NEW CAR ASSESSMENT PROGRAM
DYNAMIC BRAKE SUPPORT SYSTEM CONFIRMATION RESEARCH TEST
NCAP-DRI-DBS-22-15-1

2022 Tesla Model 3 AWD

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19 April 2022

Final Report

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

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
New Car Assessment Program
1200 New Jersey Avenue, SE
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16. Abstract These tests were conducted on the subject 2022 Tesla Model 3 AWD based on the specifications of the New Car Assessment Program's (NCAP's) 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. Tests were performed with the subject vehicle's stopping mode set to "Roll" and "Creep" resulting in two sets of data. Additionally, the scenario in which the subject vehicle encounters a stopped principle other vehicle was performed twice for each stopping mode. The first was performed while vehicle's battery level was approximately 51% and the second was performed at approximately 83%. The subject vehicle failed 3 out of 5 valid runs for the stopped principle other vehicle scenario with the subject vehicle's stopping mode set to "Creep" and battery level at approximately 83%. All other scenarios passed in both "Roll" and "Creep" stopping modes.		
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TABLE OF CONTENTS

Section I

INTRODUCTION

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 (SV) 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 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 2022 Tesla Model 3 AWD with the vehicle's "Stopping Mode" setting in "Roll" and "Creep" mode and at different battery charge levels. 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 SUMMARY

2022 Tesla Model 3 AWD

VIN: *5YJ3E1EB9NF17xxxx*

Software version: *v.11.0 (2022.3.101.1 d9ebde288c88)*

Test start date: *3/23/2022* Test end date: *3/29/2022*

Dynamic Brake Support System setting: *"Medium" FCW warning timing (but does not influence AEB)*

Stopping Mode setting: *Roll*

Test 1a – Subject Vehicle Encounters Stopped Principal Other Vehicle

SV 25 mph: *Pass*

Test 1b – 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*

DYNAMIC BRAKE SUPPORT

DATA SHEET 1: TEST RESULTS SUMMARY

2022 Tesla Model 3 AWD

Notes: Test 1 (SV Encounters Stopped POV) was performed twice, with Test 1a performed with the battery charge level at approximately 51%, and Test 1b performed at approximately 83%. A total of two valid runs were performed for each scenario.

2022 Tesla Model 3 AWD

VIN: *5YJ3E1EB9NF17xxxx*

Software version: *v.11.0 (2022.3.101.1 d9ebde288c88)*

Test start date: *3/23/2022* Test end date: *3/29/2022*

Dynamic Brake Support System setting: *"Medium" FCW warning timing (but does not influence AEB)*

Stopping Mode setting: *Creep*

Test 1a – Subject Vehicle Encounters Stopped Principal Other Vehicle

SV 25 mph: *Pass*

Test 1b – Subject Vehicle Encounters Stopped Principal Other Vehicle

SV 25 mph: *Fail*

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: *Fail*

2022 Tesla Model 3 AWD

Notes: Test 1 (SV Encounters Stopped POV) was performed twice, with Test 1a performed with the battery charge level at approximately 51%, and Test 1b performed at approximately 83%. A total of five valid runs were performed for each scenario.

DYNAMIC BRAKE SUPPORT

DATA SHEET 2: VEHICLE DATA

(Page 1 of 1)

2022 Tesla Model 3 AWD

TEST VEHICLE INFORMATION

VIN: *5YJ3E1EB9NF17xxxx*

Body Style: *Sedan* Color: *Midnight Silver*

Date Received: *3/10/2022* Odometer Reading: *28 mi*

DATA FROM VEHICLE'S CERTIFICATON LABEL

Vehicle manufactured by: *TESLA, INC.*

Date of manufacture: *02/22*

Vehicle Type: *Passenger Car*

DATA FROM TIRE PLACARD

Tires size as stated on Tire Placard: Front: *235/45R18*

Rear: *235/45R18*

Recommended cold tire pressure: Front: *290 kPa (42 psi)*

Rear: *290 kPa (42 psi)*

TIRES

Tire manufacturer and model: *Michelin Primacy MXM4*

Front tire specification: *235/45R18 98W*

Rear tire specification: *235/45R18 98W*

Front tire DOT prefix: *B9EL 086X*

Rear tire DOT prefix: *B9EL 086X*

DYNAMIC BRAKE SUPPORT

DATA SHEET 3: TEST CONDITIONS

(Page 1 of 2)

2022 Tesla Model 3 AWD

GENERAL INFORMATION

Test start date: *4/23/2022* Test start date: *4/29/2022*

AMBIENT CONDITIONS

Air temperature: *27.2 C (81 F)*

Wind speed: *1.0 m/s (2.3 mph)*

X Wind speed ≤ 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: *290 kPa (42 psi)*

Rear: *290 kPa (42 psi)*

DYNAMIC BRAKE SUPPORT

DATA SHEET 3: TEST CONDITIONS

(Page 2 of 2)

2022 Tesla Model 3 AWD

WEIGHT

Weight of vehicle as tested including driver and instrumentation

Left Front:	*493.5 kg (1088 lb)*	Right Front:	*498.5 kg (1099 lb)*
Left Rear:	*497.6 kg (1097 lb)*	Right Rear:	*474.9 kg (1047 lb)*
		Total:	*1964.5 kg (4331 lb)*

DATA SHEET 4: DYNAMIC BRAKE SUPPORT SYSTEM OPERATION

(Page 1 of 4)

2022 Tesla Model 3 AWD

Name of the DBS option, option package, etc.:

Collision Avoidance Assist

Type and location of sensor(s) the system uses:

Triple camera located at the top center of the windshield.

System settings used for test (if applicable):

FCW warning timing set to "Medium". However, this does not affect the sensitivity/performance of the AEB system. (Per manufactured supplied information). Stopping mode setting set to "Roll" or "Creep".

