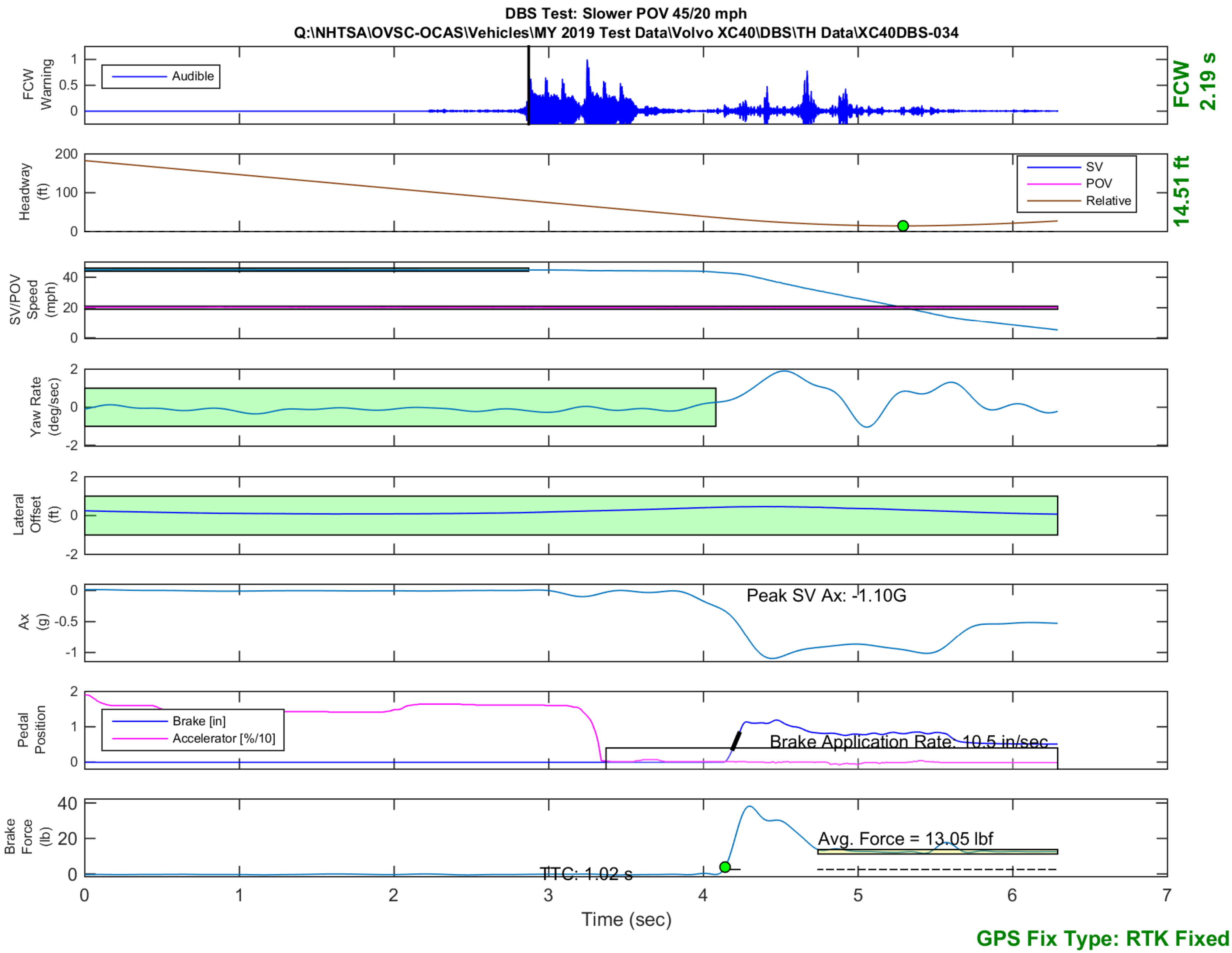


Figure E27. Time History for DBS Run 34, SV Encounters Slower POV, SV 45 mph, POV 20 mph

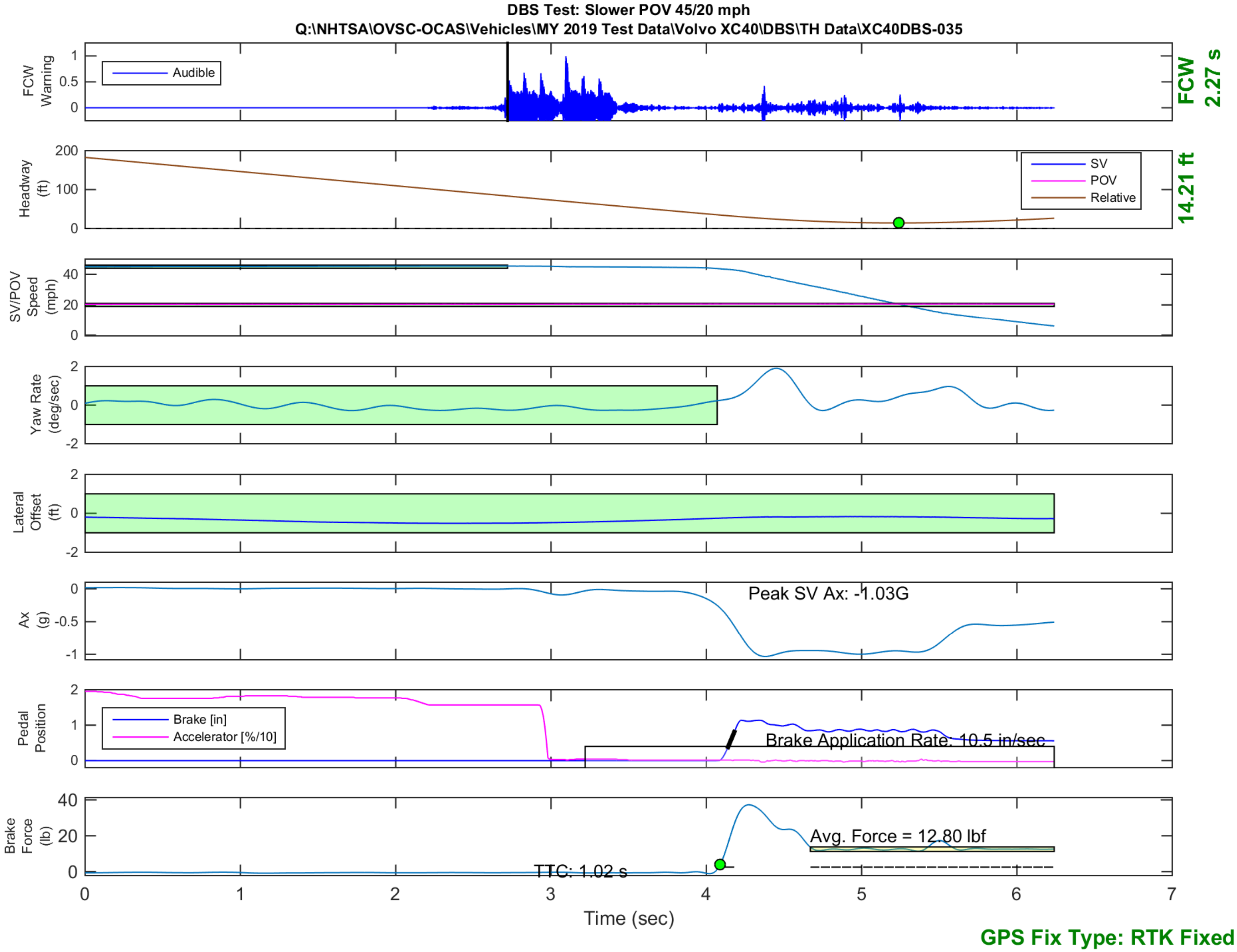


Figure E28. Time History for DBS Run 35, SV Encounters Slower POV, SV 45 mph, POV 20 mph

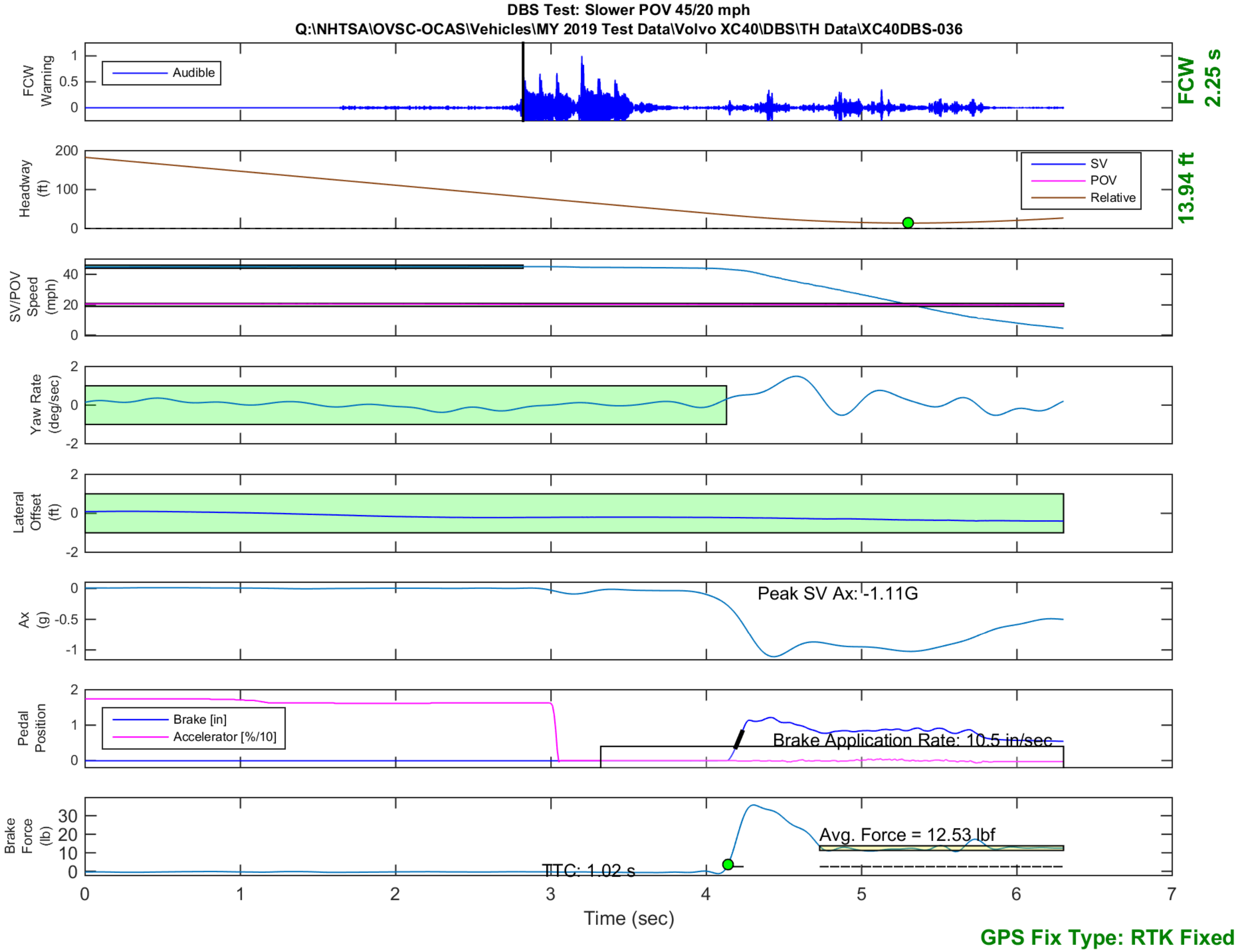


Figure E29. Time History for DBS Run 36, SV Encounters Slower POV, SV 45 mph, POV 20 mph

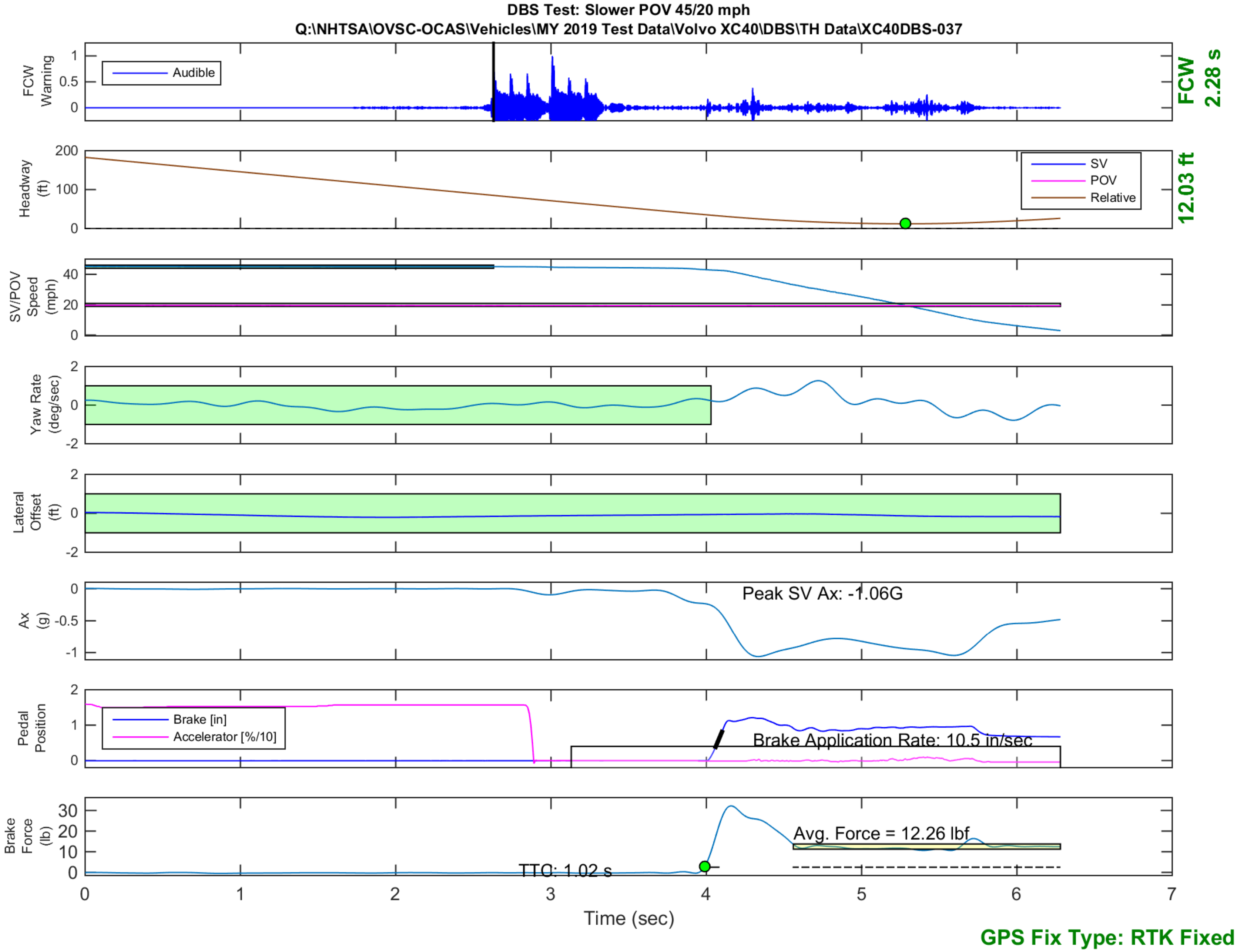


Figure E30. Time History for DBS Run 37, SV Encounters Slower POV, SV 45 mph, POV 20 mph

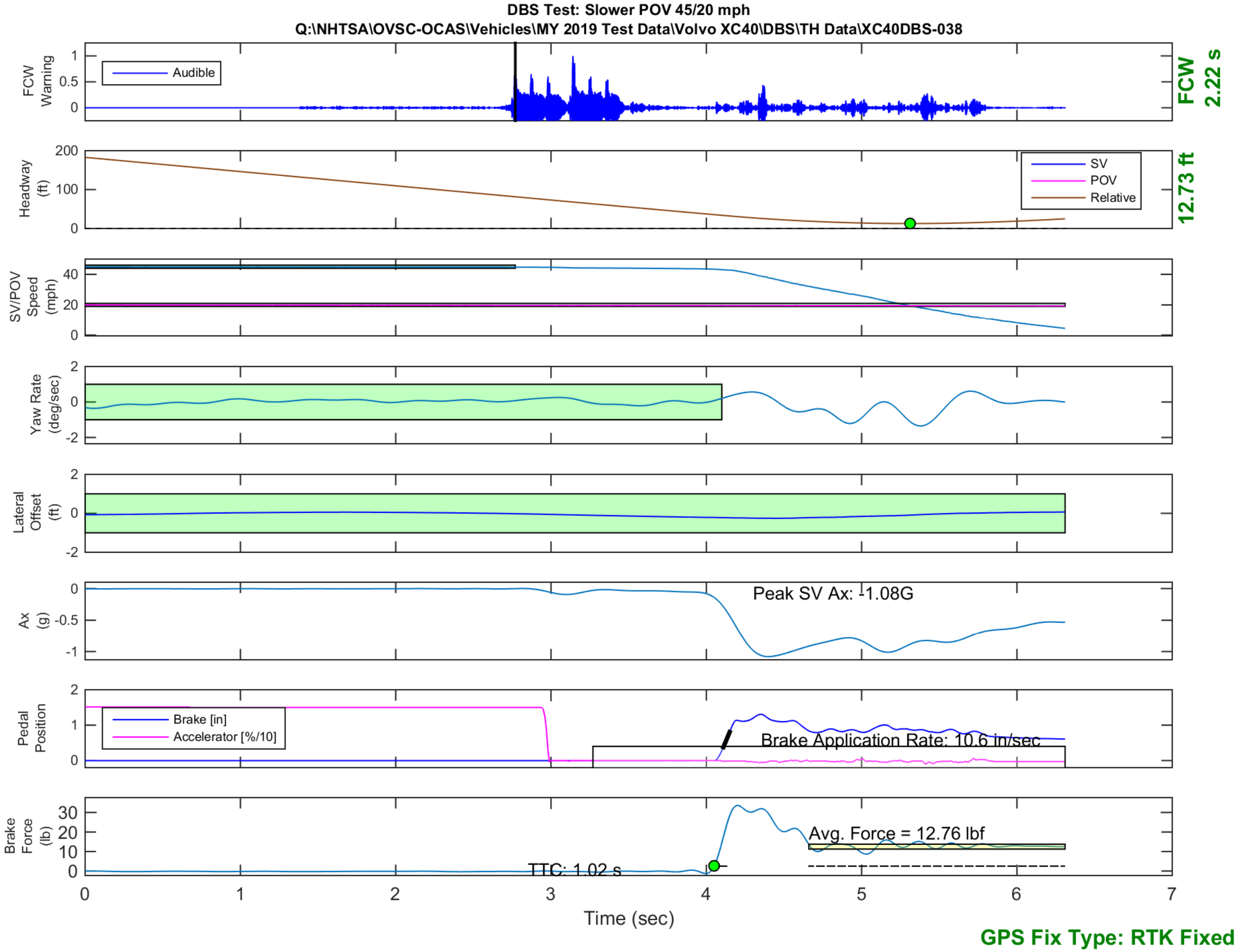


Figure E31. Time History for DBS Run 38, SV Encounters Slower POV, SV 45 mph, POV 20 mph

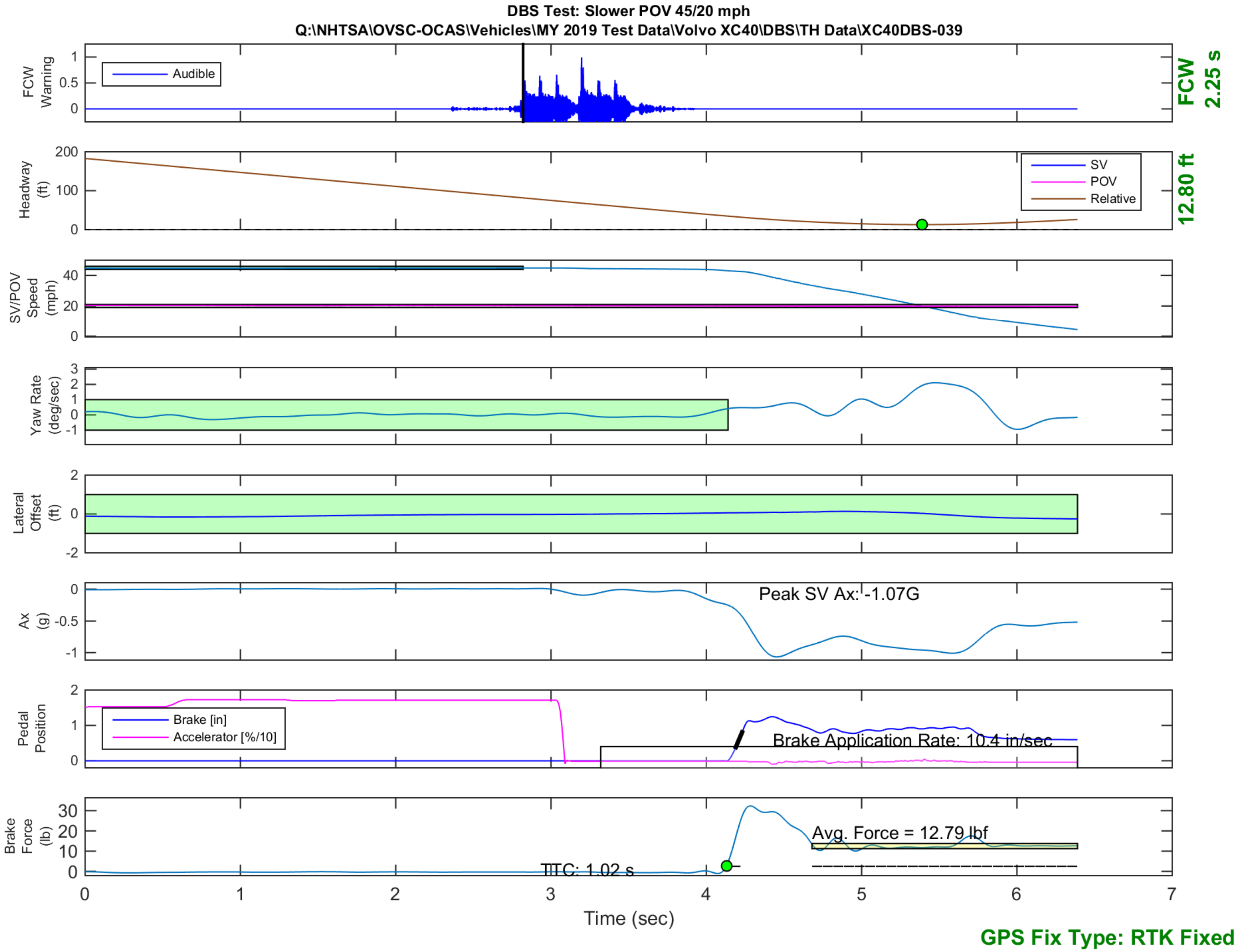


Figure E32. Time History for DBS Run 39, SV Encounters Slower POV, SV 45 mph, POV 20 mph