Brake application mode used for test: *Hybrid*

Over what speed range is the system operational?

The AEB system is operational between 5-150 km/h (3-90 mph) per the owner's manual page 113 shown in Appendix B page B-3. (Per manufacturer supplied information)

Does the vehicle system require an initialization sequence/procedure? **X** Yes

___ No

If yes, please provide a full description.

The cameras perform a self-calibration process that completes after driving approximately 50 mi.

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

X No

If yes, please provide a full description.

How is the Forward Collision Warning presented to the driver?

(Check all that apply)

X Warning light

X Buzzer or auditory alarm

___ Vibration

___ 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, auditory, vibration, or combination), etc.

The AEB system alerts the driver with a visual and auditory alert. The visual alert consists of an animation of the SV behind the POV shown in real time. When the visual alert activates, the POV turns red. The auditory alert consists of repeated beeps with a primary frequency of approximately 1100 Hz.

Is there a way to deactivate the system?

X Yes

___ No

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

The FCW system can be turned on/off using the touch screen display in the center console. The procedure is as follows:

1. Select "Controls".

2. Select "Autopilot".

3. Select "Automatic Emergency Braking" to turn the AEB system on/off.

The system is automatically enabled each time the engine switch is turned on.

DYNAMIC BRAKE SUPPORT

DATA SHEET 4: DYNAMIC BRAKE SUPPORT SYSTEM OPERATION

2022 Tesla Model 3 AWD

Is the vehicle equipped with a control whose purpose is to adjust the range setting or otherwise influence the operation of DBS?	____	Yes
	X	No

If yes, please provide a full description.

The range setting of the FCW system can be adjusted using the touch screen display in the center console. However, as stated above, this does not affect the sensitivity/performance of the AEB system. The procedure is as follows:

1. Select "Controls".

2. Select "Autopilot".

3. Select between "Late", "Medium", "Early".

The range setting is retained when the engine switch is turned off.

The AEB system sensitivity/performance cannot be adjusted per manufacturer supplied information. However, the stopping mode setting selected was shown to influence AEB performance due to the setting's effect on regenerative braking. The procedure for adjusting the stopping mode setting is as follows:

1. Select "Pedals & Steering".

2. Under “Stopping Mode” select between "Creep", "Roll", or "Hold".

2022 Tesla Model 3 AWD

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.

The AEB system cannot always detect all objects, vehicles, bicycles, or pedestrians and may miss warnings or exhibit unnecessary, inaccurate, or invalid warnings. Possible reasons for this are listed in the examples below:

1. The road has sharp curves.

2. Visibility is poor (due to heavy rain, snow, fog, etc.).

3. Bright light (such as from oncoming headlights or direct sunlight) is interfering with the view of the camera(s).

4. The camera sensor is obstructed (dirty, covered, fogged over, covered by a sticker, etc.).

5. Weather conditions (heavy rain, snow, fog, or extremely hot or cold temperatures) are interfering with its operation.

Refer to the owner's manual page 114 shown in Appendix B page B-4 for additional information.

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.

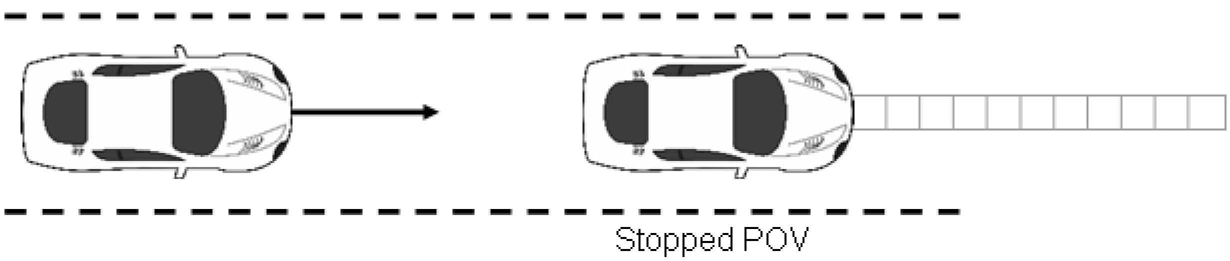


Figure 1. Depiction of Test 1

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 km/h) 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 or SV brake application if no FCW alert was given. 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 lateral distance between the centerline of the SV to the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The yaw rate of the SV could not deviate more than ±1 deg/sec during the validity period.
- The SV speed could not deviate from the nominal speed by more than ±1.0 mph (±1.6 km/h) during an interval defined by a Time to Collision (TTC) = 5.1 seconds to t_{FCW} or impact if no FCW alert was given.

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 km/h)	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-to-POV impact for at least five of the seven valid test trials.

2. <u>TEST 2 – SUBJECT VEHICLE ENCOUNTERS SLOWER PRINCIPAL OTHER VEHICLE</u>

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.

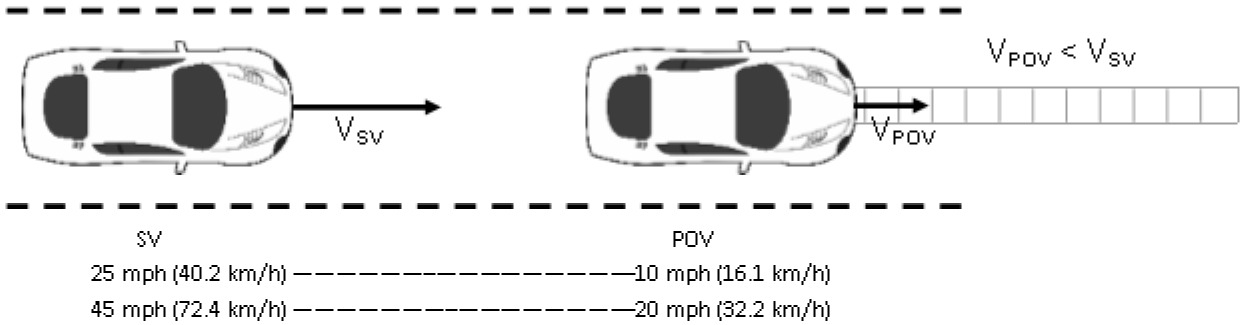


Figure 2. Depiction of Test 2

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 km/h) in the center of the lane of travel while the SV was driven at 25.0 mph (40.2 km/h), 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 km/h) in the center of the lane of travel while the SV was driven at 45.0 mph (72.4 km/h), 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 or SV brake application if no FCW alert was given. 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 SV and POV to the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The yaw rate of the SV and POV could not deviate more than ±1 deg/sec during the validity period.
- The SV speed could not deviate more than ±1.0 mph (±1.6 km/h) during an interval defined by TTC = 5.0 seconds to t_{FCW} or impact if no FCW alert was given.
- The POV speed could not deviate more than ±1.0 mph (±1.6 km/h) 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 km/h)	10 mph (16 km/h)	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 km/h)	20 mph (32 km/h)	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-to-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.

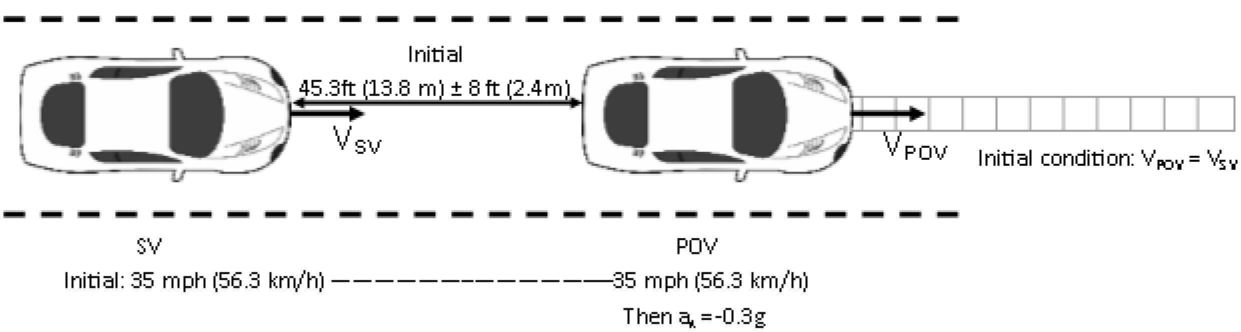


Figure 3. Depiction of Test 3

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 km/h) in the center of the lane, with headway of 45.3 ft (13.8 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 of deceleration within 1.5 ± 0.1 sec. The SV throttle pedal was released within 500 ms of t_{FCW} or SV brake application if no FCW alert was given. 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 SV and POV to the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The yaw rate of the SV and POV could not deviate more than ±1 deg/sec during the validity period.
- The SV speed could not deviate more than ±1.0 mph (1.6 km/h) during an interval defined by 3.0 seconds before the onset of POV braking to t_{FCW} or impact if no FCW alert was given.
- The POV speed could not deviate more than ±1.0 mph (1.6 km/h) during an interval of 3.0 seconds before the onset of POV braking.
- The SV- POV headway distance could not deviate more than ±8 ft (2.4 m) 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 km/h)	35 mph (56 km/h)	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-to-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 km/h) and 45 mph (72.4 km/h). 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 1.5 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 auditory, and the onset of the alert is determined by post-processing the test data.

For systems that implement auditory or haptic alerts, part of the pre-test instrumentation verification process is to determine the tonal frequency of the auditory 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 auditory or tactile warning data so that the beginning of such warnings can be programmatically determined. The band-pass 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. Auditory and Tactile Warning Filter Parameters

Warning Type	Filter Order	Peak-to-Peak Ripple	Minimum Stop Band Attenuation	Passband Frequency Range
Auditory	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.

Test 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, and immediately after 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."

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 offset was adjusted to output zero, another pre-test static calibration data file was collected, and the test series was repeated.

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 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.

The key requirements of the POV element 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.

The key requirements of the POV delivery system are to:

- Accurately control the nominal POV speed up to 35 mph (56 km/h).
- 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.

Operationally, the POV shell is attached to the slider and load frame, which includes rollers that allow 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 SV-to-POV 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 forward in a two-stage manner along the rail and 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 100 psi	Omega DPG8001	17042707002	By: DRI Date: 10/5/2021 Due: 10/5/2022
Platform Scales	Vehicle Total, Wheel, and Axle Load	2200 lb/platform	0.1% of reading	Intercomp SW wireless	0410MN20001	By: DRI Date: 2/11/2022 Due: 2/11/2023
Linear (string) encoder	Throttle pedal travel	10 in	0.1 in	UniMeasure LX-EP	50060727	By: DRI Date: 4/15/2021 Due: 4/15/2022
Load Cell	Force applied to brake pedal					By: DRI
		0-250 lb	0.05% FS	Stellar Technology PNC700	2002506	Date: 2/25/2022 Due: 2/25/2023
		0-250 lb 1112 N	0.05% FS	Stellar Technology PNC700	1607338	Date: 3/30/2022 Due: 3/30/2023
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 km/h	Trimble GPS Receiver, 5700 (base station and in-vehicle)	00440100989	N/A