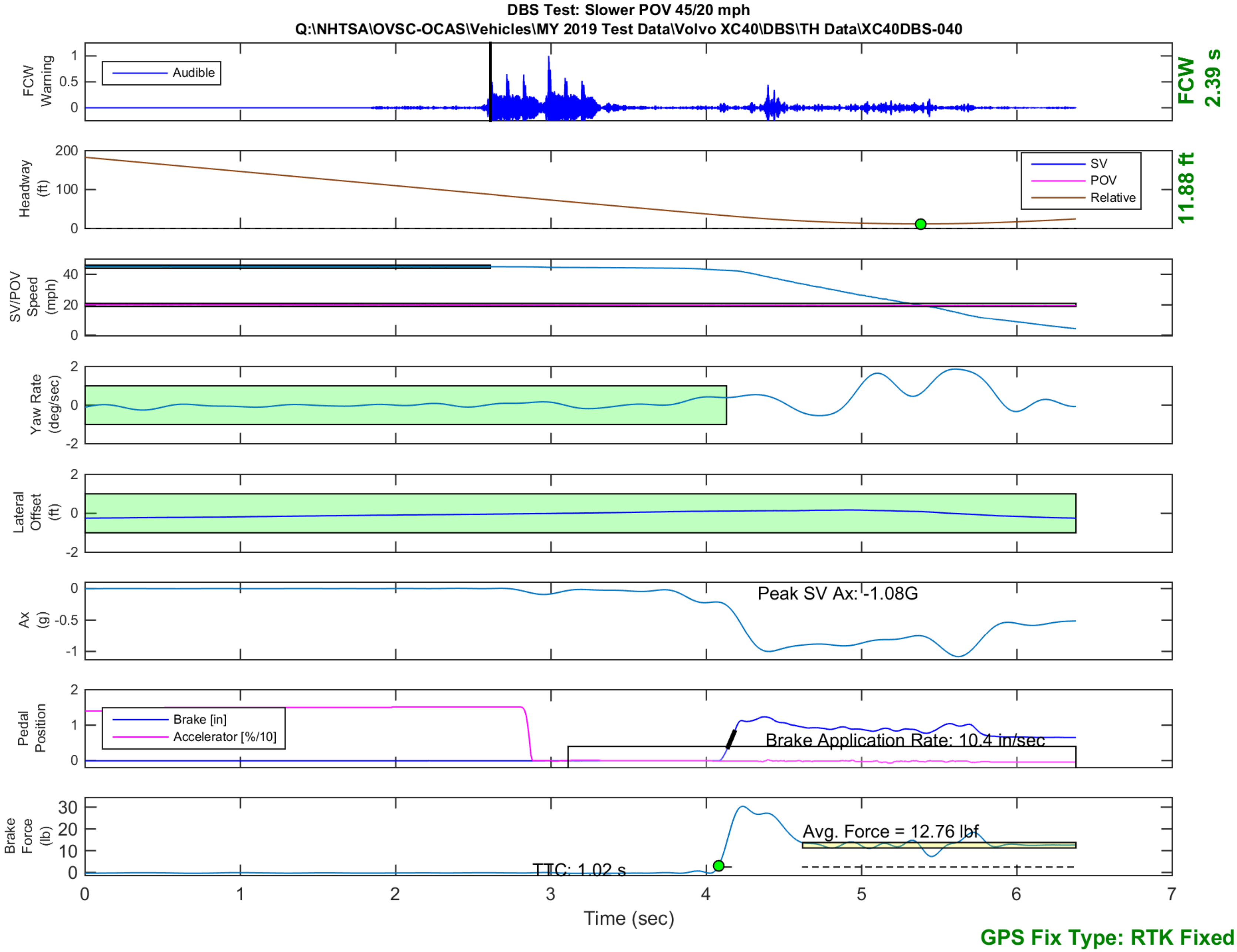


Figure E33. Time History for DBS Run 40, SV Encounters Slower POV, SV 45 mph, POV 20 mph

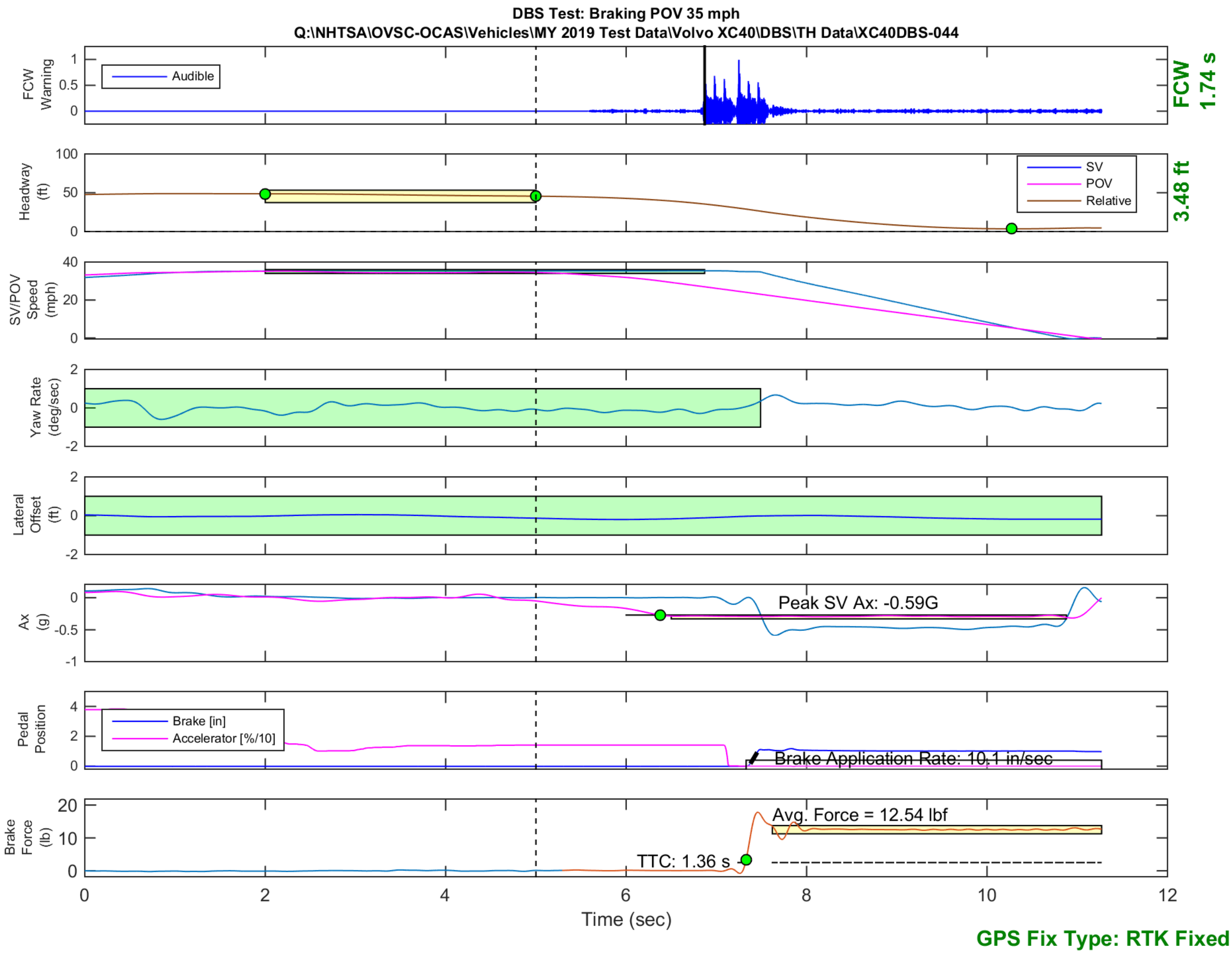


Figure E34. Time History for DBS Run 44, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

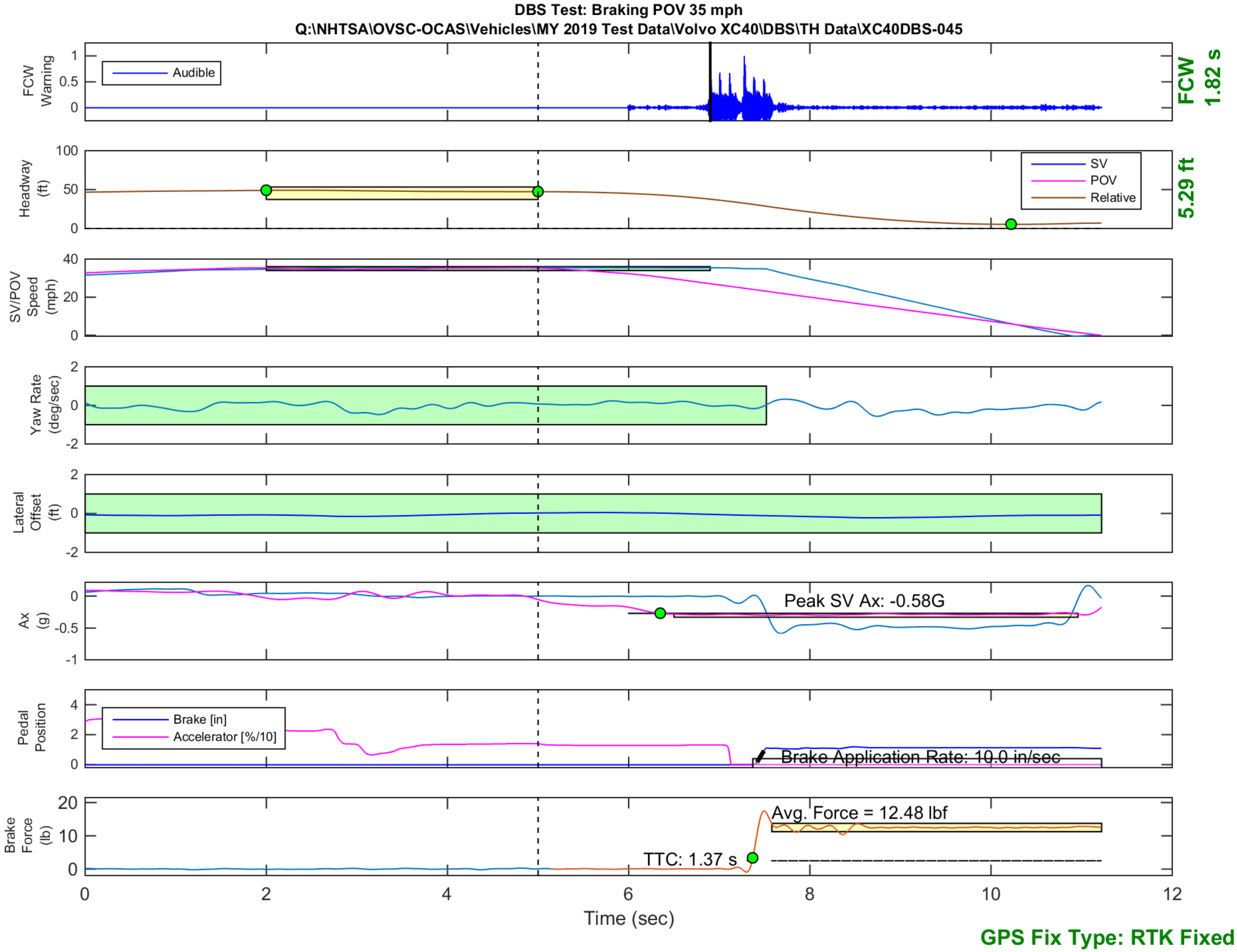


Figure E35. Time History for DBS Run 45, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

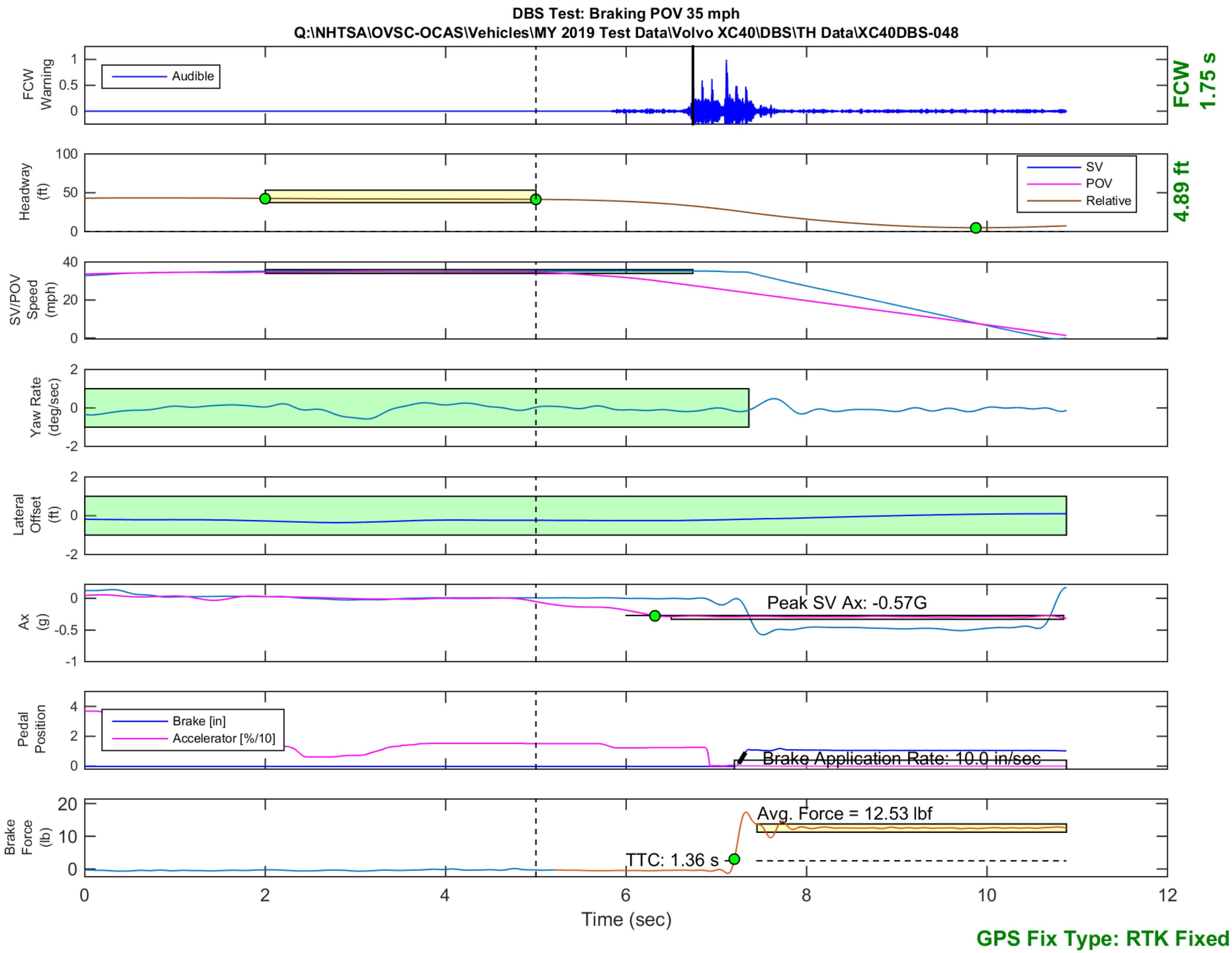


Figure E36. Time History for DBS Run 48, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

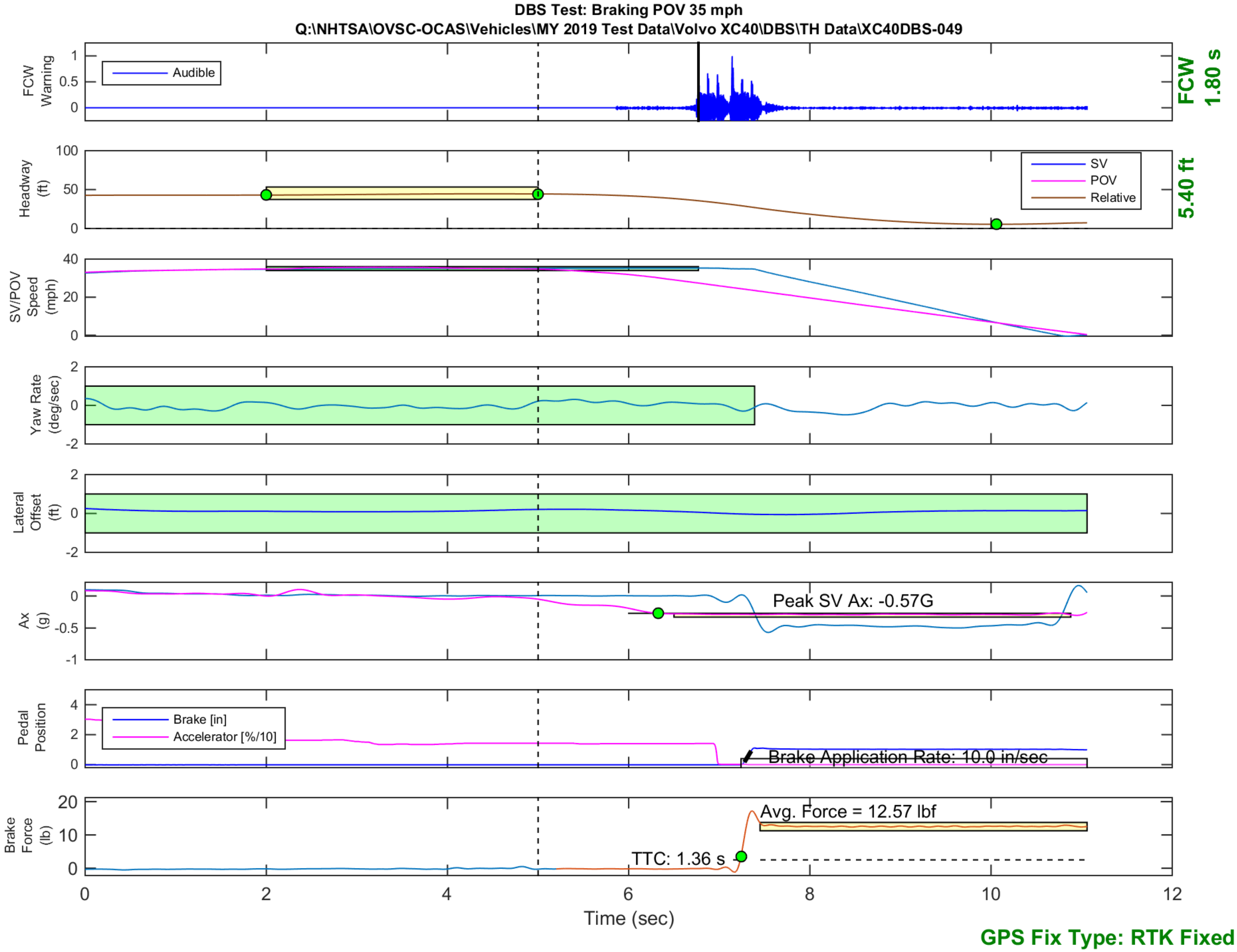


Figure E37. Time History for DBS Run 49, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

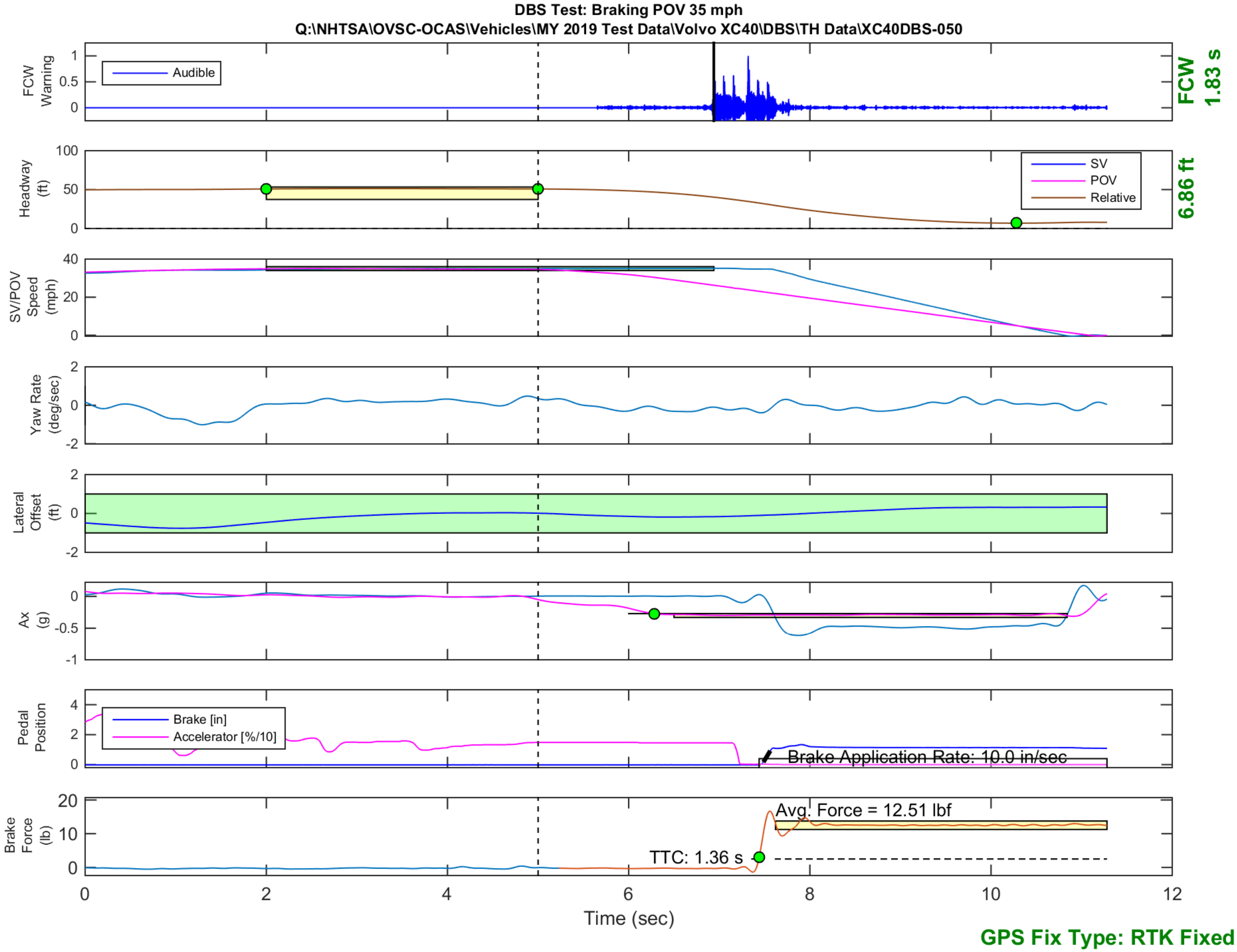


Figure E38. Time History for DBS Run 50, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

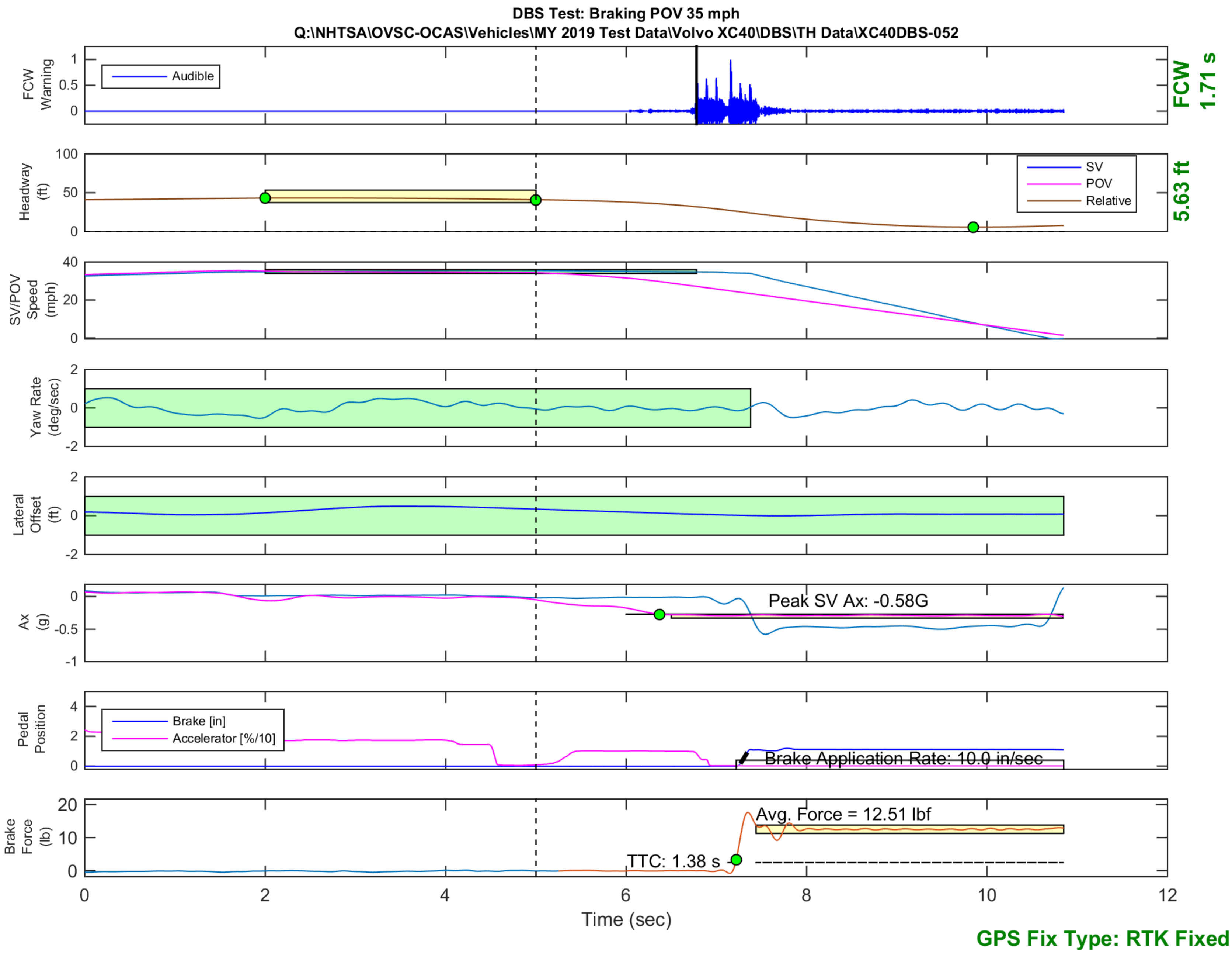


Figure E39. Time History for DBS Run 52, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