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 Rate ±100 deg/s, Angle >45 deg, Velocity >200 km/h	Accels .01g, Angular Rate 0.05 deg/s, Angle 0.05 deg, Velocity 0.1 km/h	Oxford Inertial +		By: Oxford Technical Solutions
					2176	Date: 6/26/2020 Due: 6/26/2022
					2258	Date: 4/28/2021 Due: 4/28/2023
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	N/A
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	N/A	N/A
Light Sensor	Light intensity (to measure time at alert)	Spectral Bandwidth: 440-800 nm	Rise time < 10 msec	DRI designed and developed Light Sensor	N/A	N/A
Accelerometer	Acceleration (to measure time at alert)	±5g	≤ 3% of full range	Silicon Designs, 2210-005	N/A	N/A

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: 1/6/2022 Due: 1/6/2023

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).	dSPACE 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

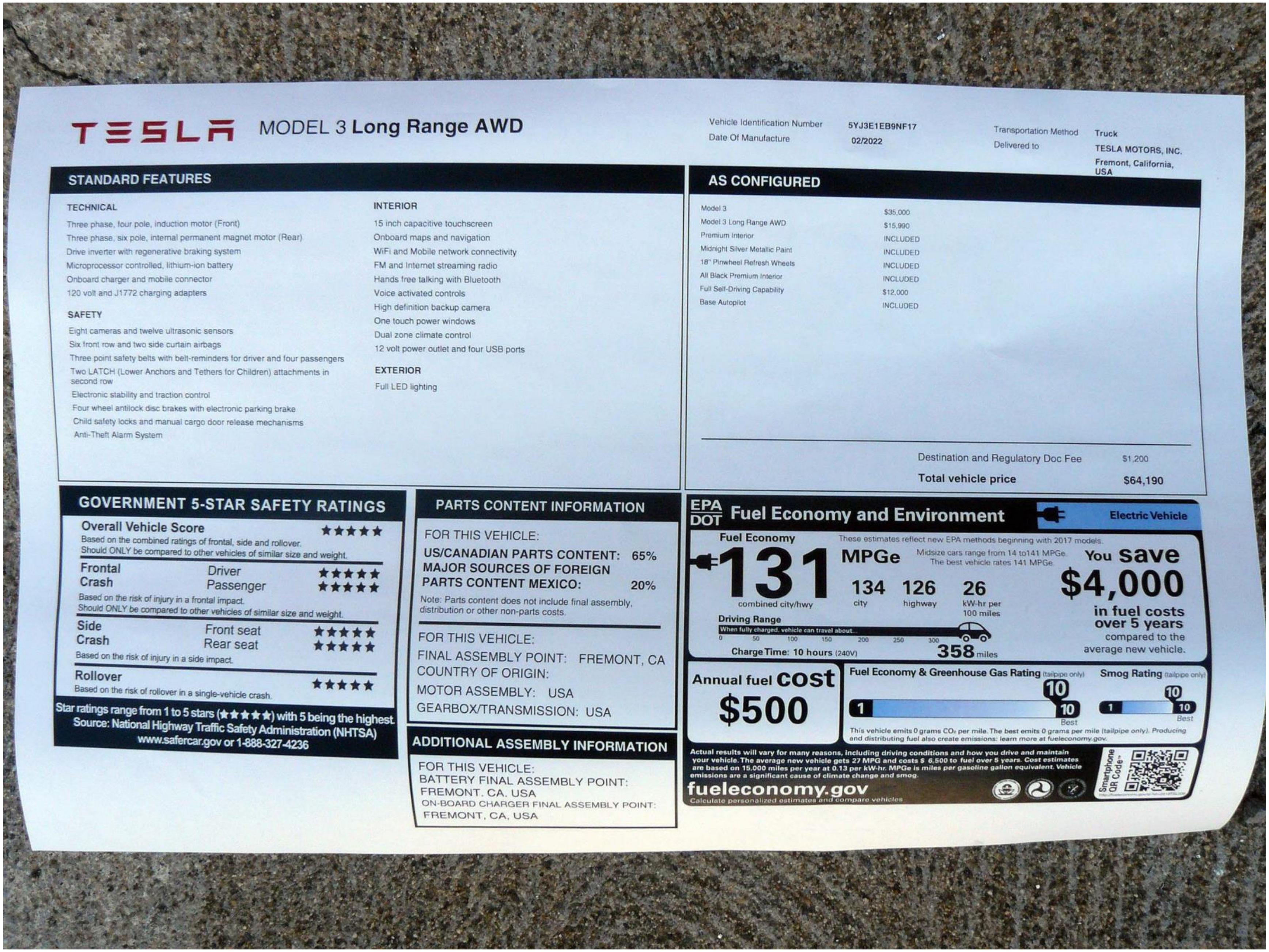


Figure A3. Window Sticker (Monroney Label)

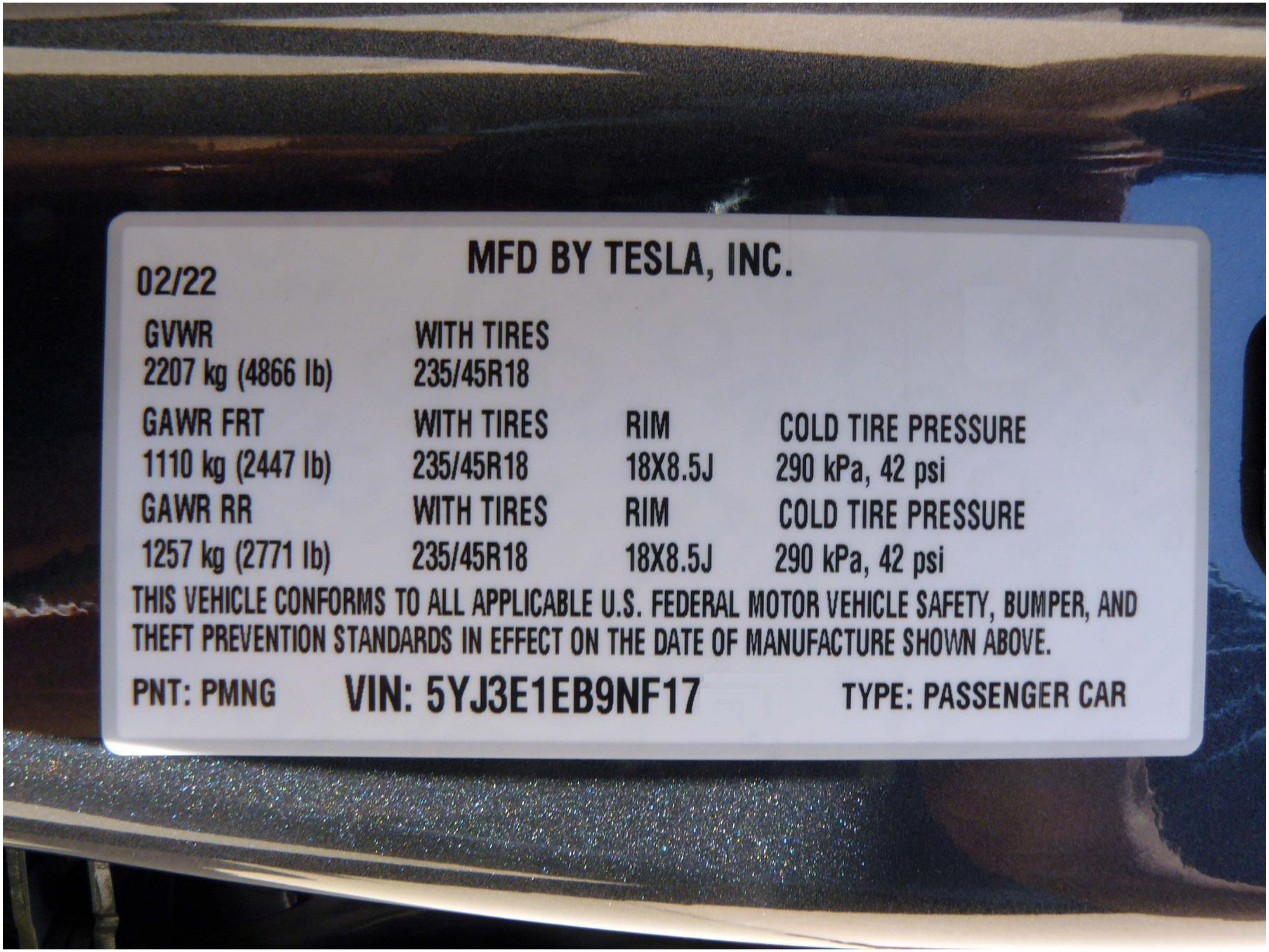


Figure A4. Vehicle Certification Label

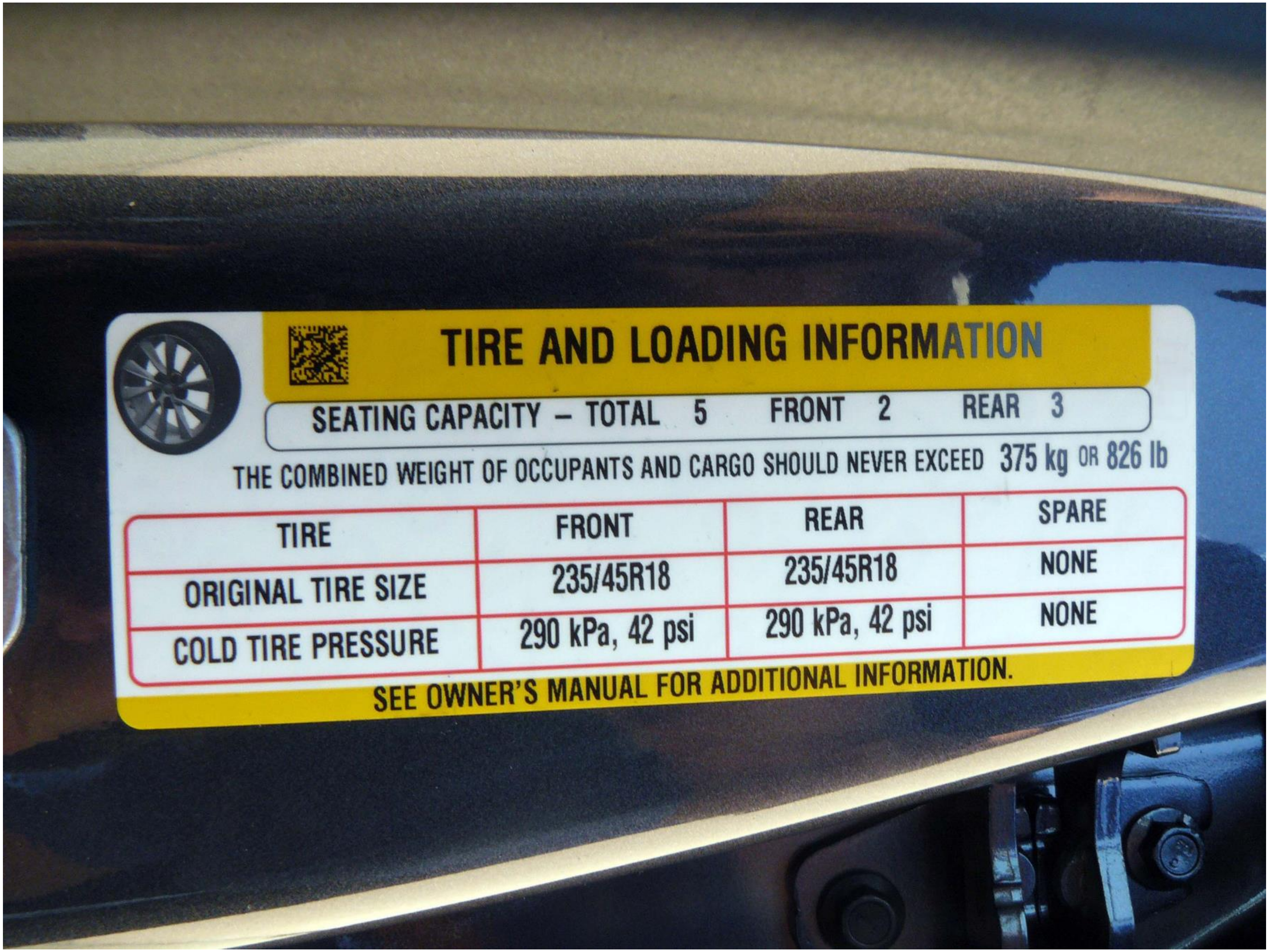


Figure A5. Tire Placard