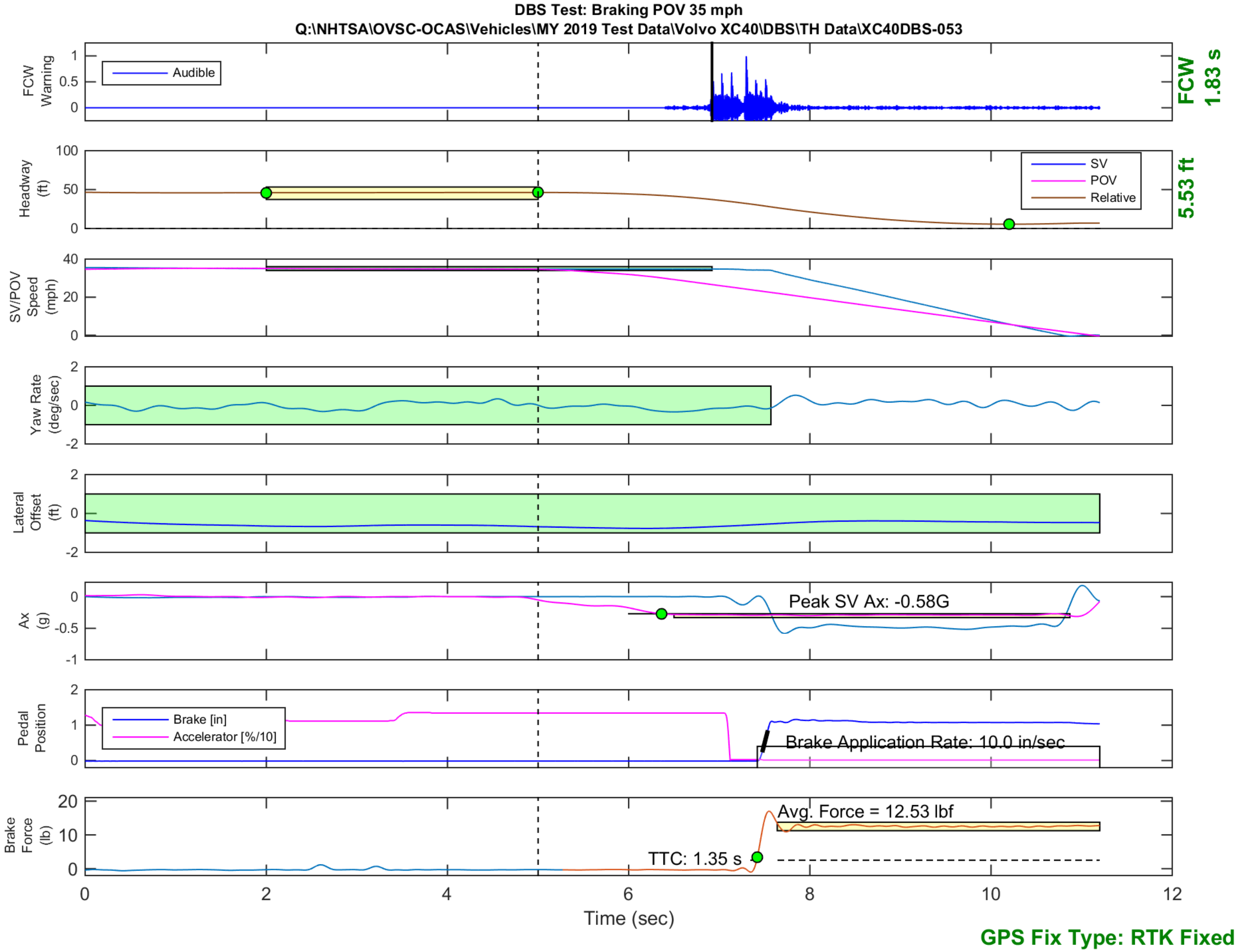


Figure E40. Time History for DBS Run 53, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

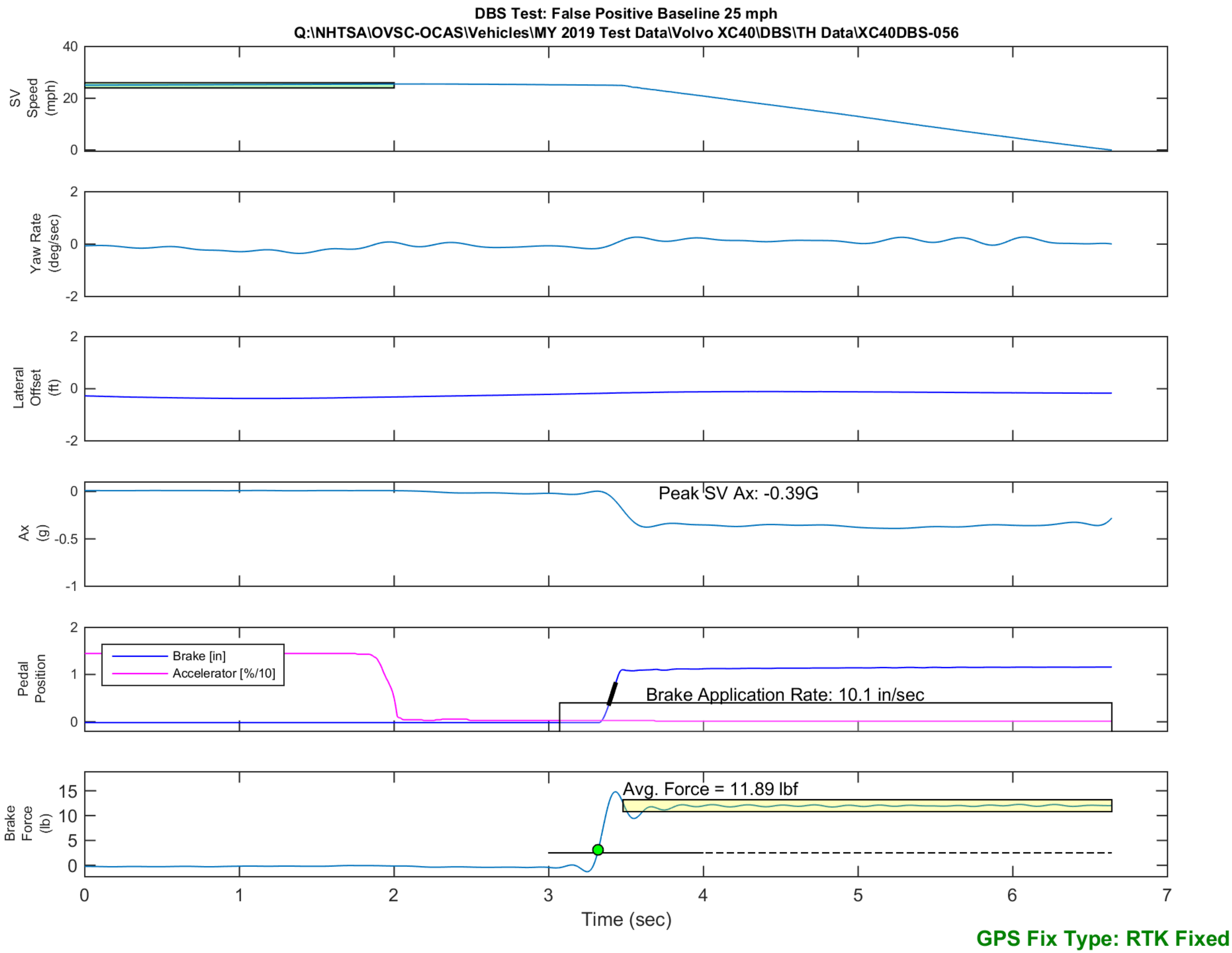


Figure E41. Time History for DBS Run 56, False Positive Baseline, SV 25 mph

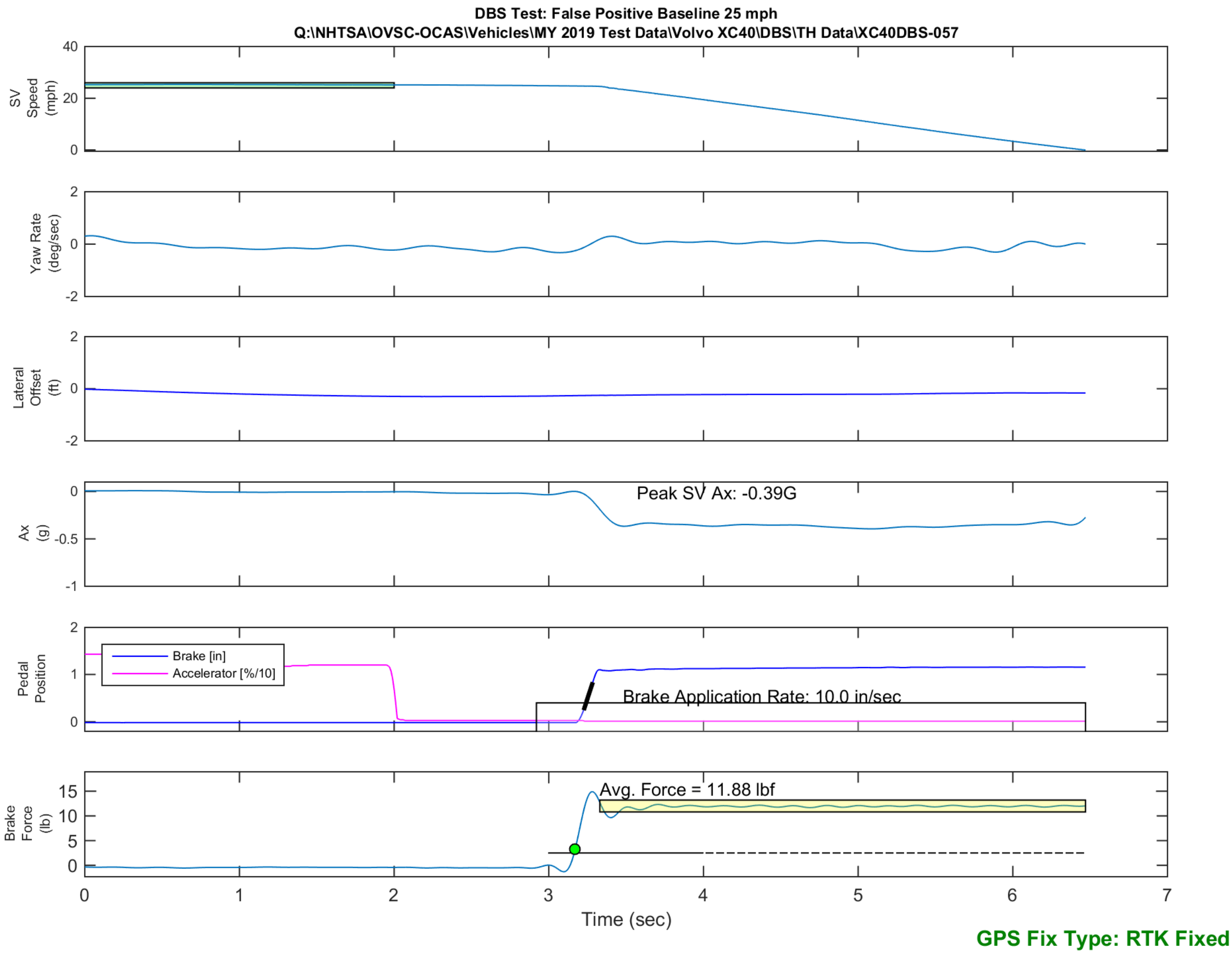


Figure E42. Time History for DBS Run 57, False Positive Baseline, SV 25 mph

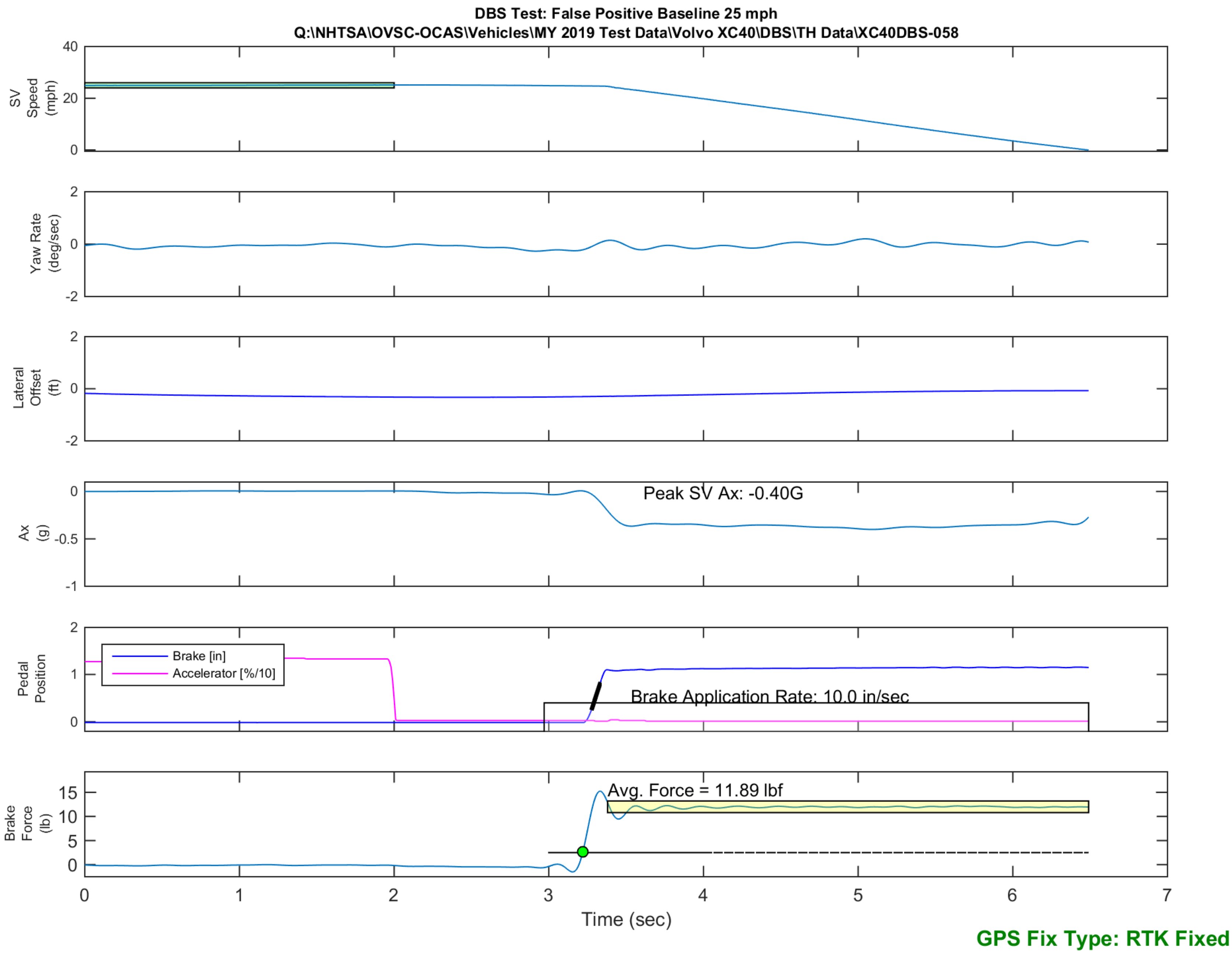


Figure E43. Time History for DBS Run 58, False Positive Baseline, SV 25 mph

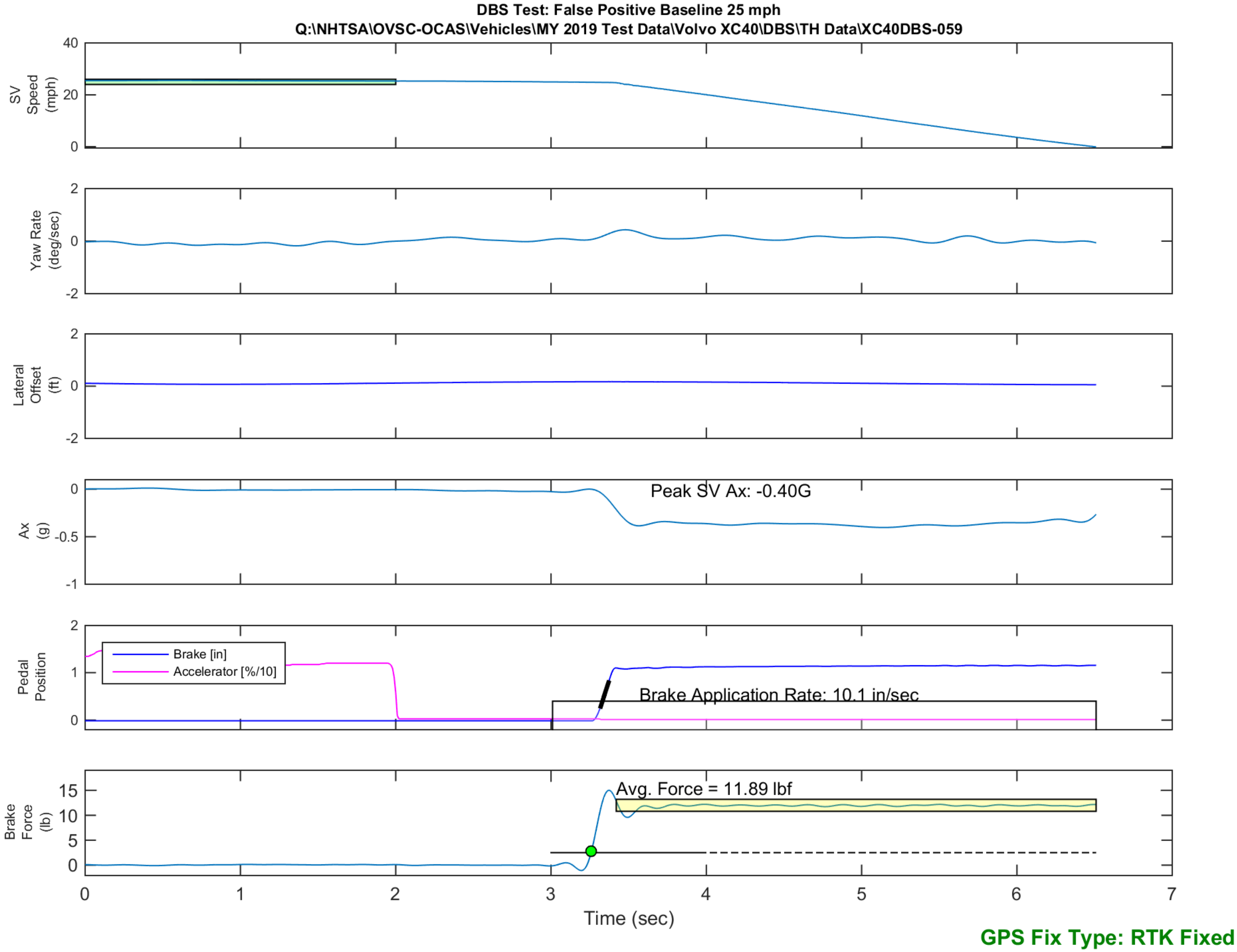


Figure E44. Time History for DBS Run 59, False Positive Baseline, SV 25 mph

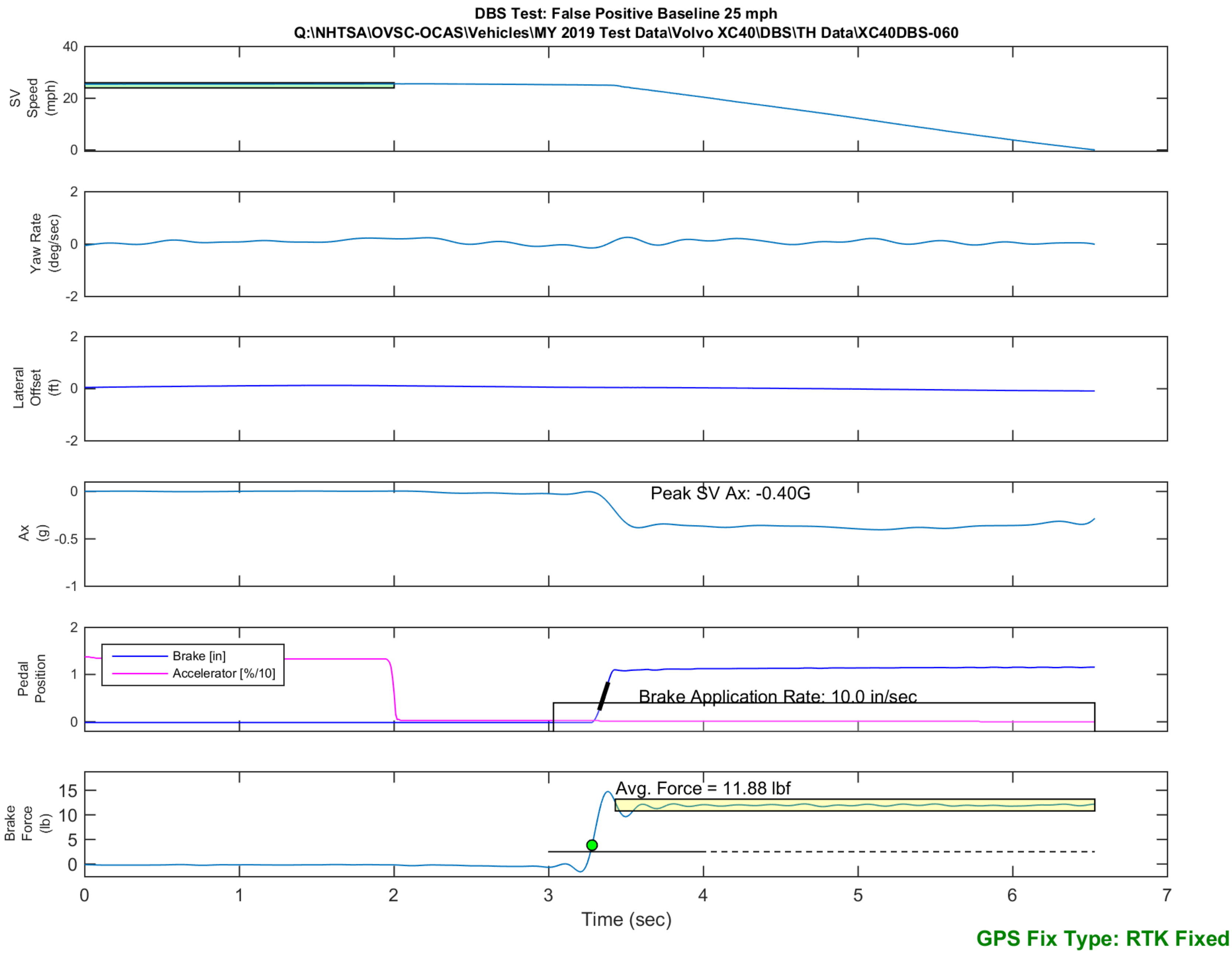


Figure E45. Time History for DBS Run 60, False Positive Baseline, SV 25 mph

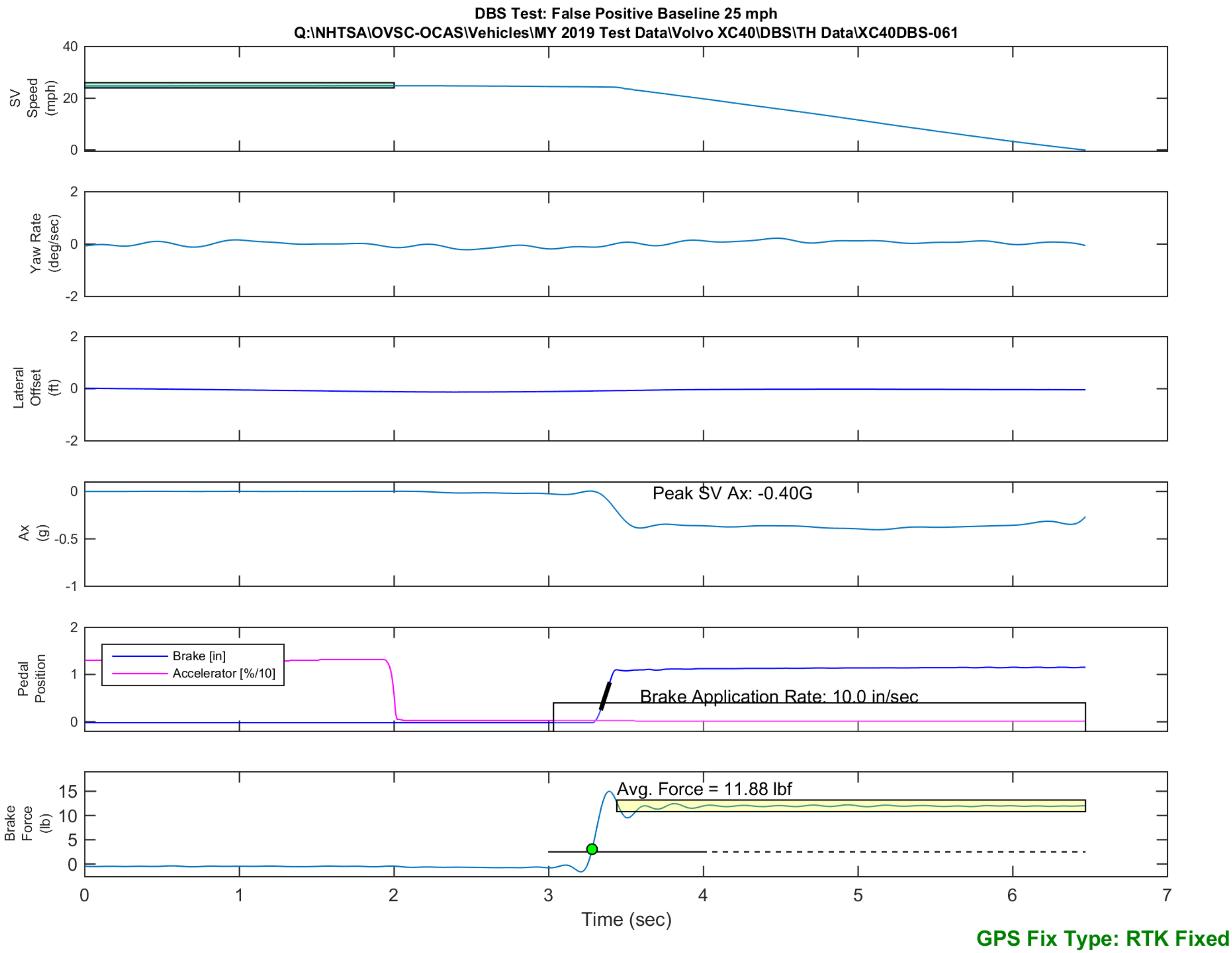


Figure E46. Time History for DBS Run 61, False Positive Baseline, SV 25 mph

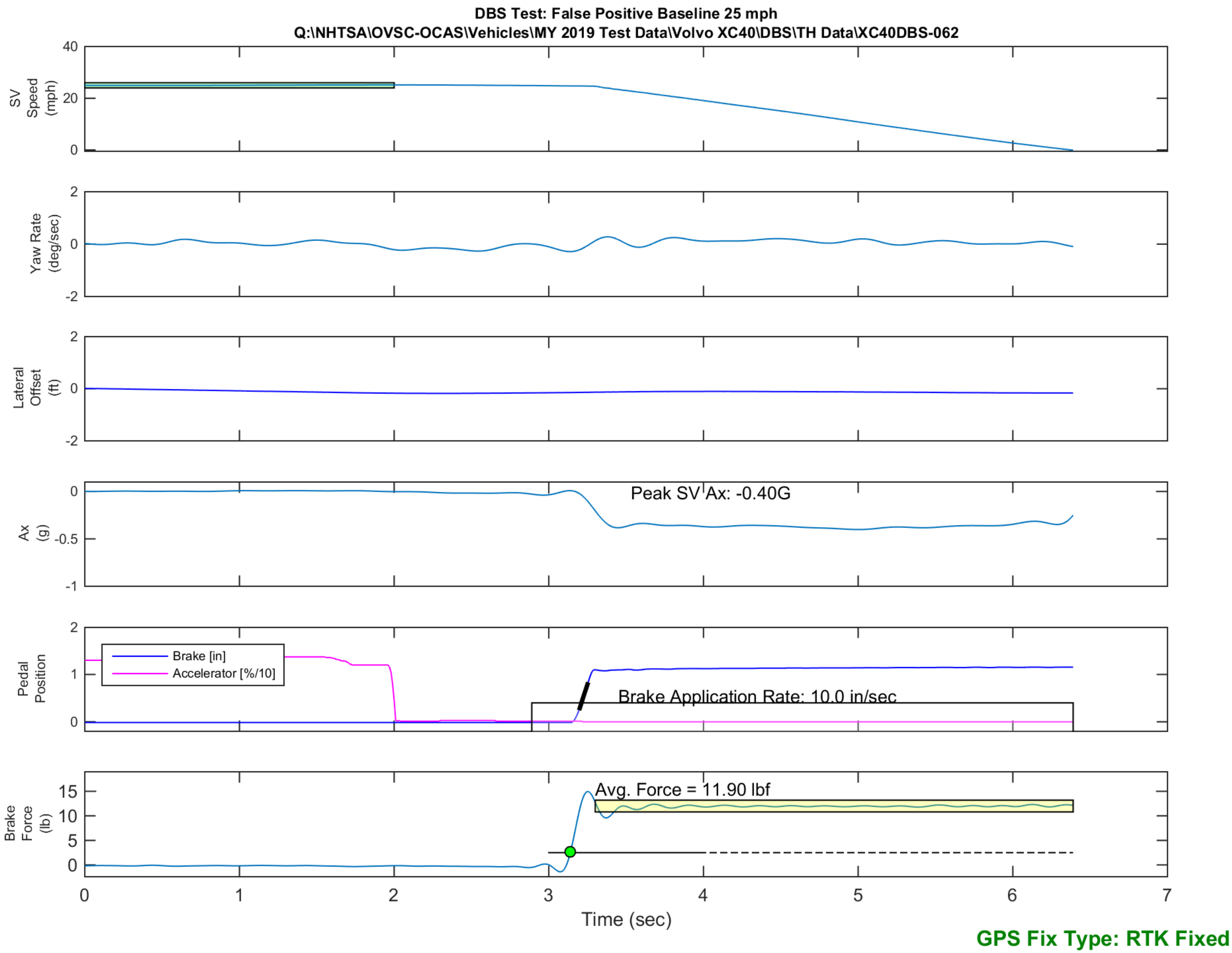


Figure E47. Time History for DBS Run 62, False Positive Baseline, SV 25 mph

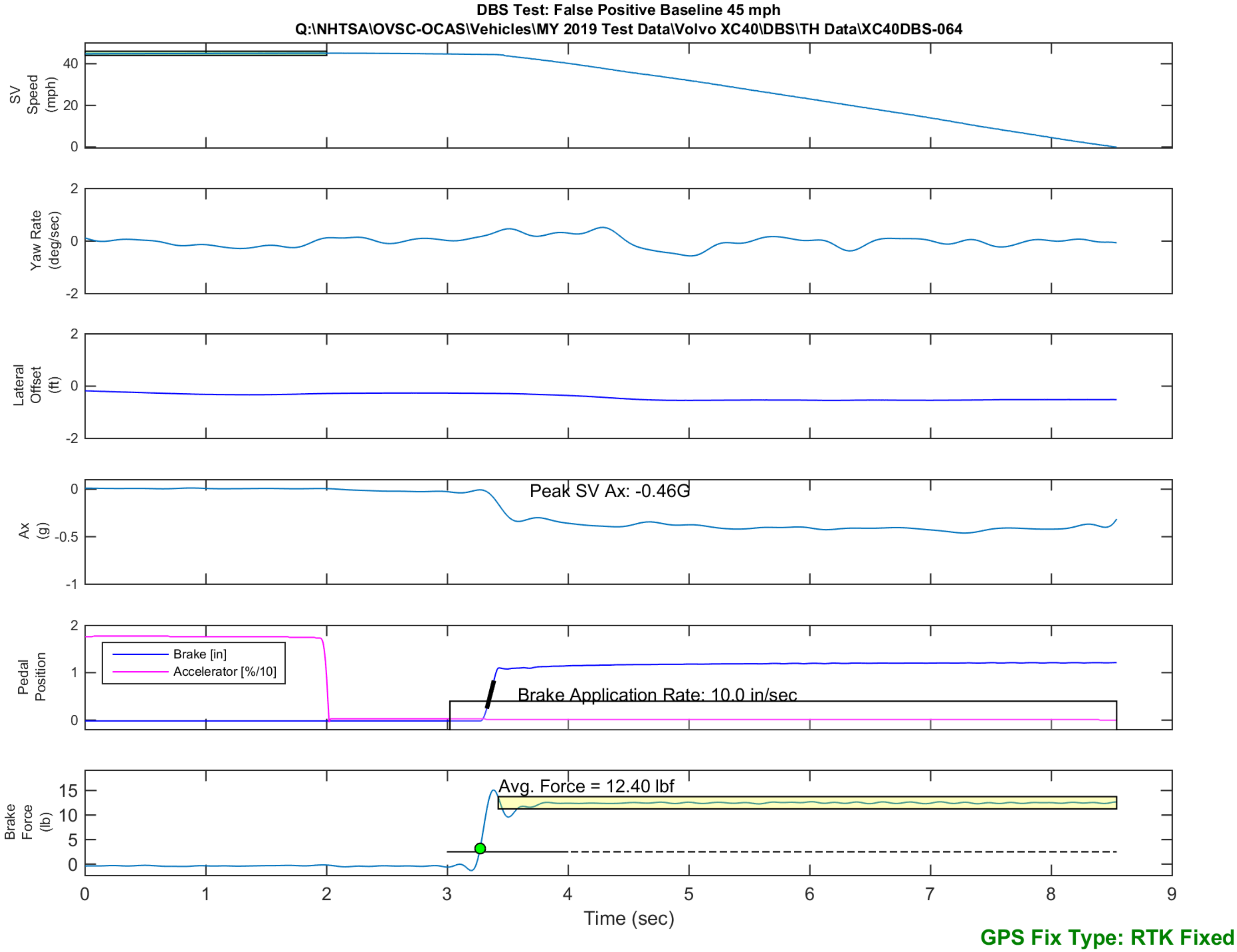


Figure E48. Time History for DBS Run 64, False Positive Baseline, SV 45 mph

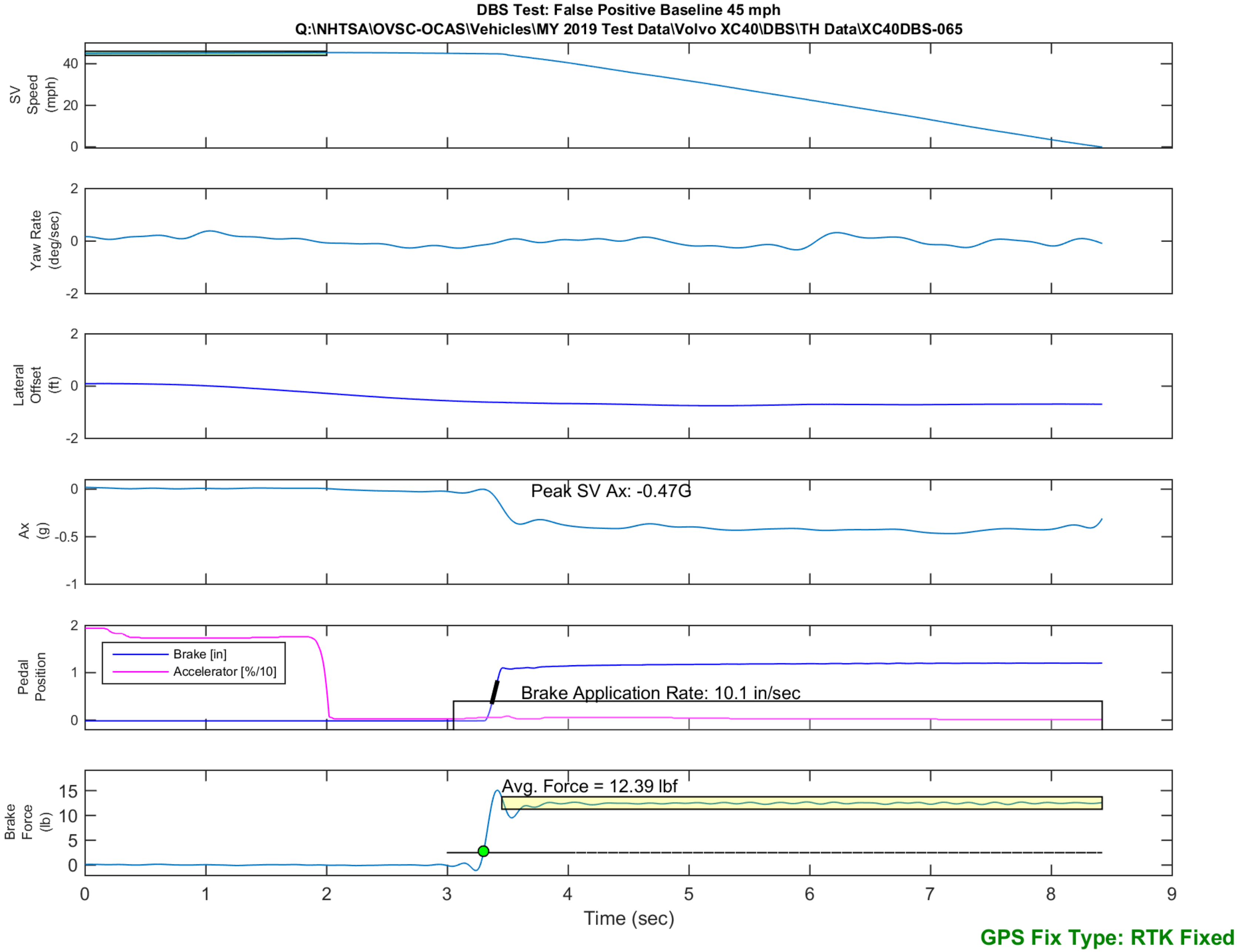


Figure E49. Time History for DBS Run 65, False Positive Baseline, SV 45 mph