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

Figure A7. Load Frame/Slider of SSV

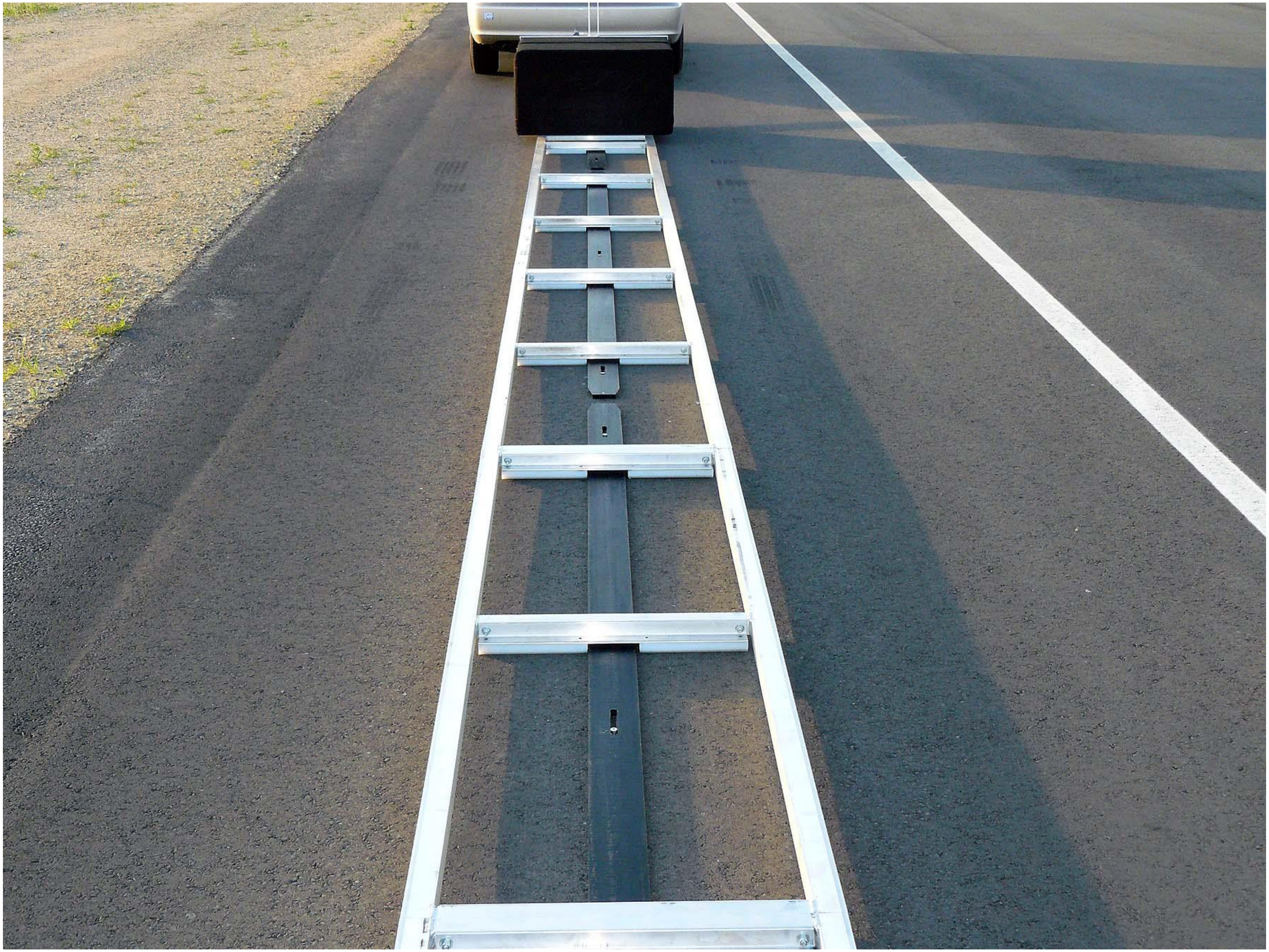


Figure A8. Two-Rail Track and Road-Based Lateral Restraint Track