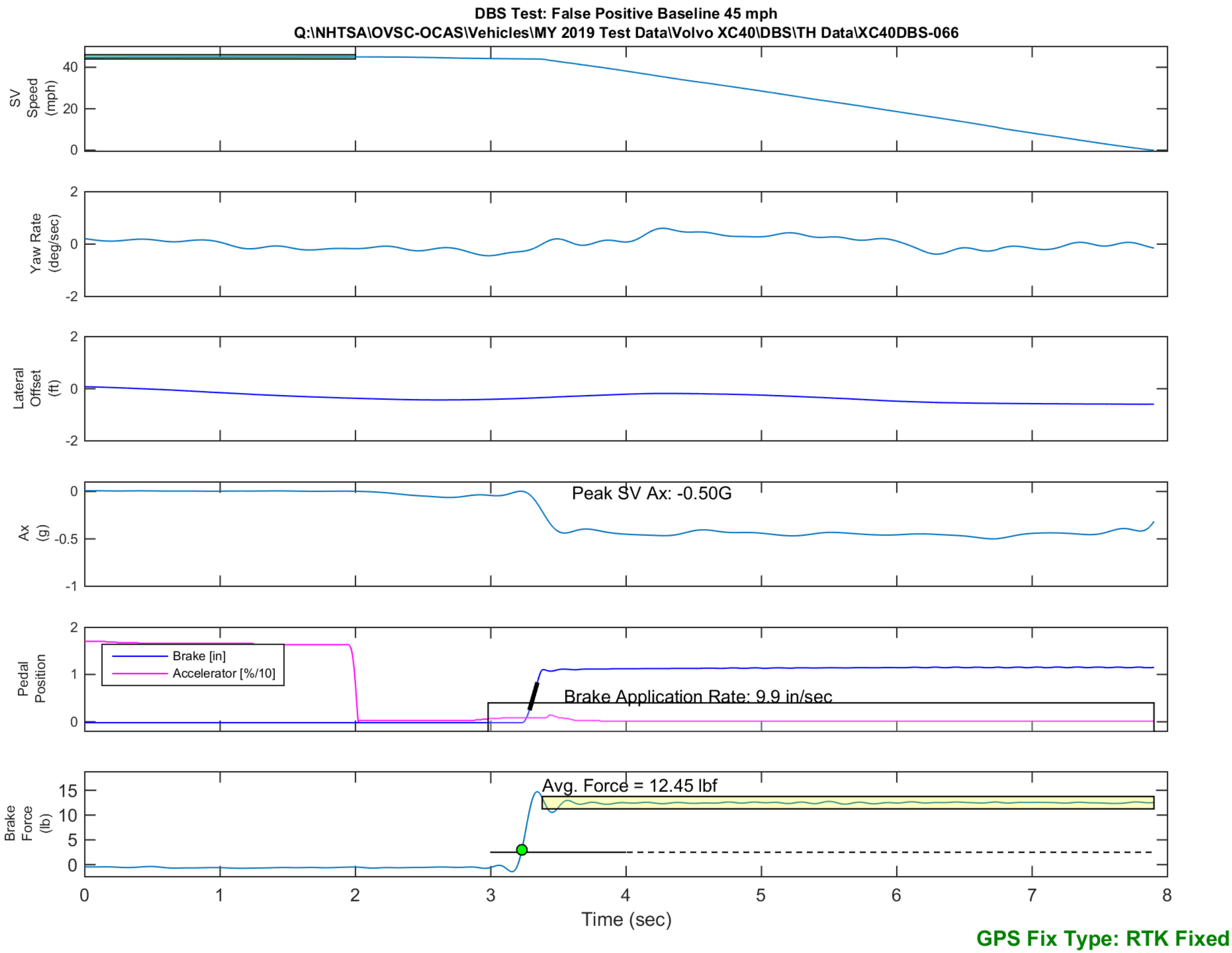


Figure E50. Time History for DBS Run 66, False Positive Baseline, SV 45 mph

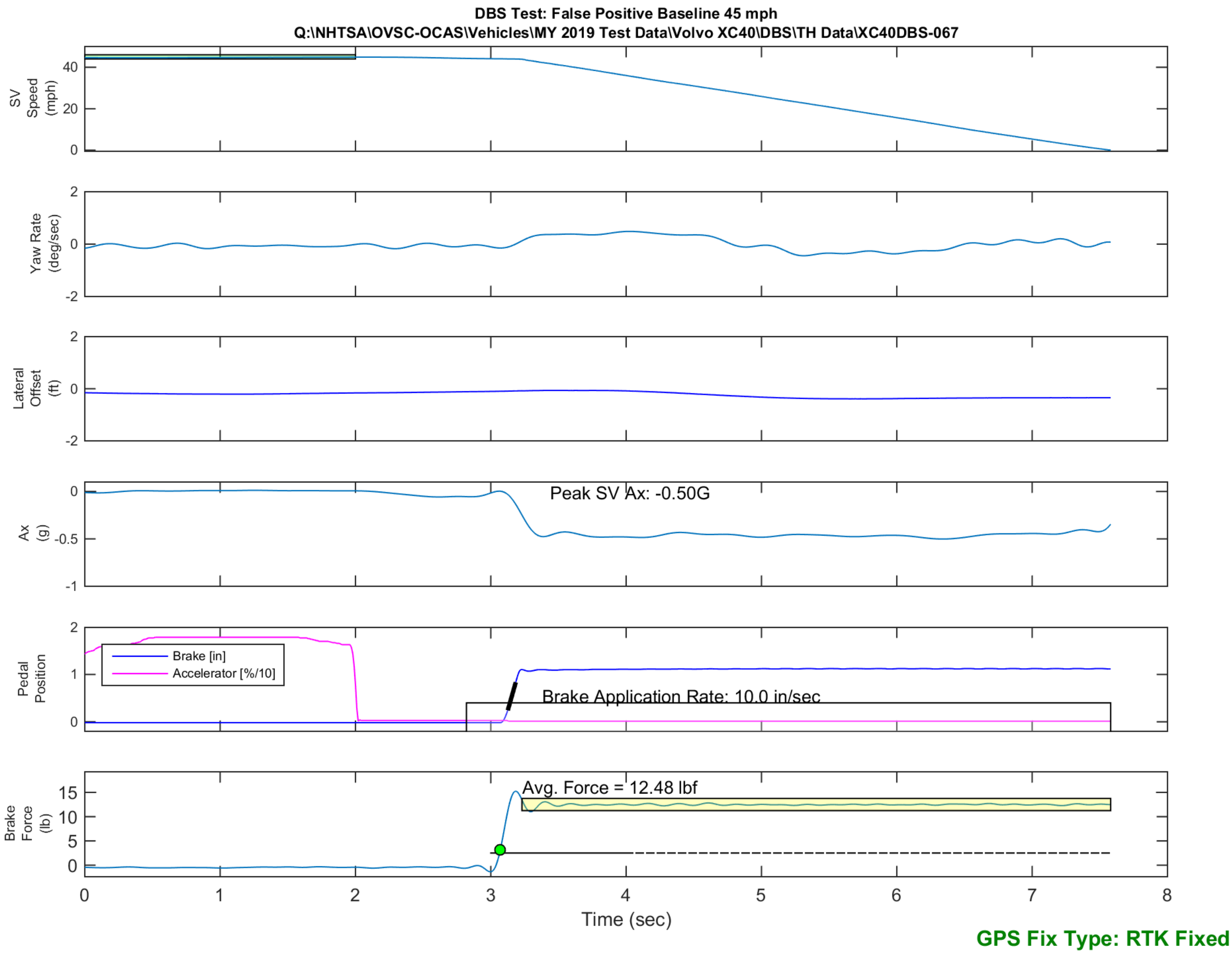


Figure E51. Time History for DBS Run 67, False Positive Baseline, SV 45 mph

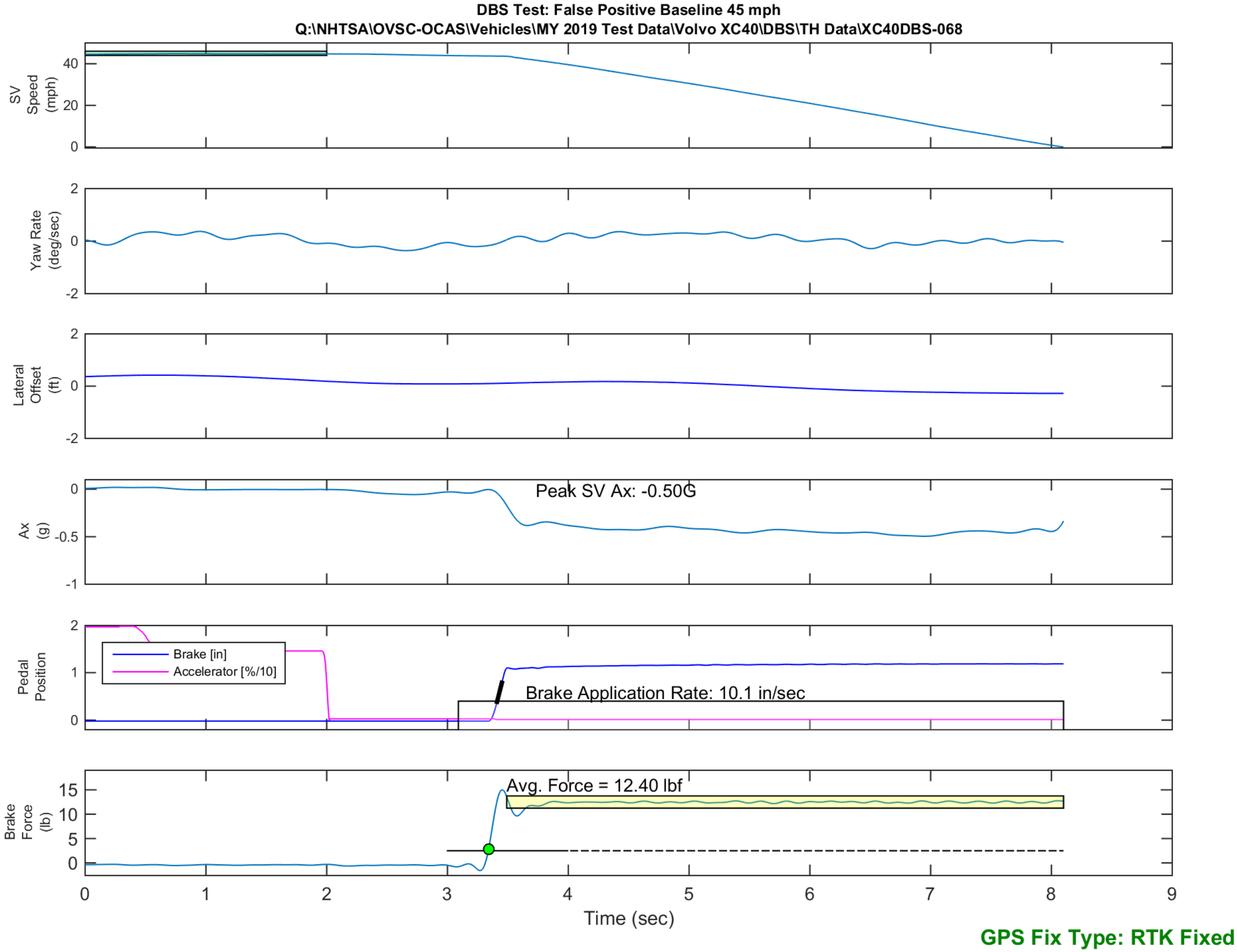


Figure E52. Time History for DBS Run 68, False Positive Baseline, SV 45 mph

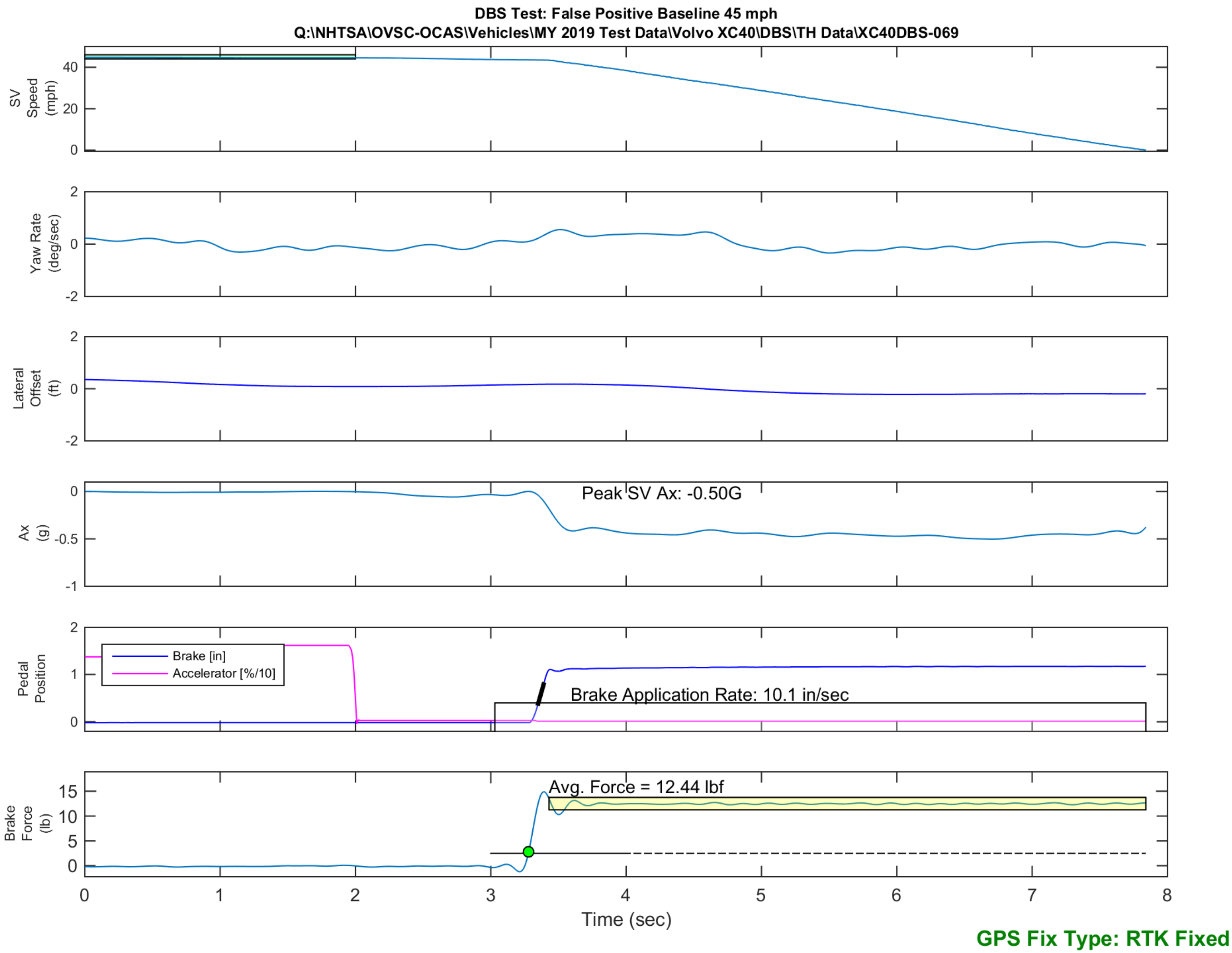


Figure E53. Time History for DBS Run 69, False Positive Baseline, SV 45 mph

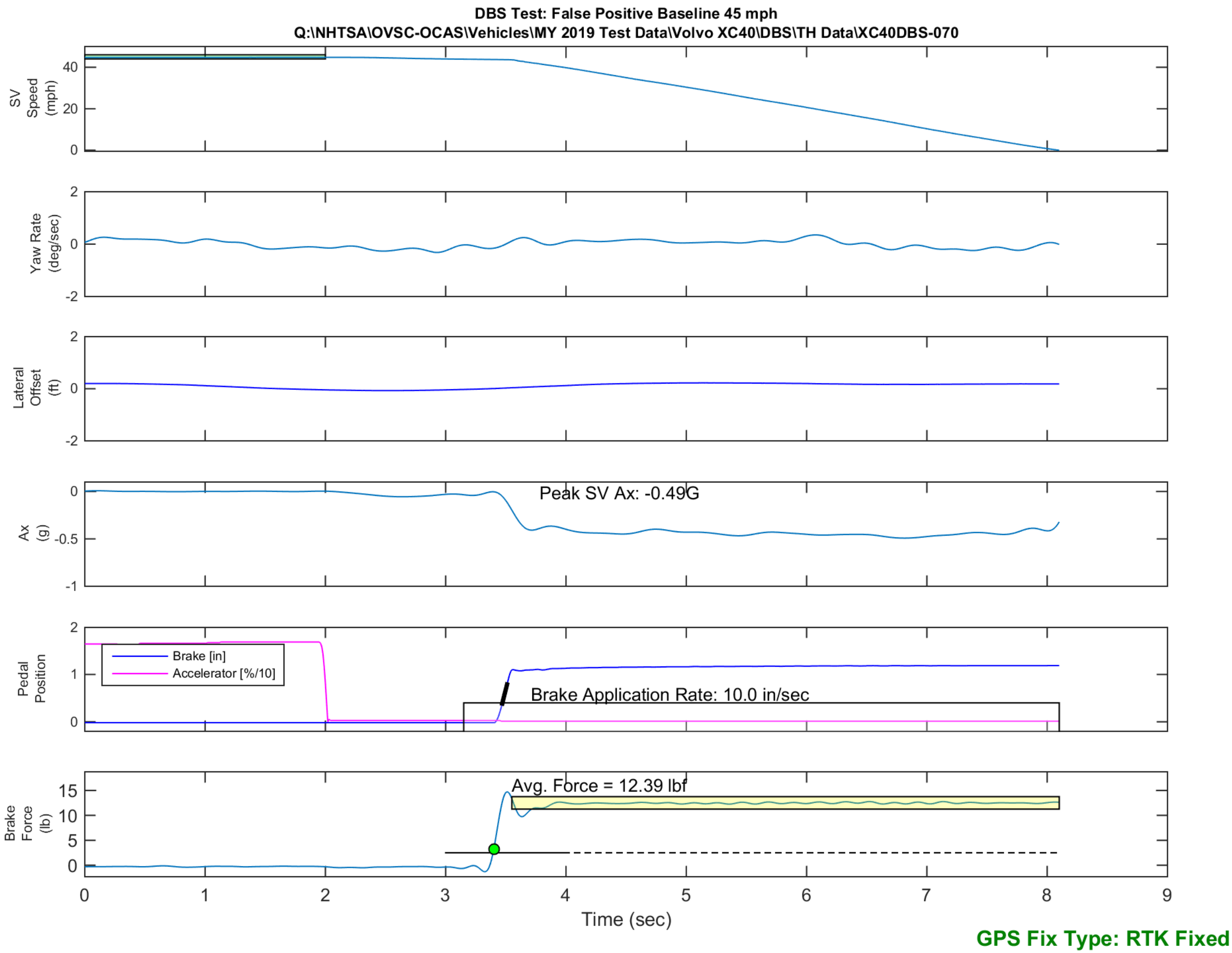


Figure E54. Time History for DBS Run 70, False Positive Baseline, SV 45 mph

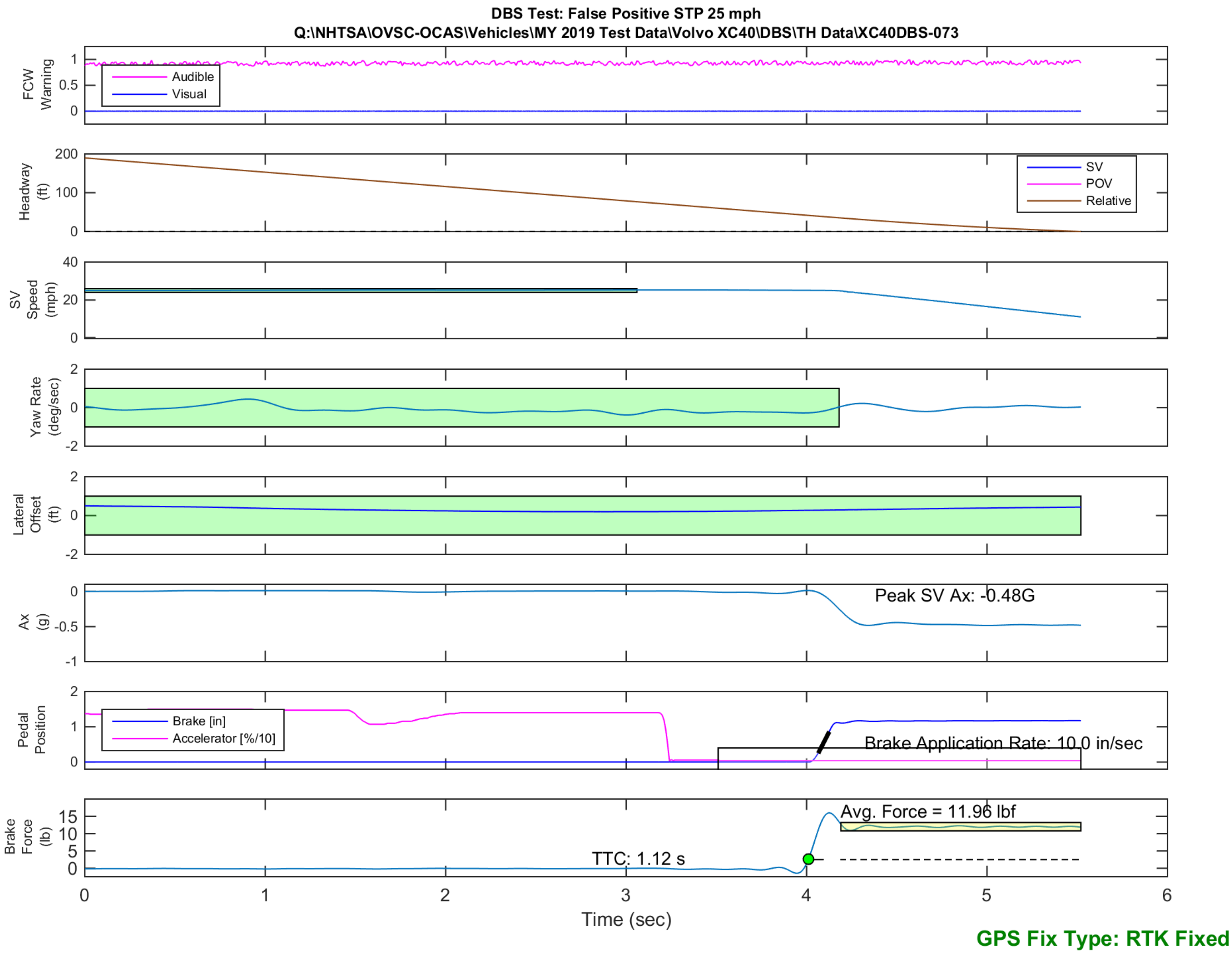


Figure E55. Time History for DBS Run 73, SV Encounters Steel Trench Plate, SV 25 mph

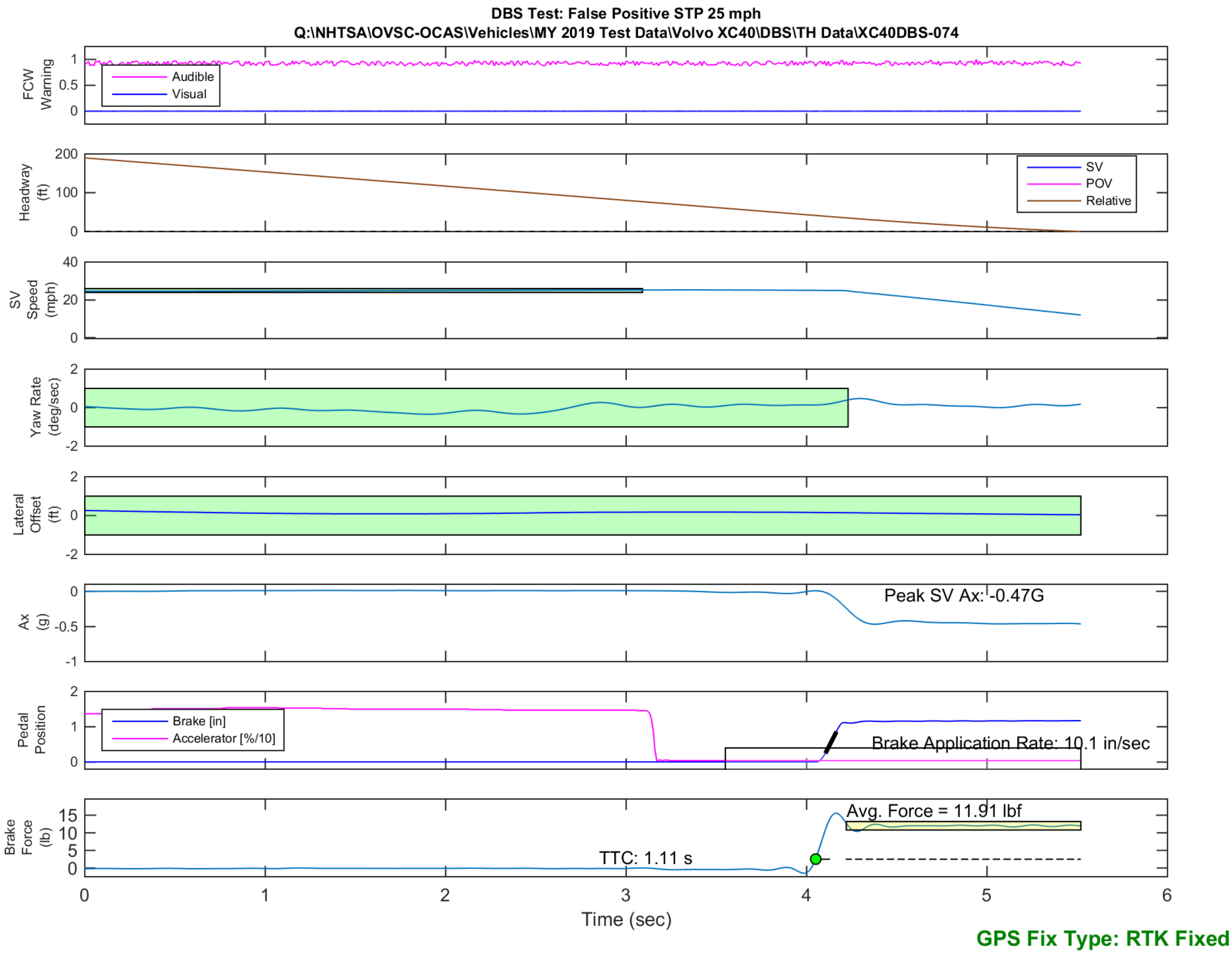


Figure E56. Time History for DBS Run 74, SV Encounters Steel Trench Plate, SV 25 mph

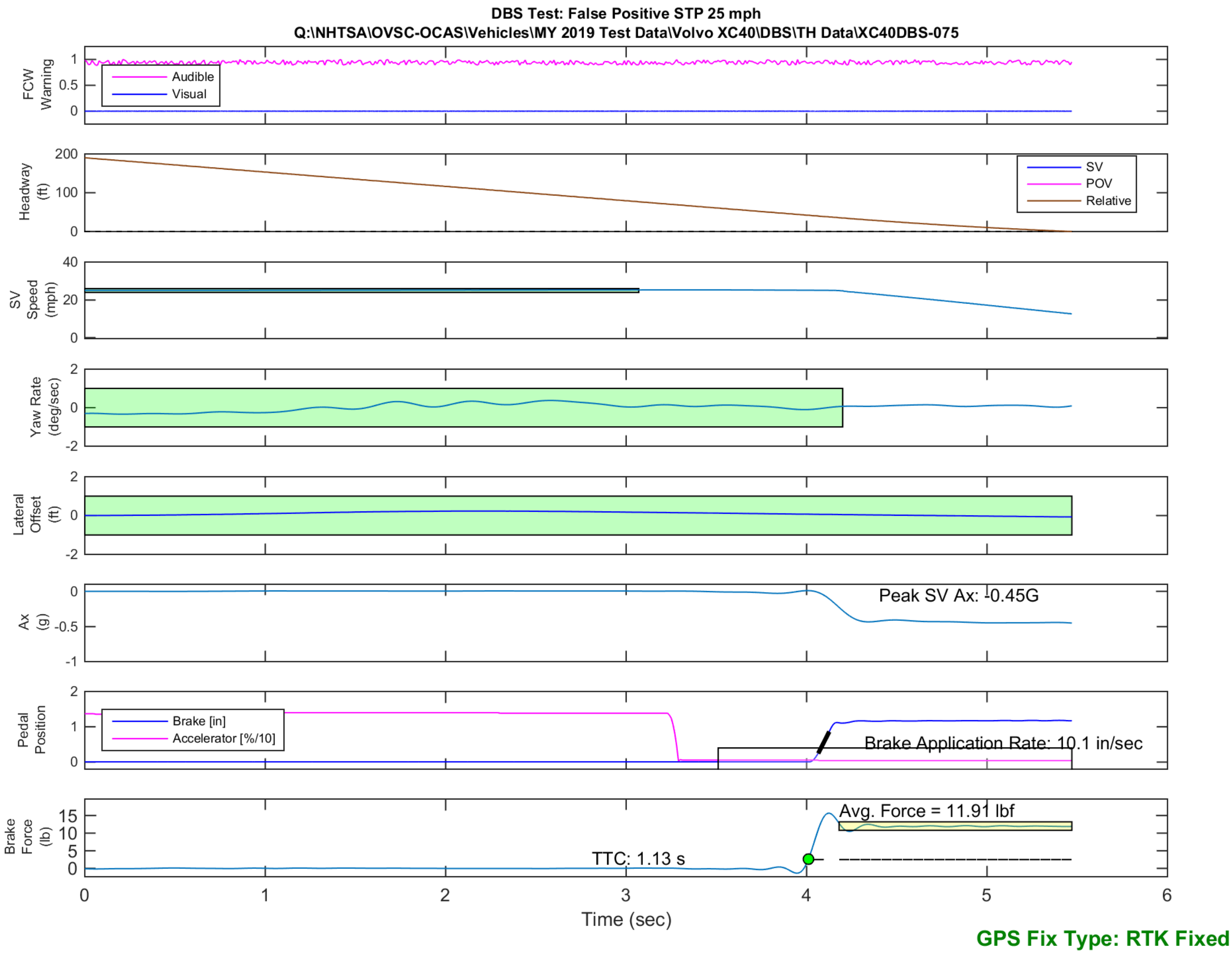


Figure E57. Time History for DBS Run 75, SV Encounters Steel Trench Plate, SV 25 mph

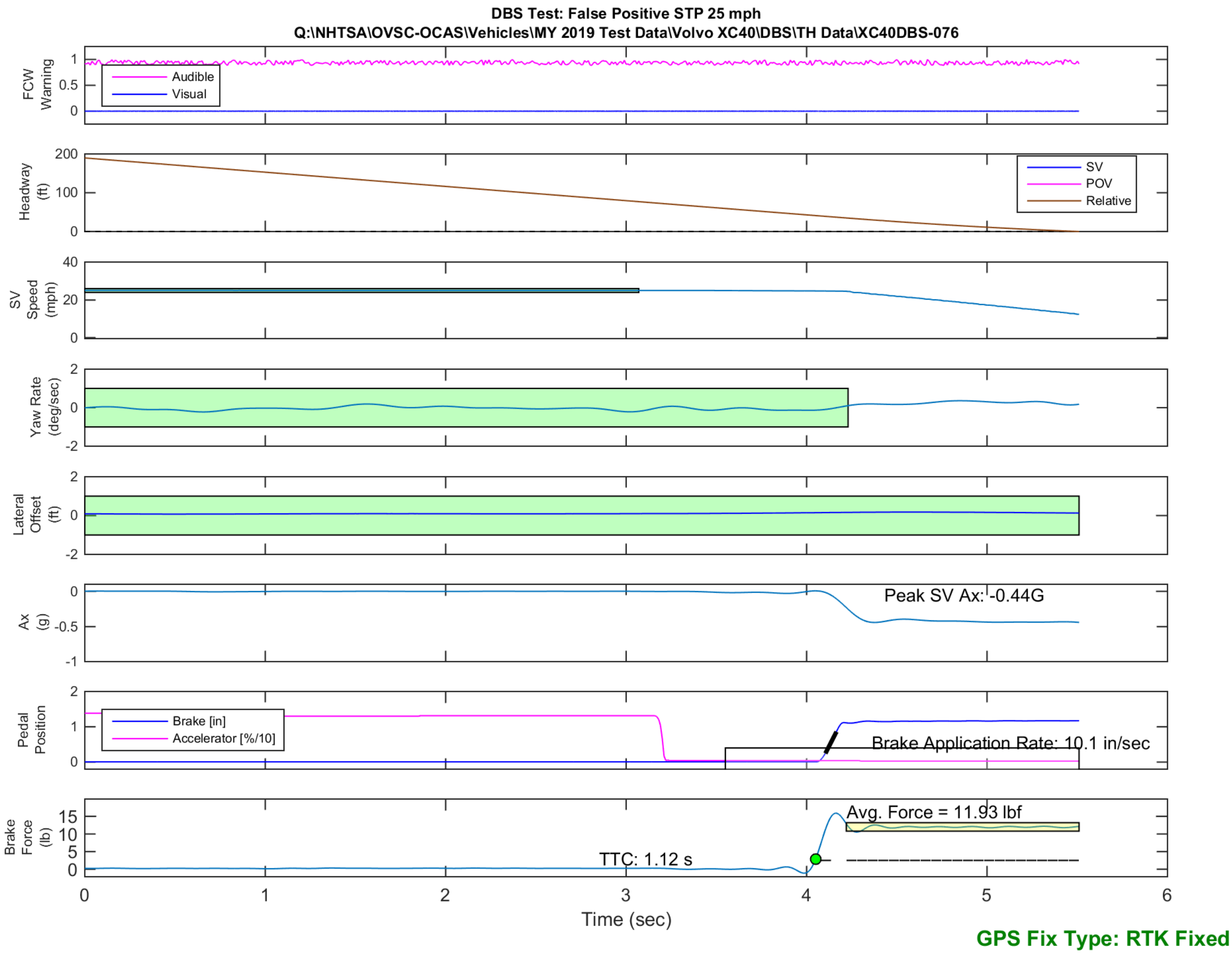


Figure E58. Time History for DBS Run 76, SV Encounters Steel Trench Plate, SV 25 mph

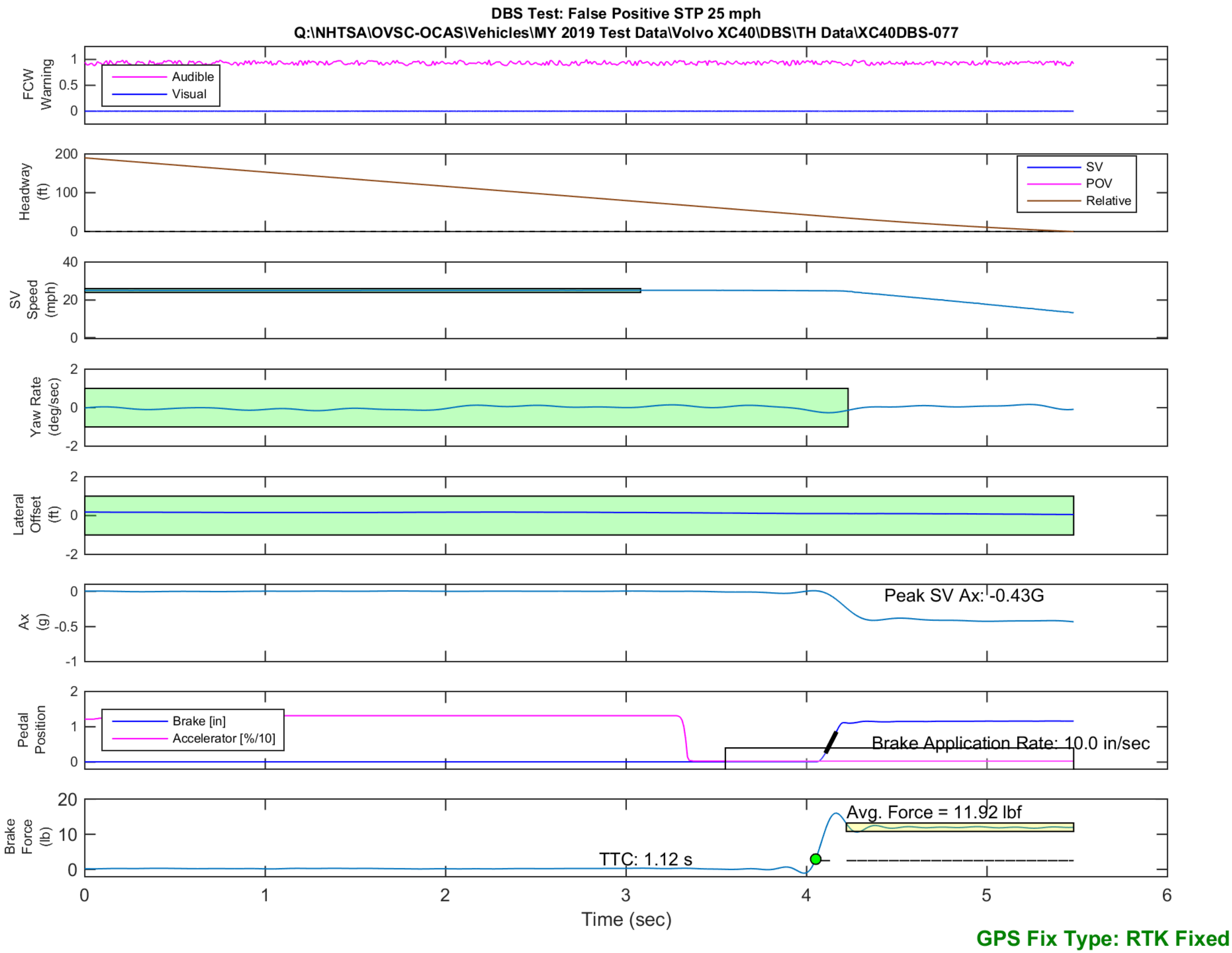


Figure E59. Time History for DBS Run 77, SV Encounters Steel Trench Plate, SV 25 mph

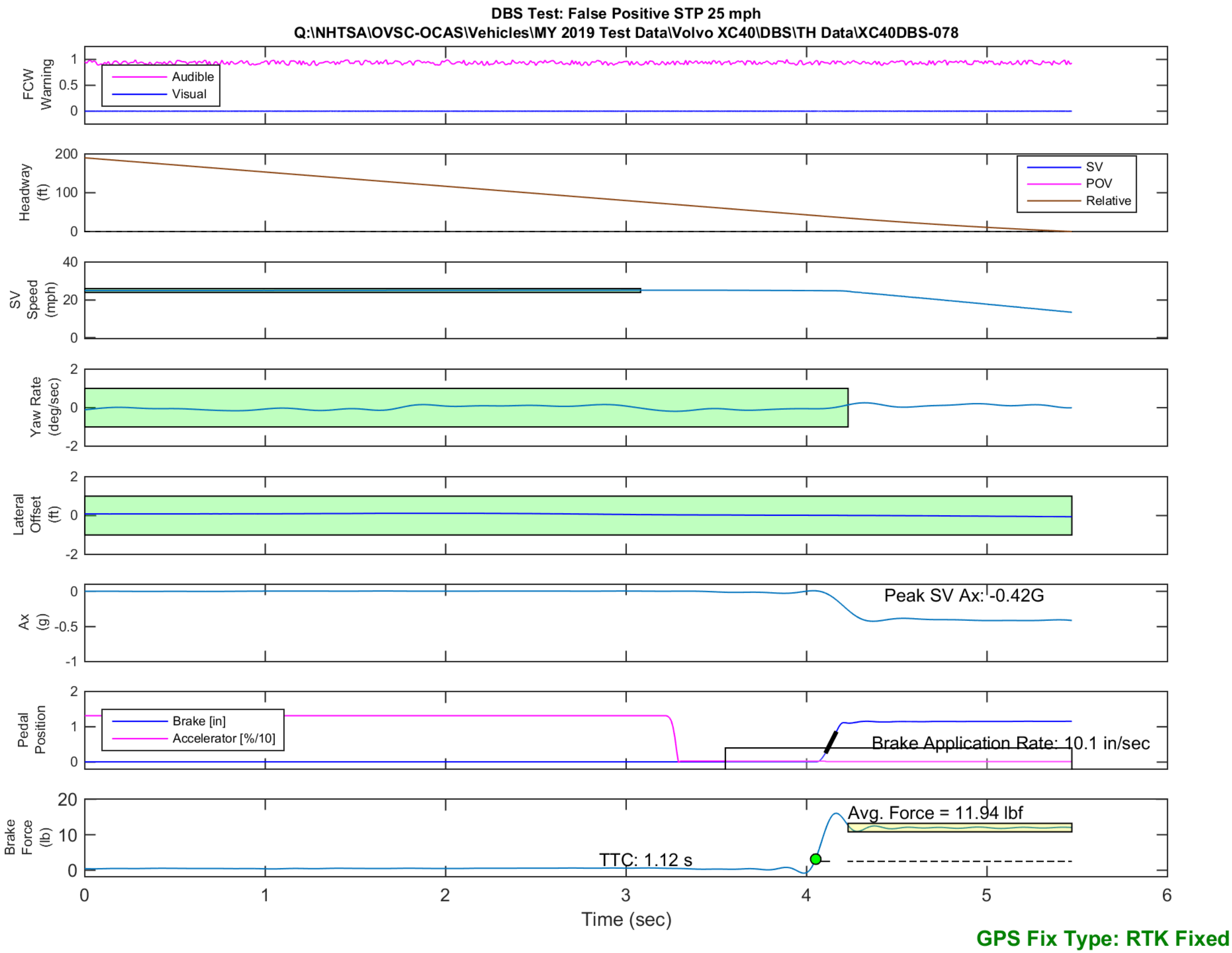


Figure E60. Time History for DBS Run 78, SV Encounters Steel Trench Plate, SV 25 mph

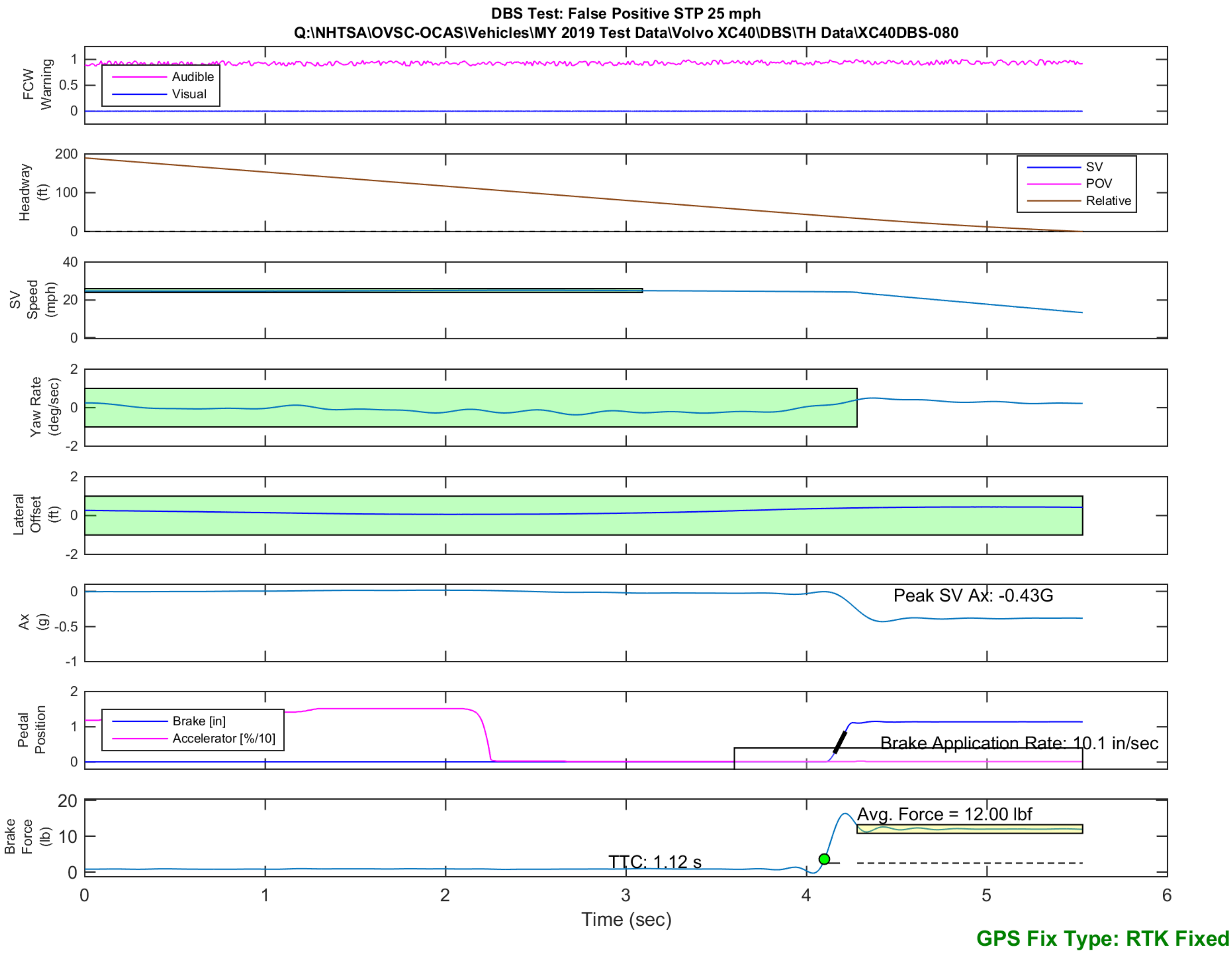


Figure E61. Time History for DBS Run 80, SV Encounters Steel Trench Plate, SV 25 mph

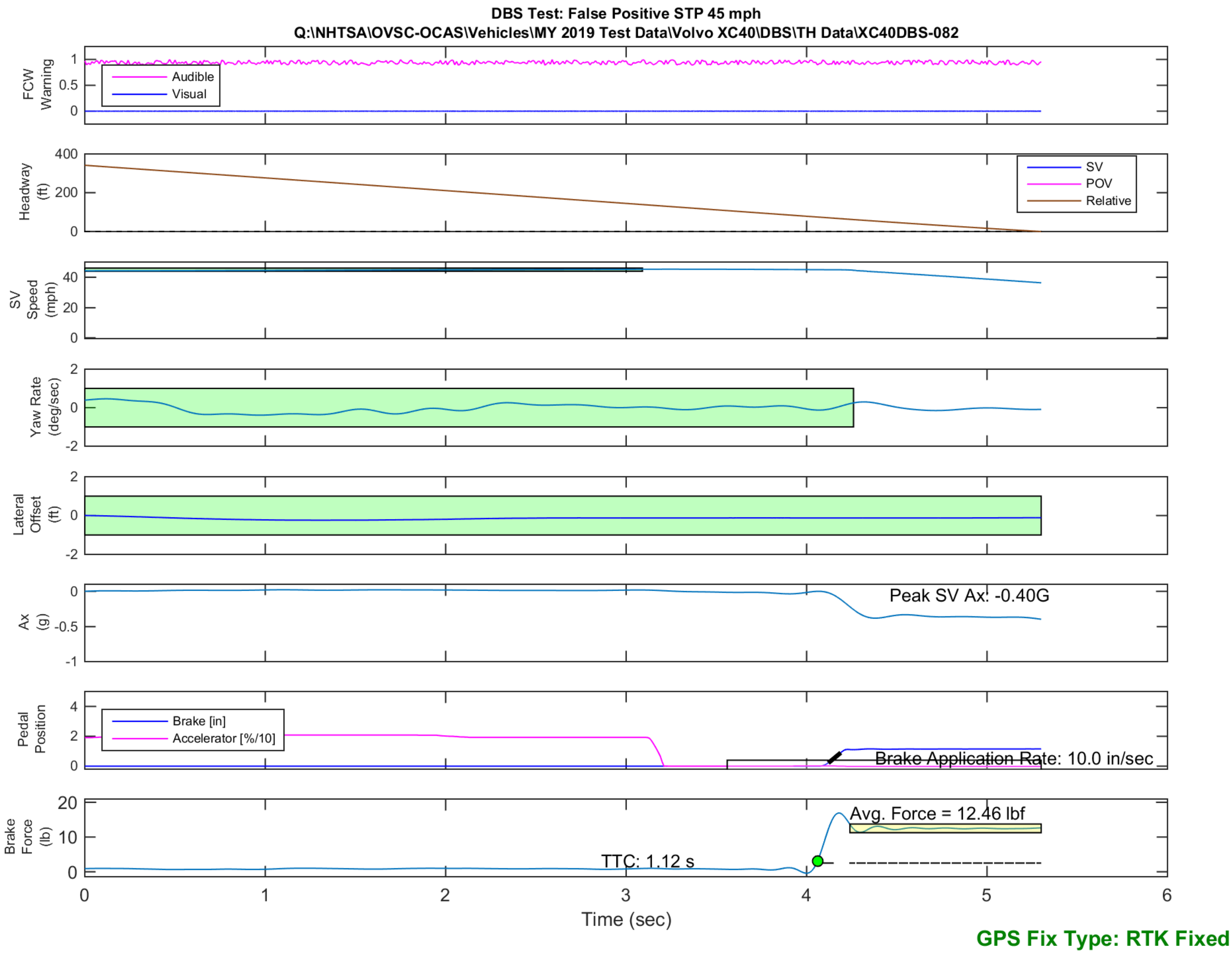


Figure E62. Time History for DBS Run 82, SV Encounters Steel Trench Plate, SV 45 mph

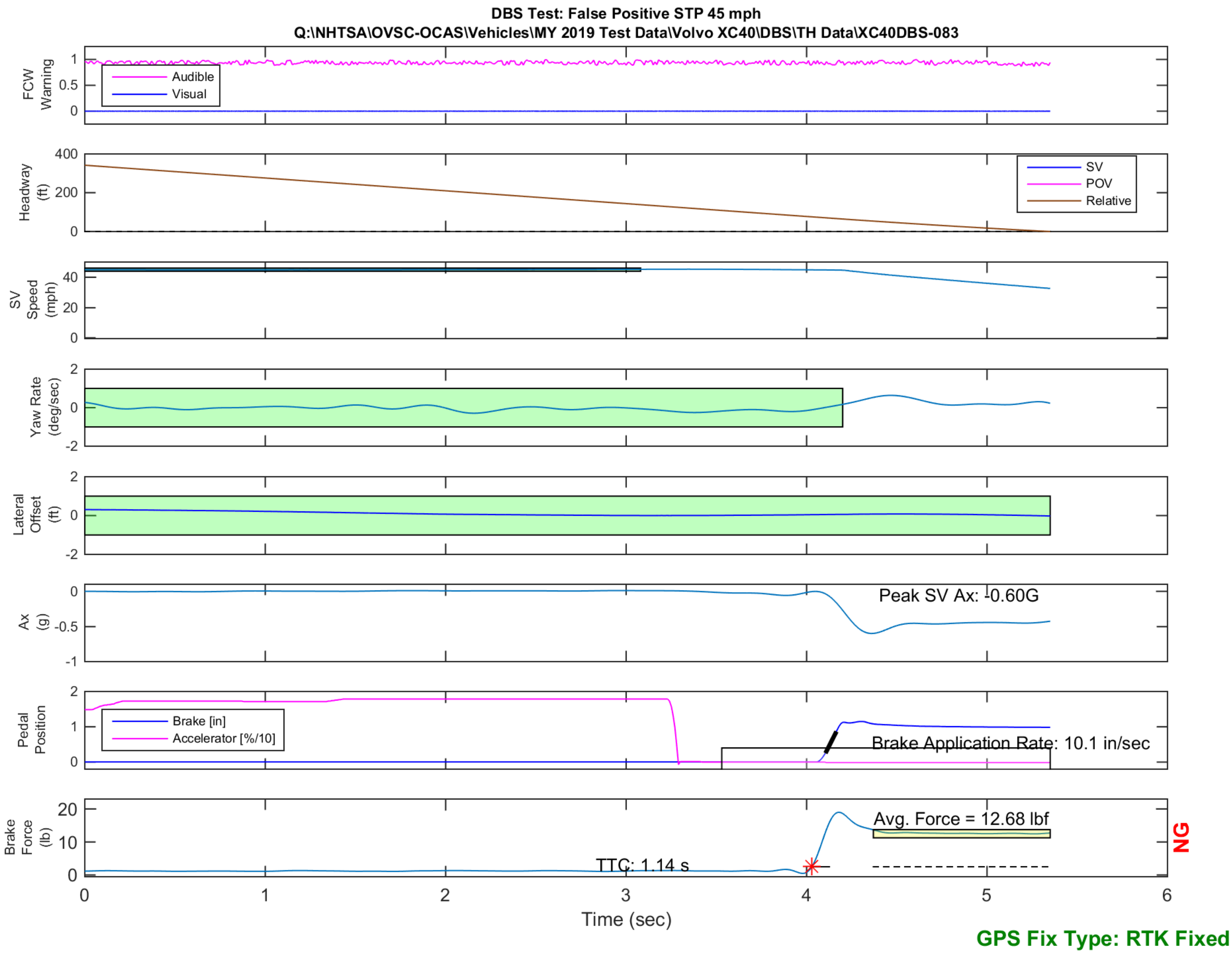


Figure E63. Time History for DBS Run 83, SV Encounters Steel Trench Plate, SV 45 mph

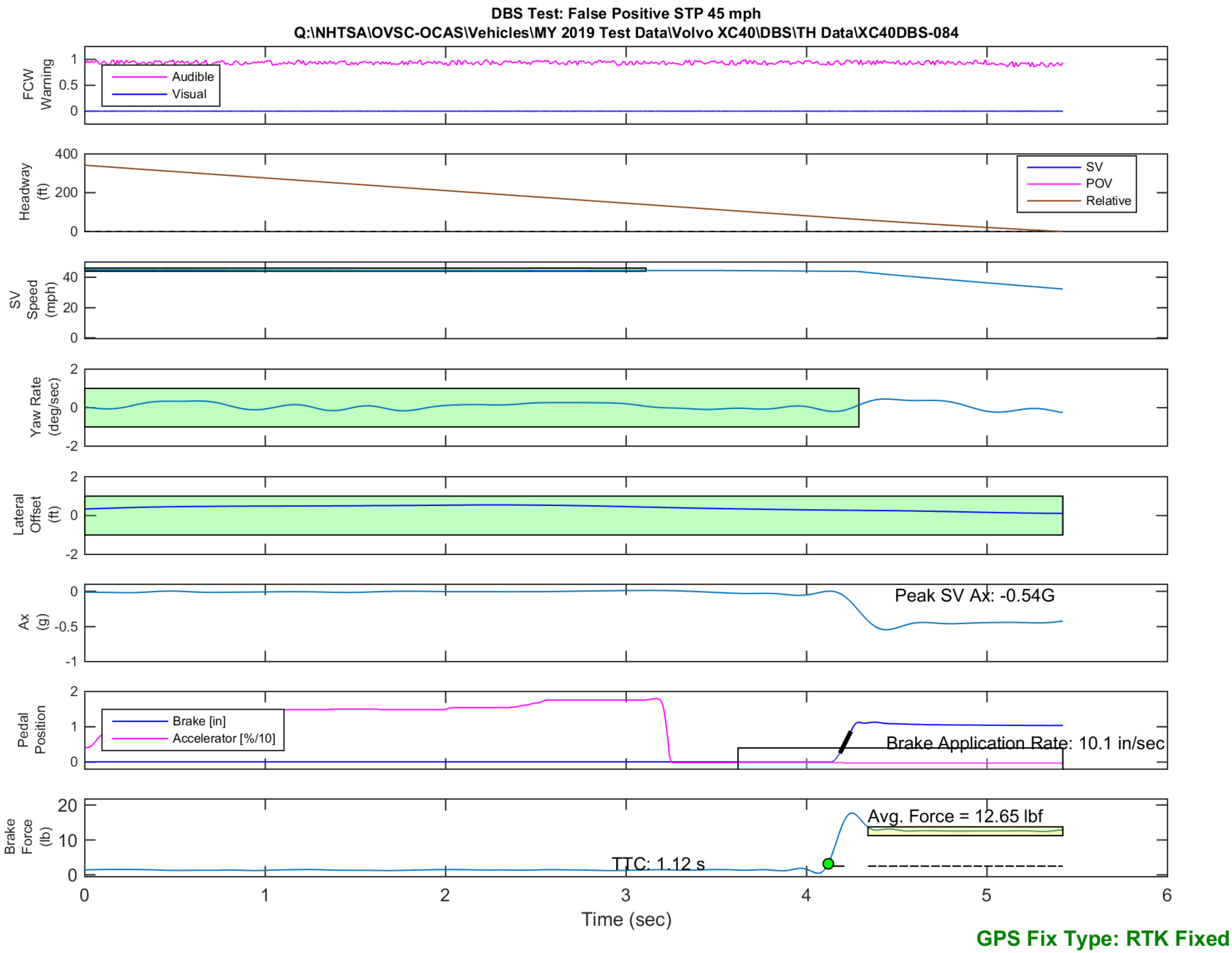


Figure E64. Time History for DBS Run 84, SV Encounters Steel Trench Plate, SV 45 mph