Figure A9. Steel Trench Plate

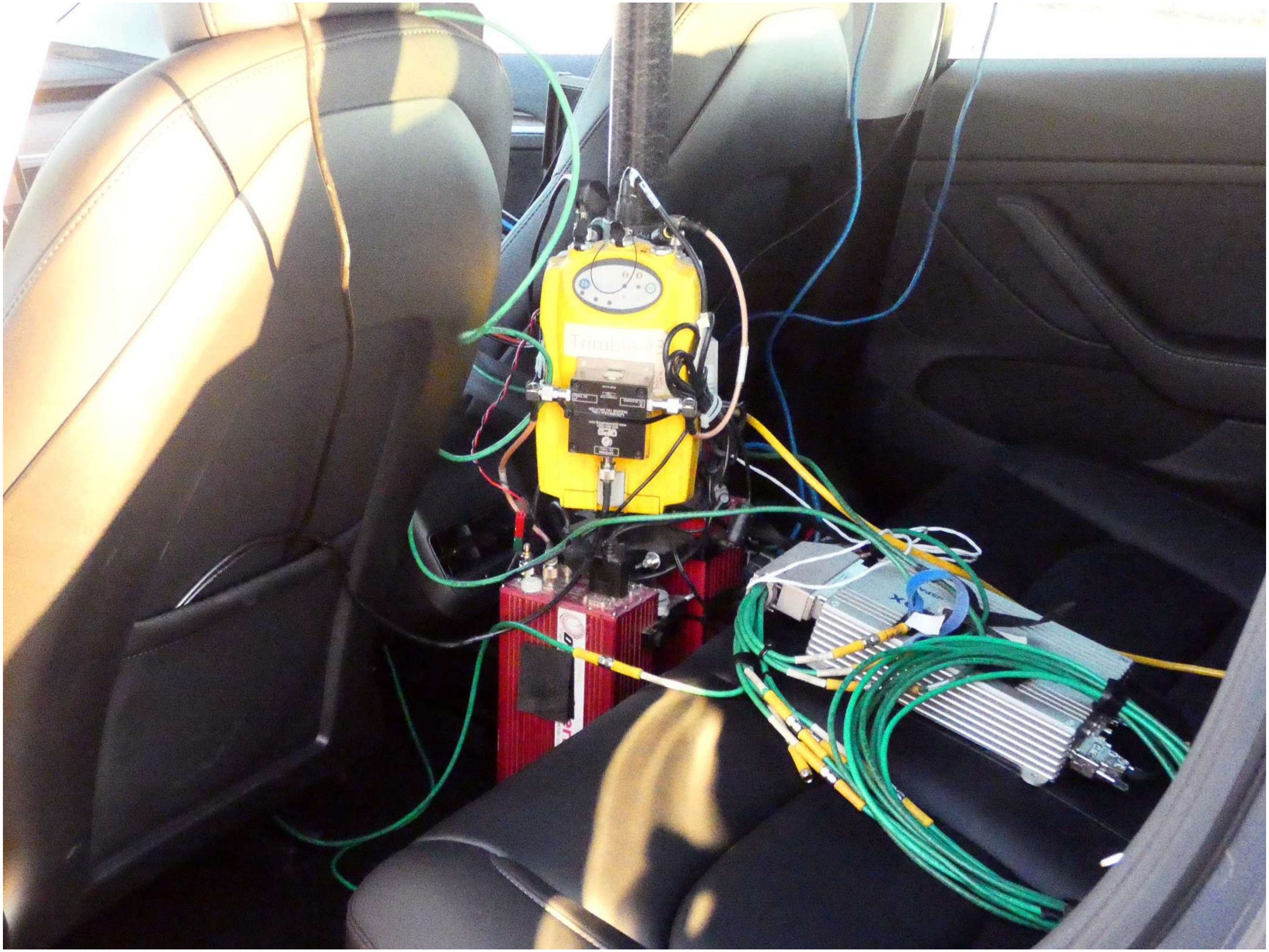


Figure A10. DGPS, Inertial Measurement Unit, and MicroAutoBox Installed in Subject Vehicle