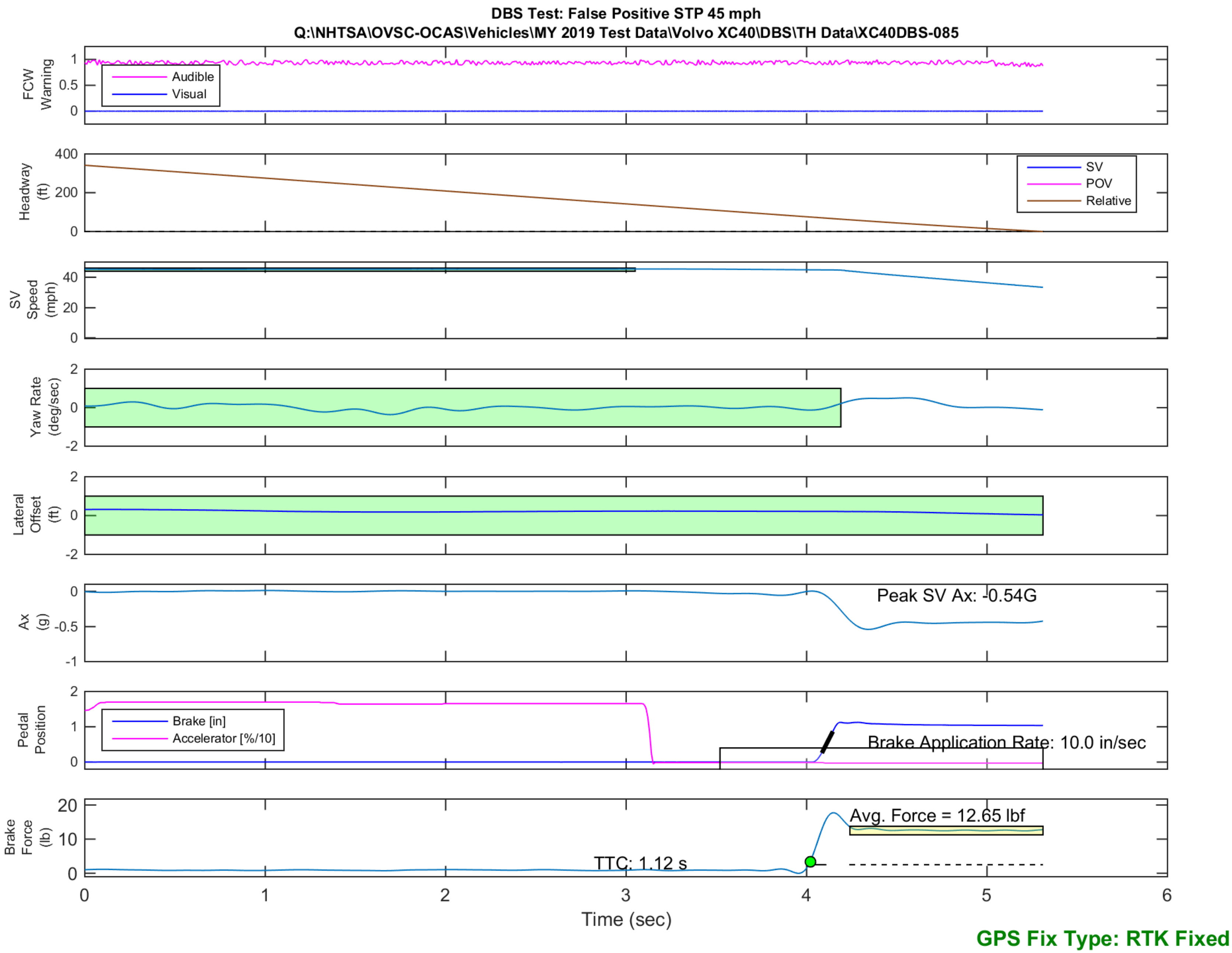


Figure E65. Time History for DBS Run 85, SV Encounters Steel Trench Plate, SV 45 mph

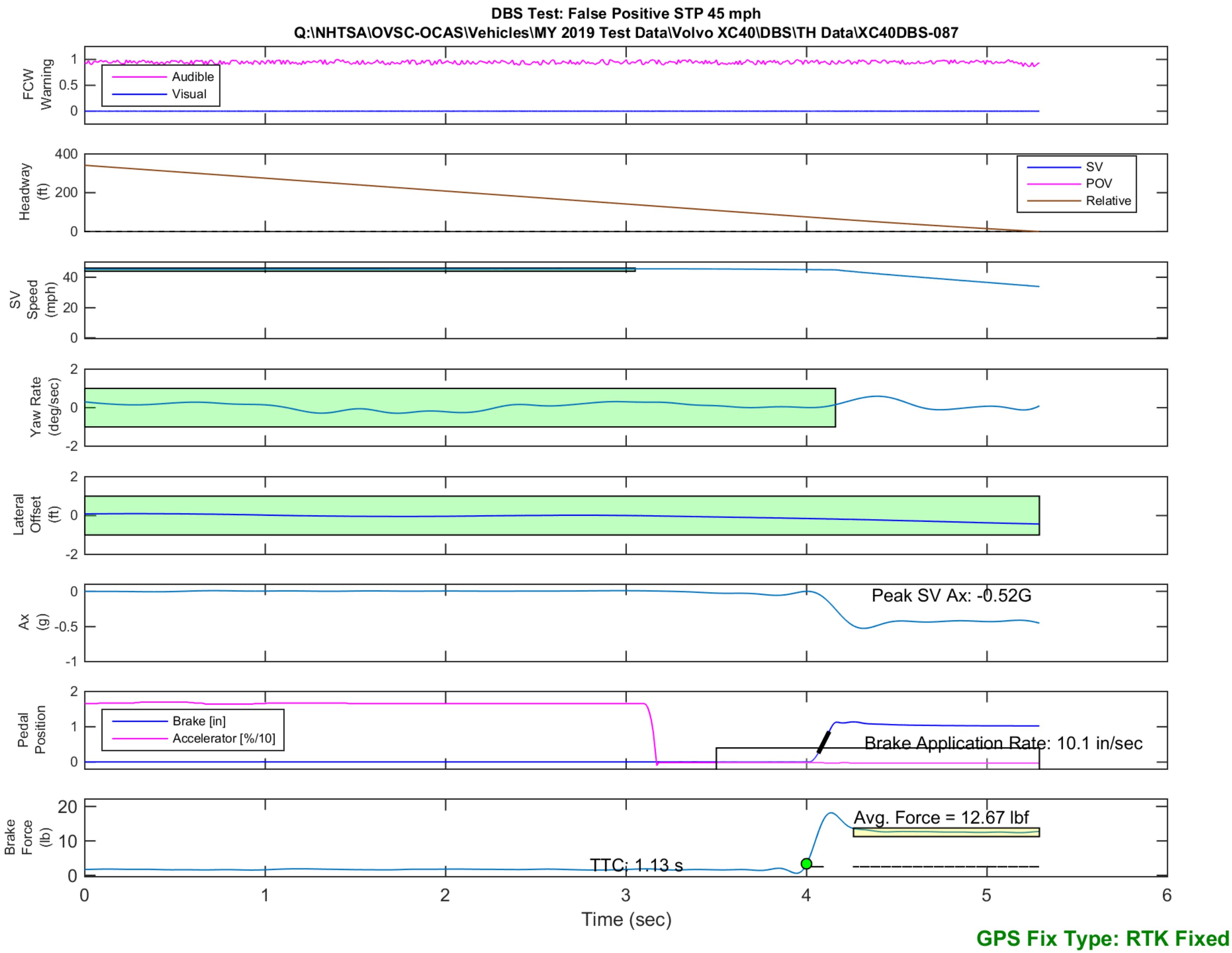


Figure E66. Time History for DBS Run 87, SV Encounters Steel Trench Plate, SV 45 mph

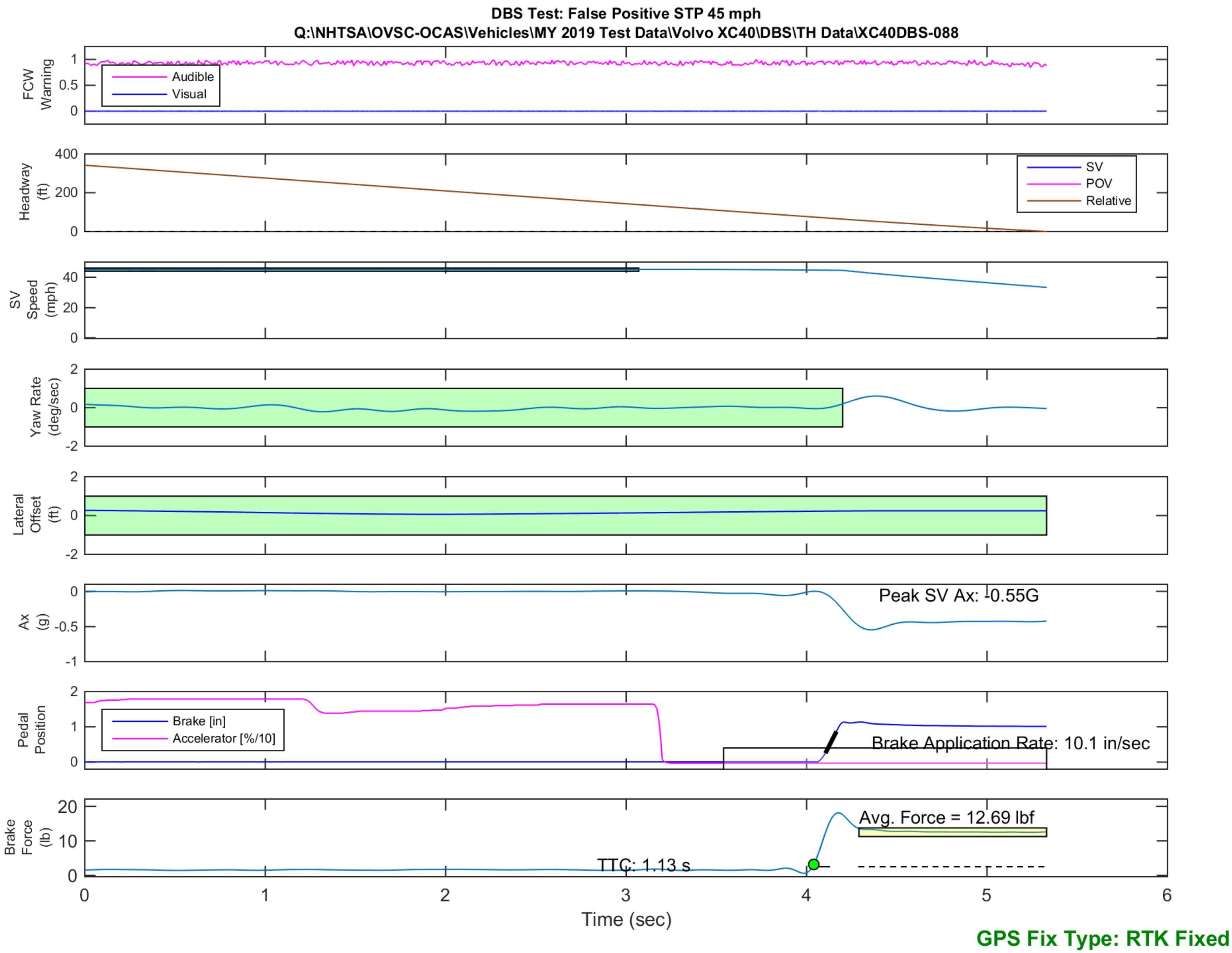


Figure E67. Time History for DBS Run 88, SV Encounters Steel Trench Plate, SV 45 mph

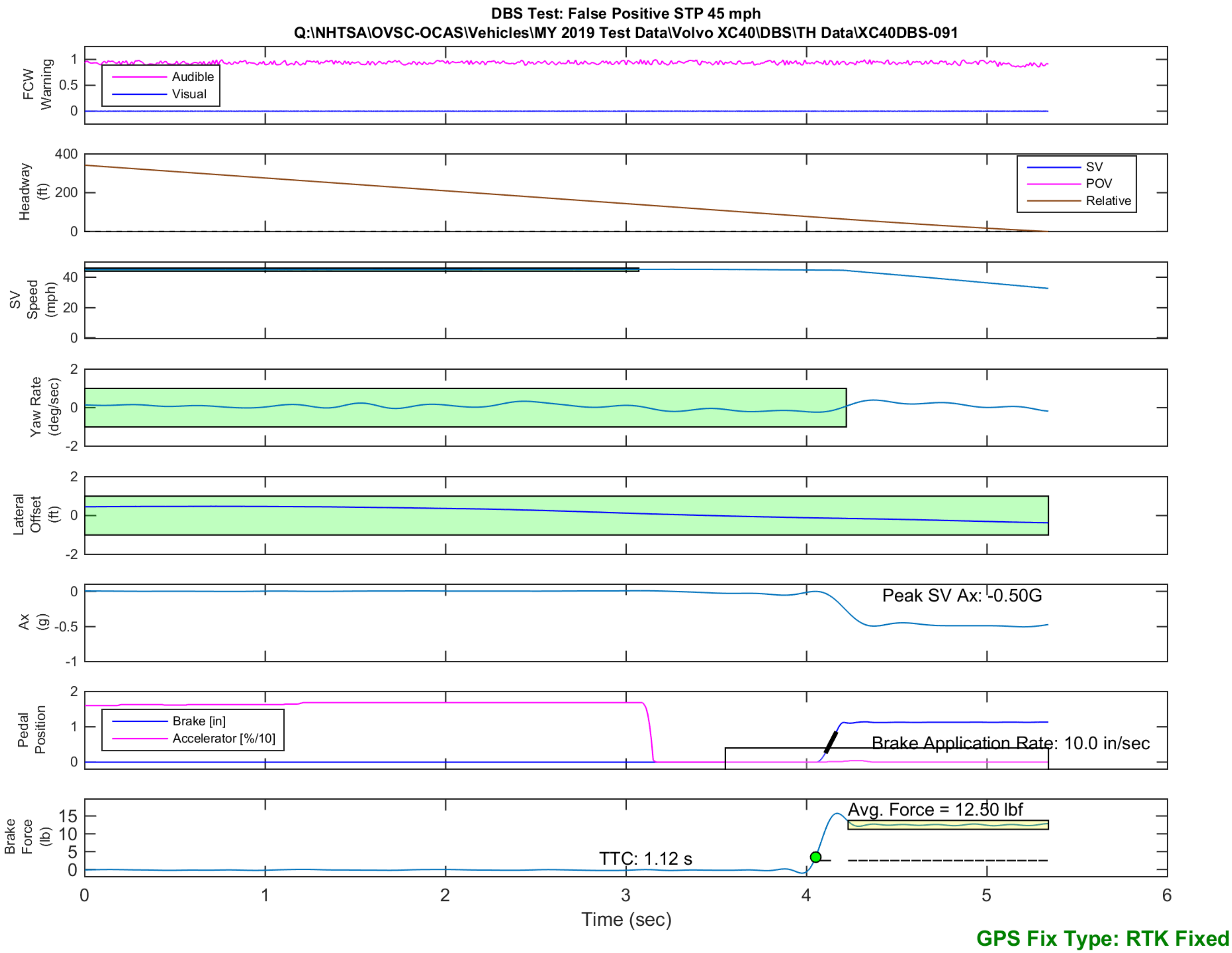


Figure E68. Time History for DBS Run 91, SV Encounters Steel Trench Plate, SV 45 mph

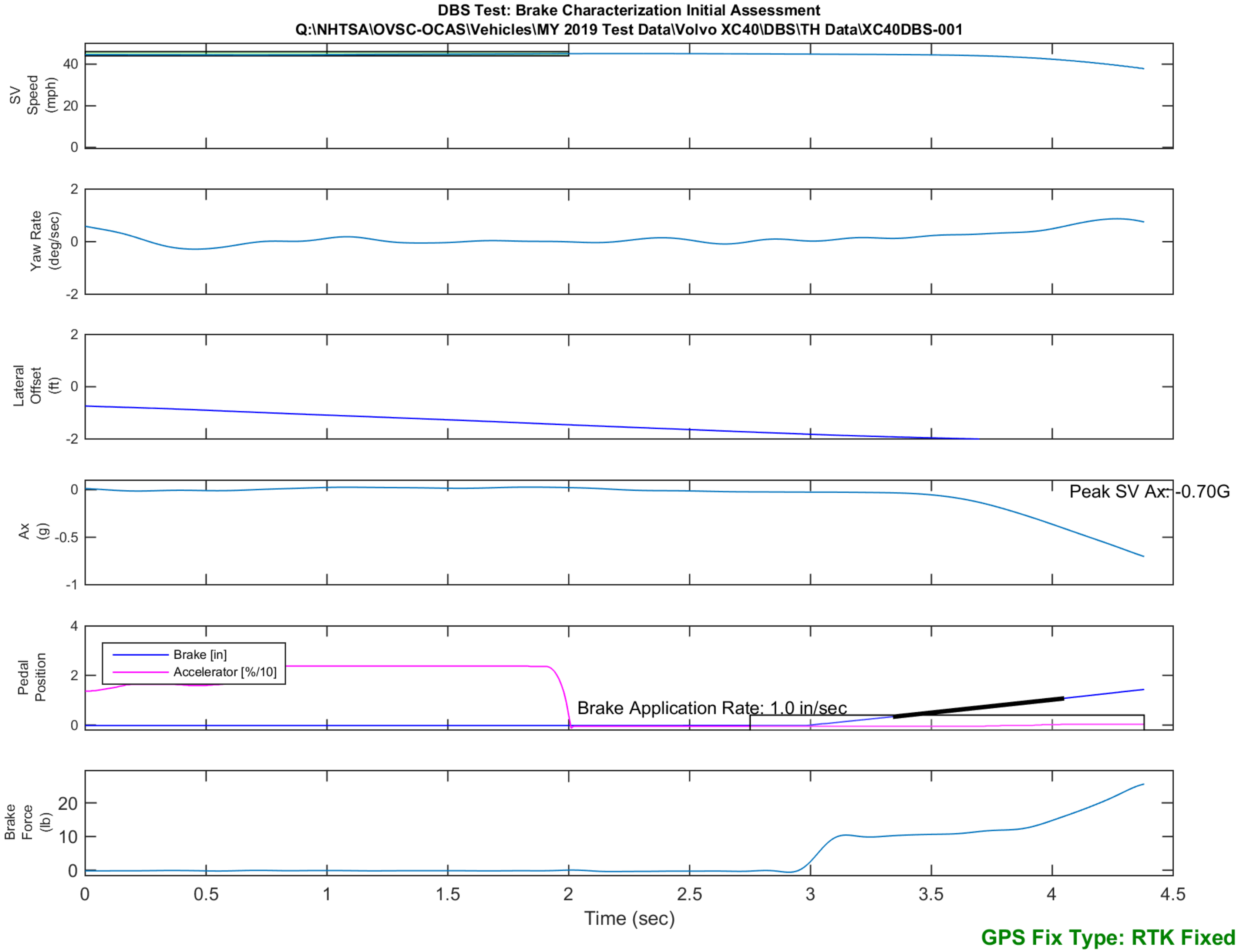


Figure E69. Time History for DBS Run 1, Brake Characterization Initial

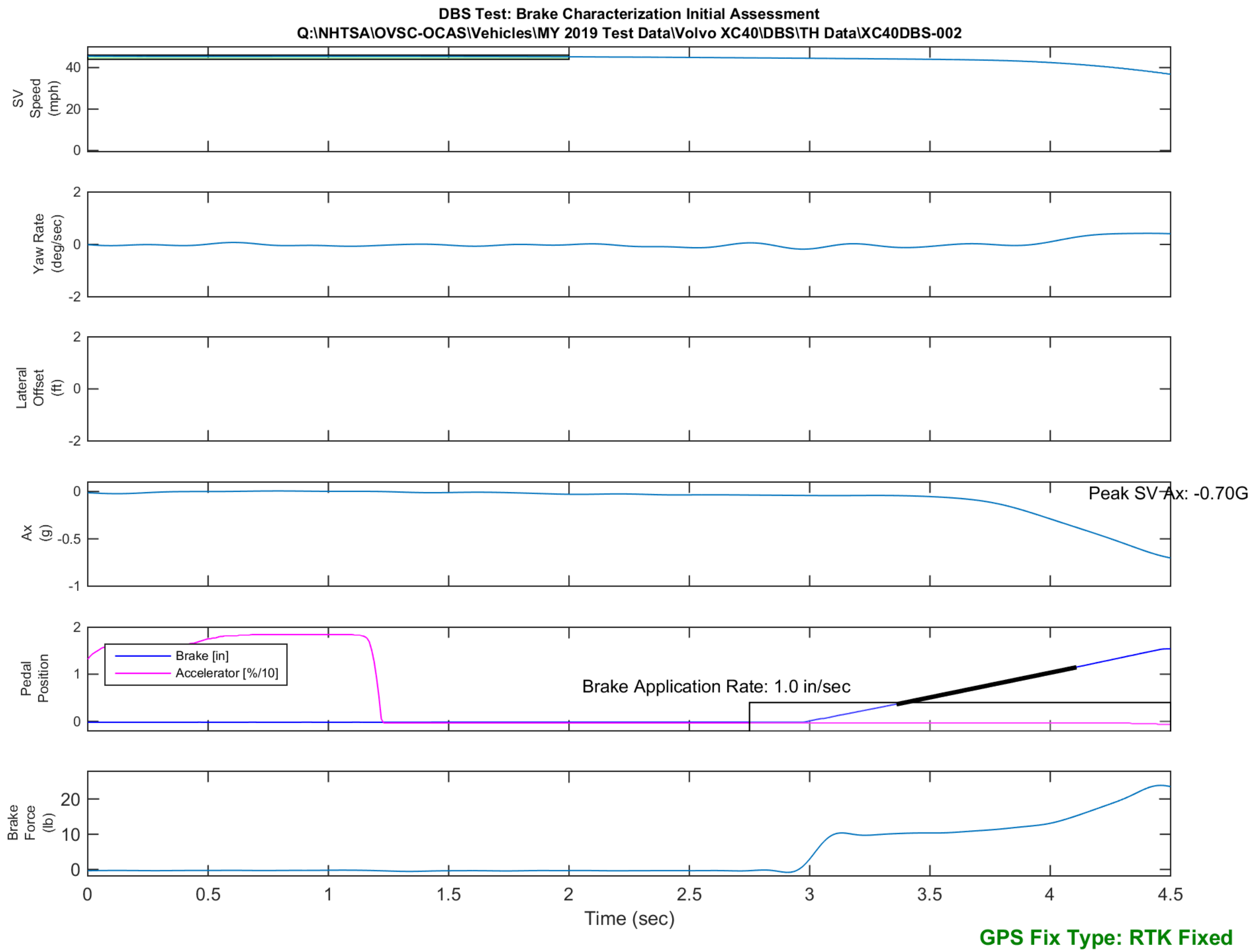


Figure E70. Time History for DBS Run 2, Brake Characterization Initial

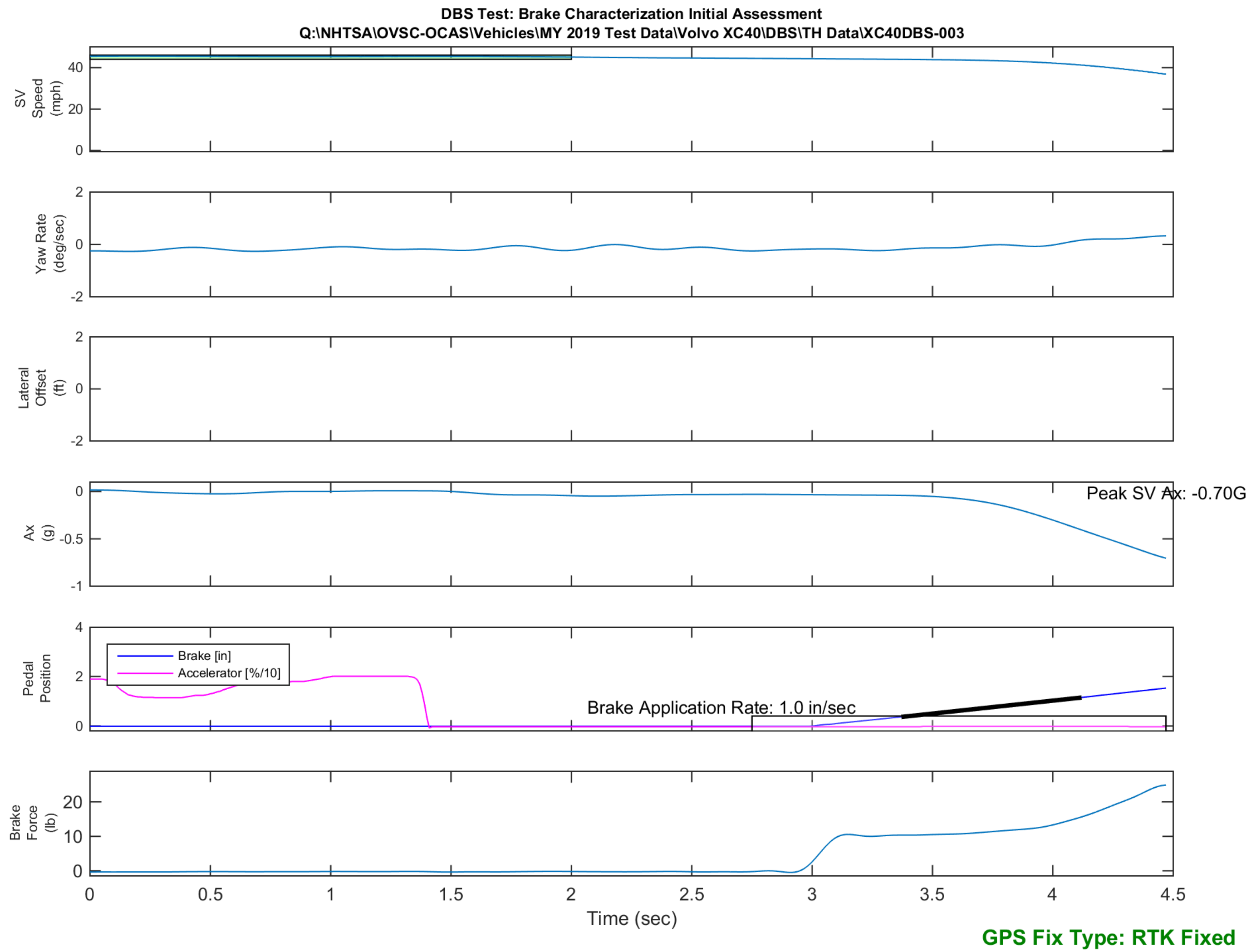


Figure E71. Time History for DBS Run 3, Brake Characterization Initial

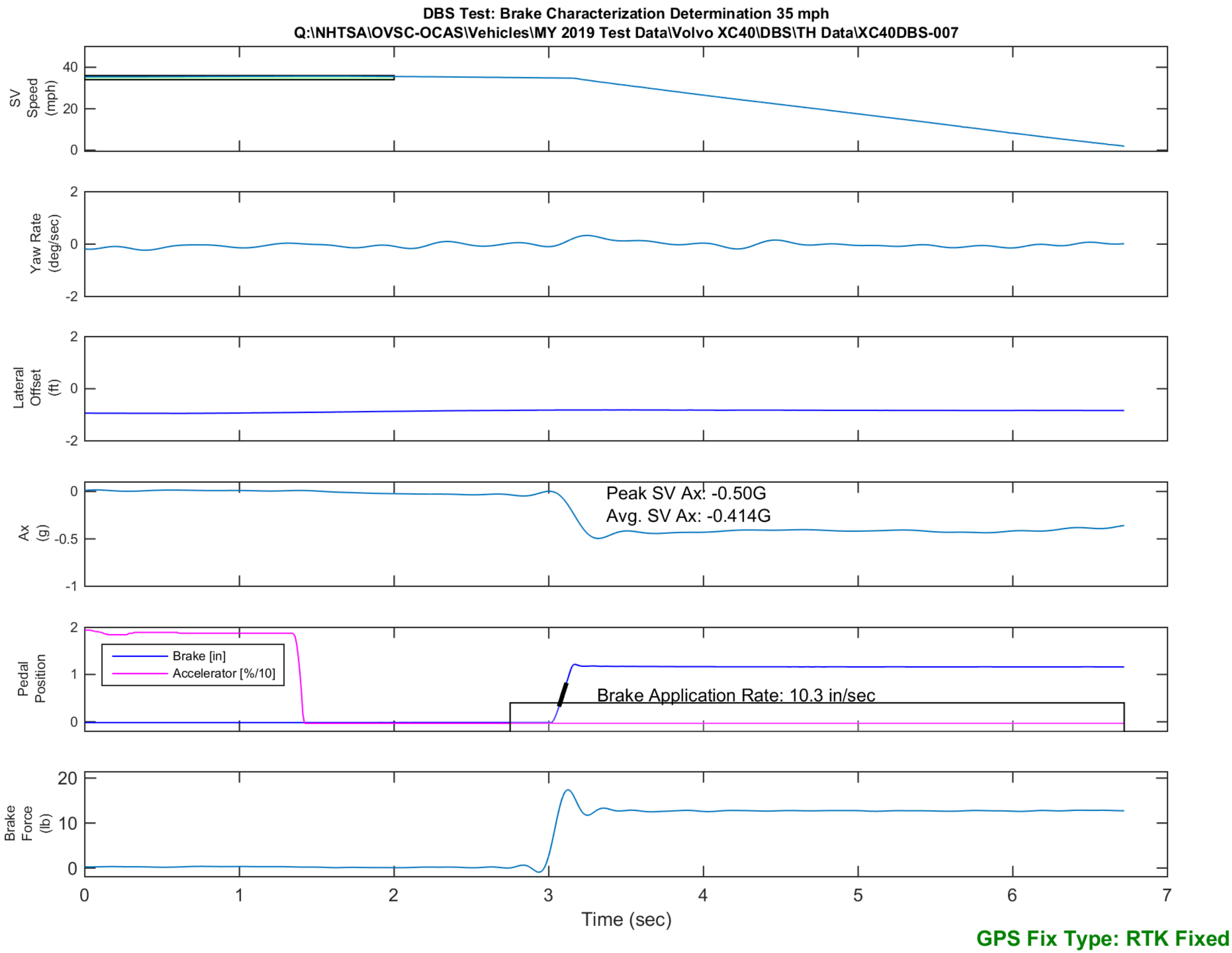


Figure E72. Time History for DBS Run 7, Brake Characterization Determination 35 mph

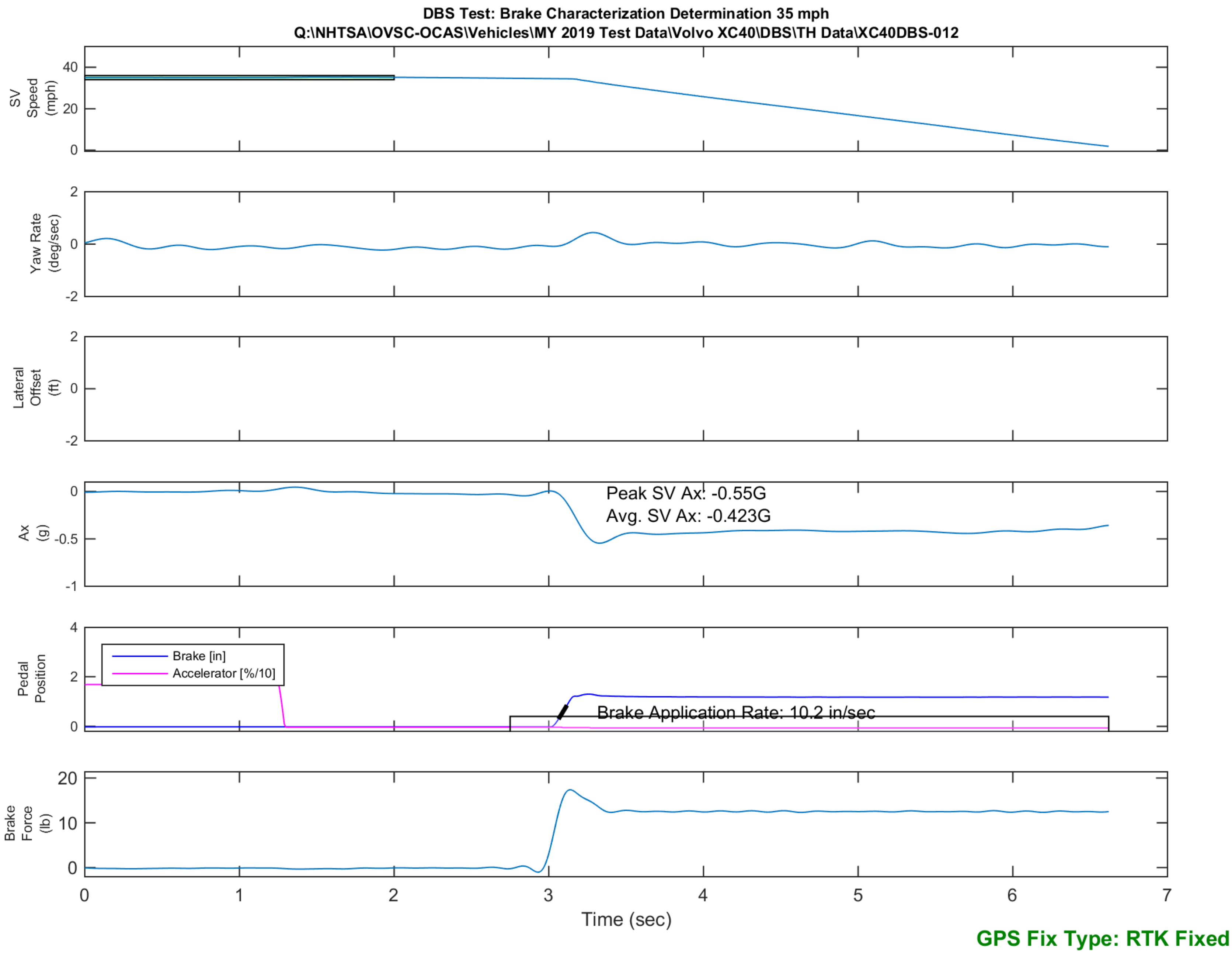


Figure E73. Time History for DBS Run 12, Brake Characterization Determination 35 mph

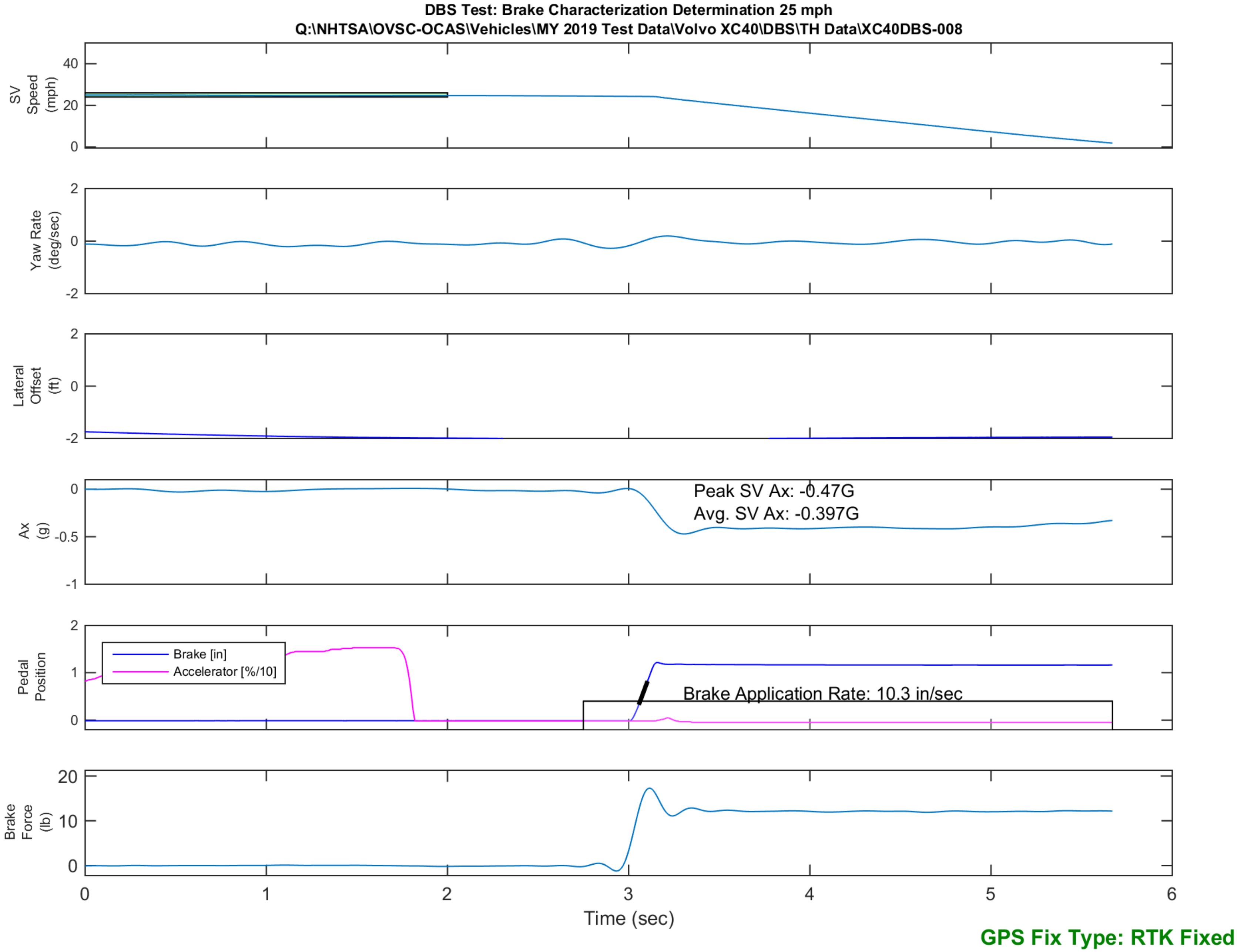


Figure E74. Time History for DBS Run 8, Brake Characterization Determination 25 mph

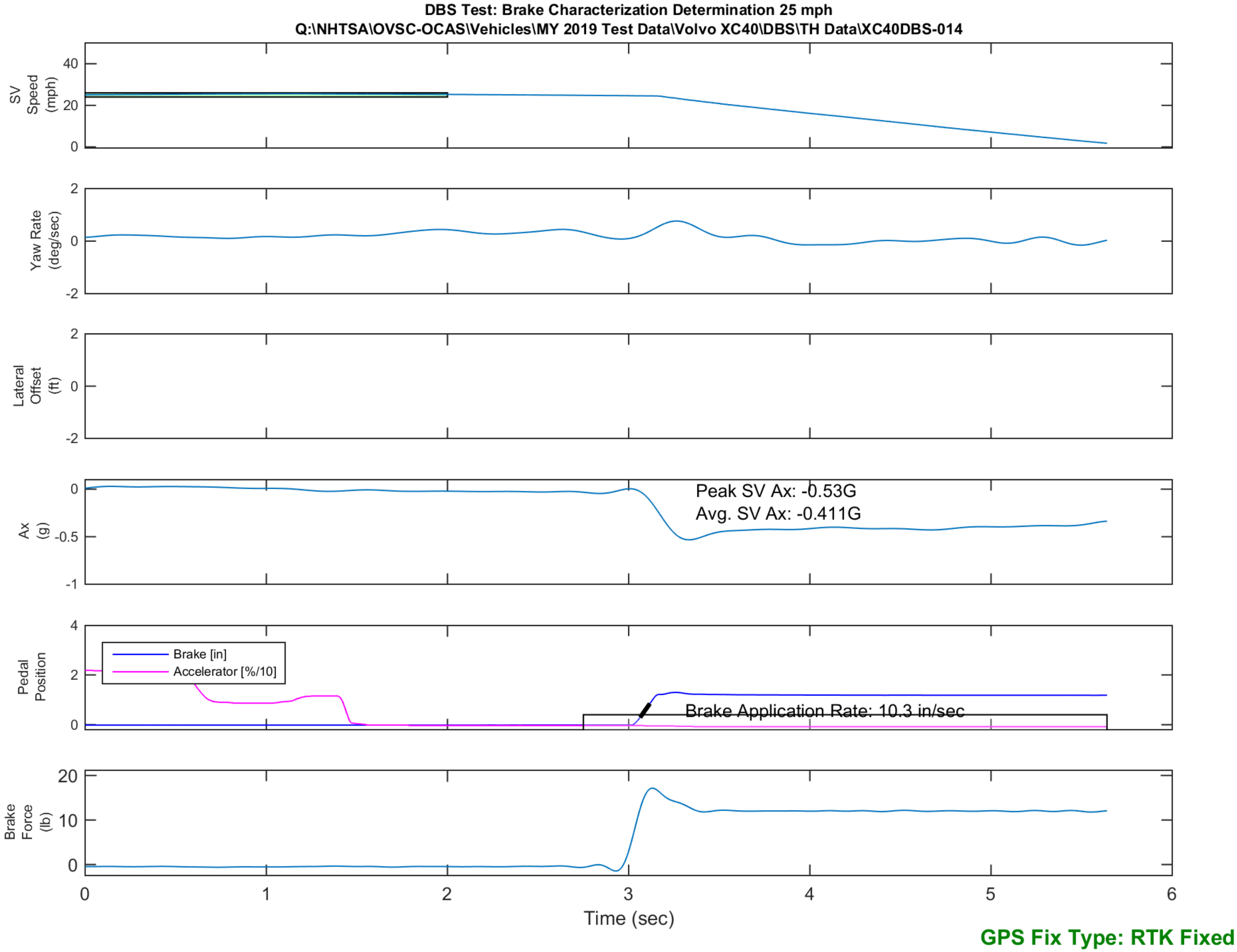


Figure E75. Time History for DBS Run 14, Brake Characterization Determination 25 mph

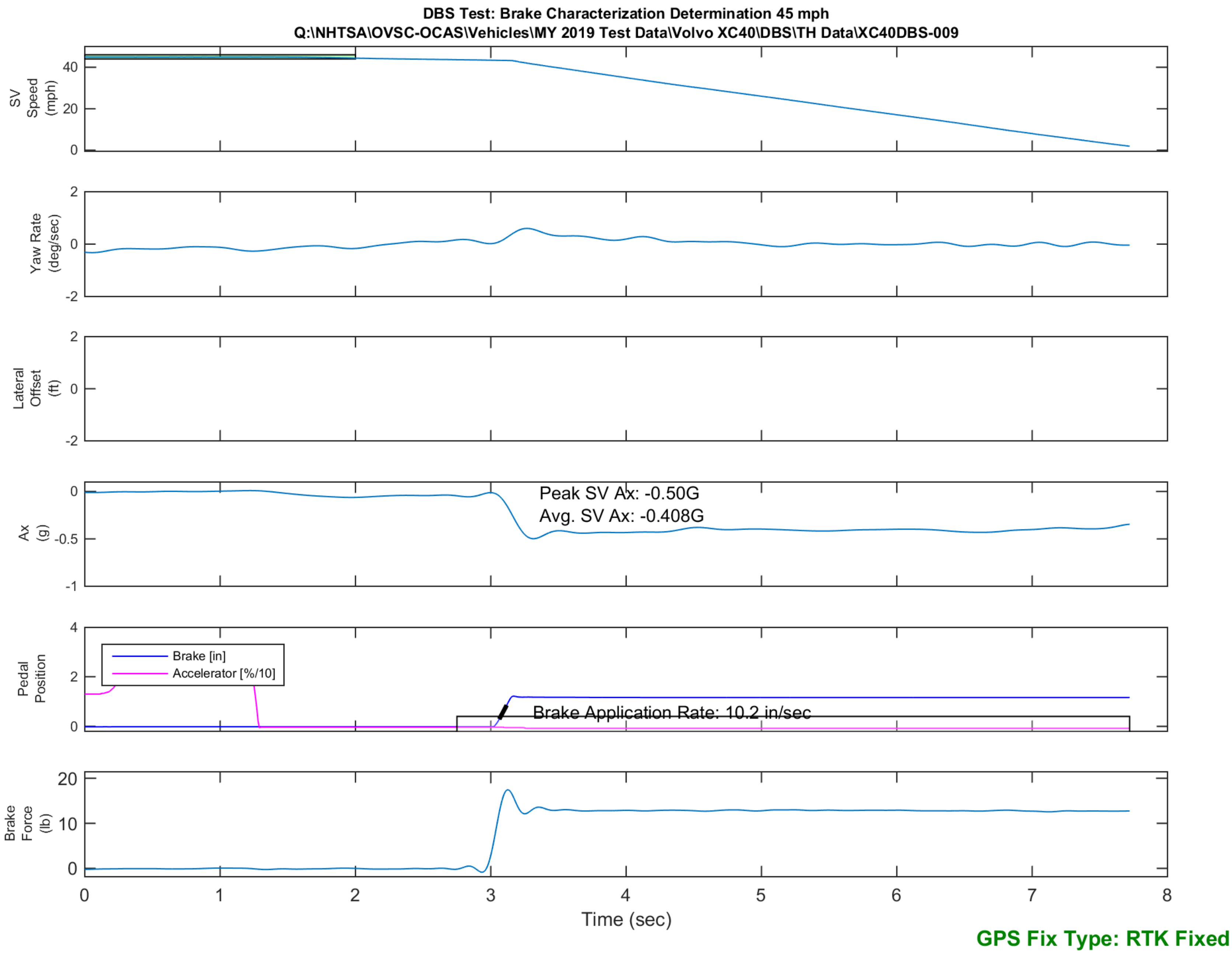


Figure E76. Time History for DBS Run 9, Brake Characterization Determination 45 mph

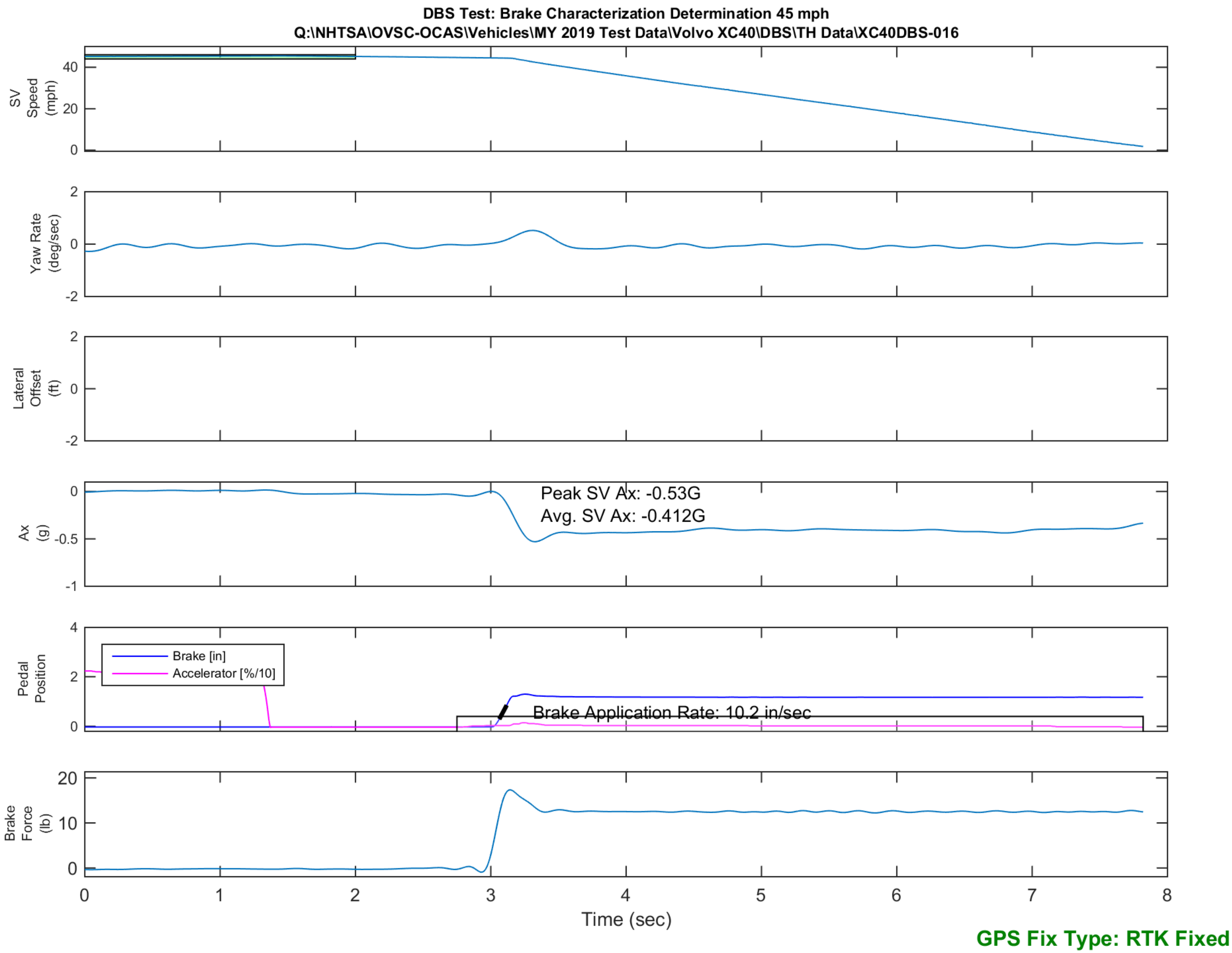


Figure E77. Time History for DBS Run 16, Brake Characterization Determination 45 mph