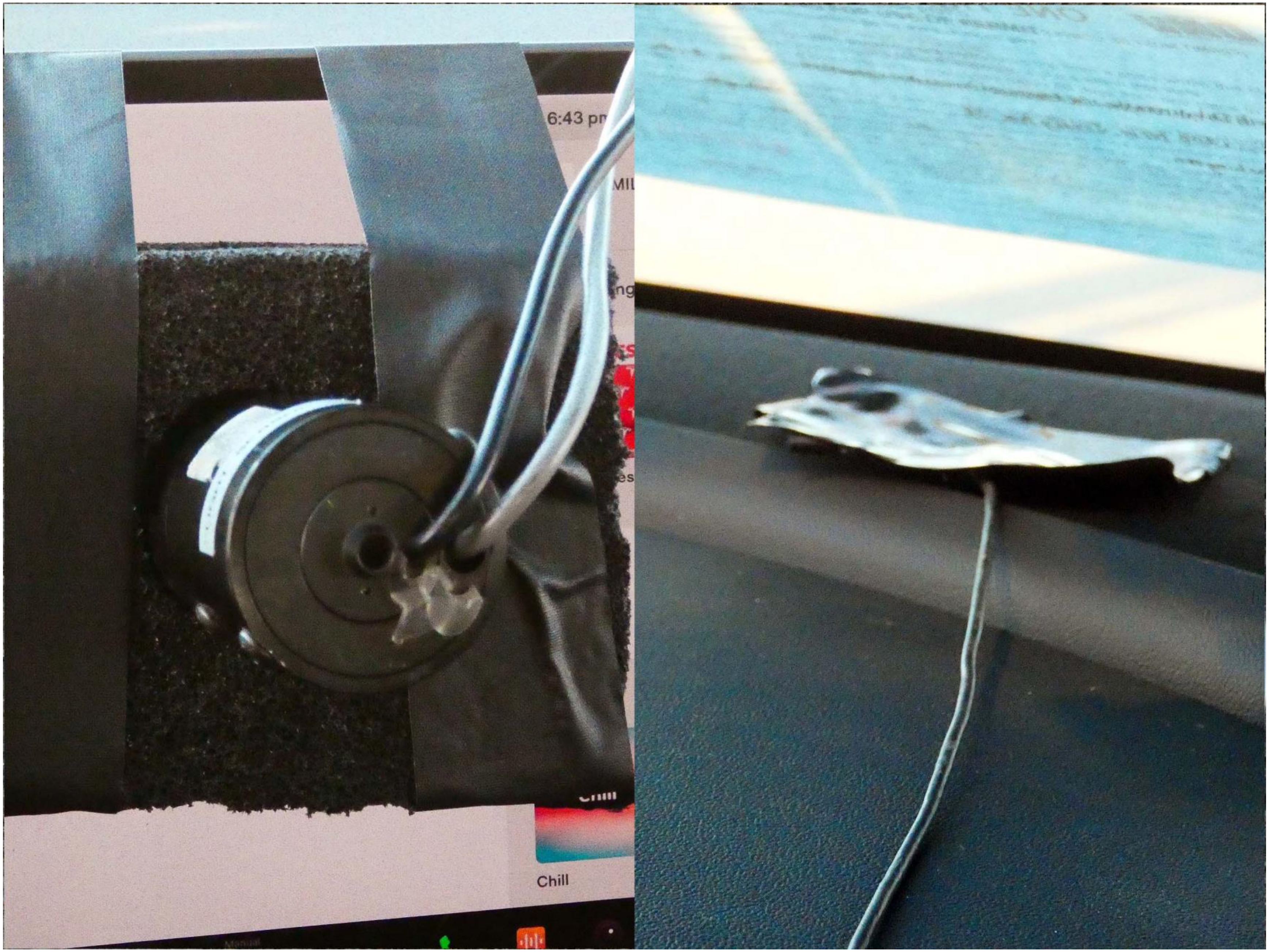


Figure A11. Sensors for Detecting Auditory and Visual Alerts

Figure A12. Computer Installed in Subject Vehicle

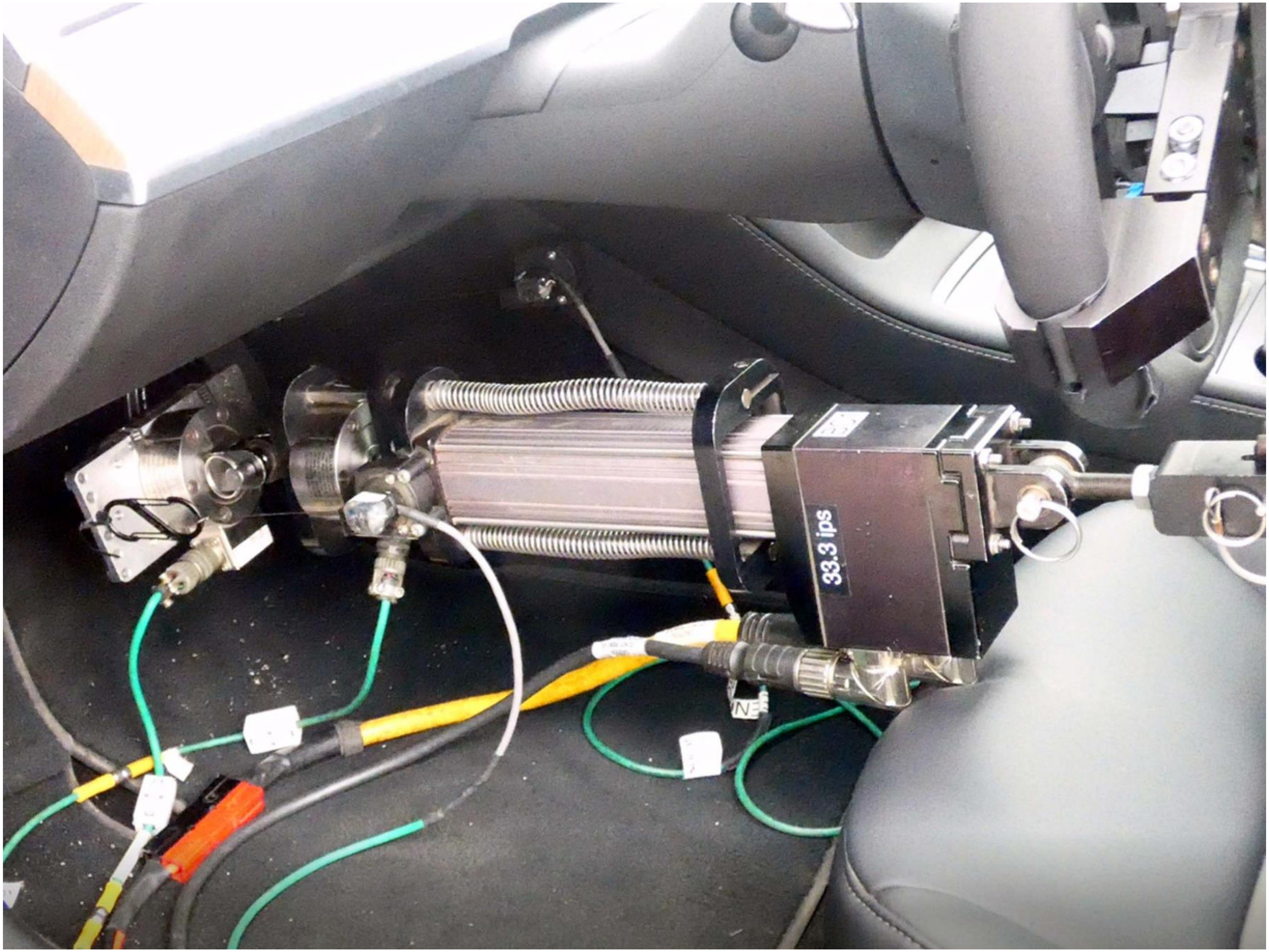


Figure A13. Brake Actuator Installed in Subject Vehicle

Figure A14. Brake Actuator Installed in POV System

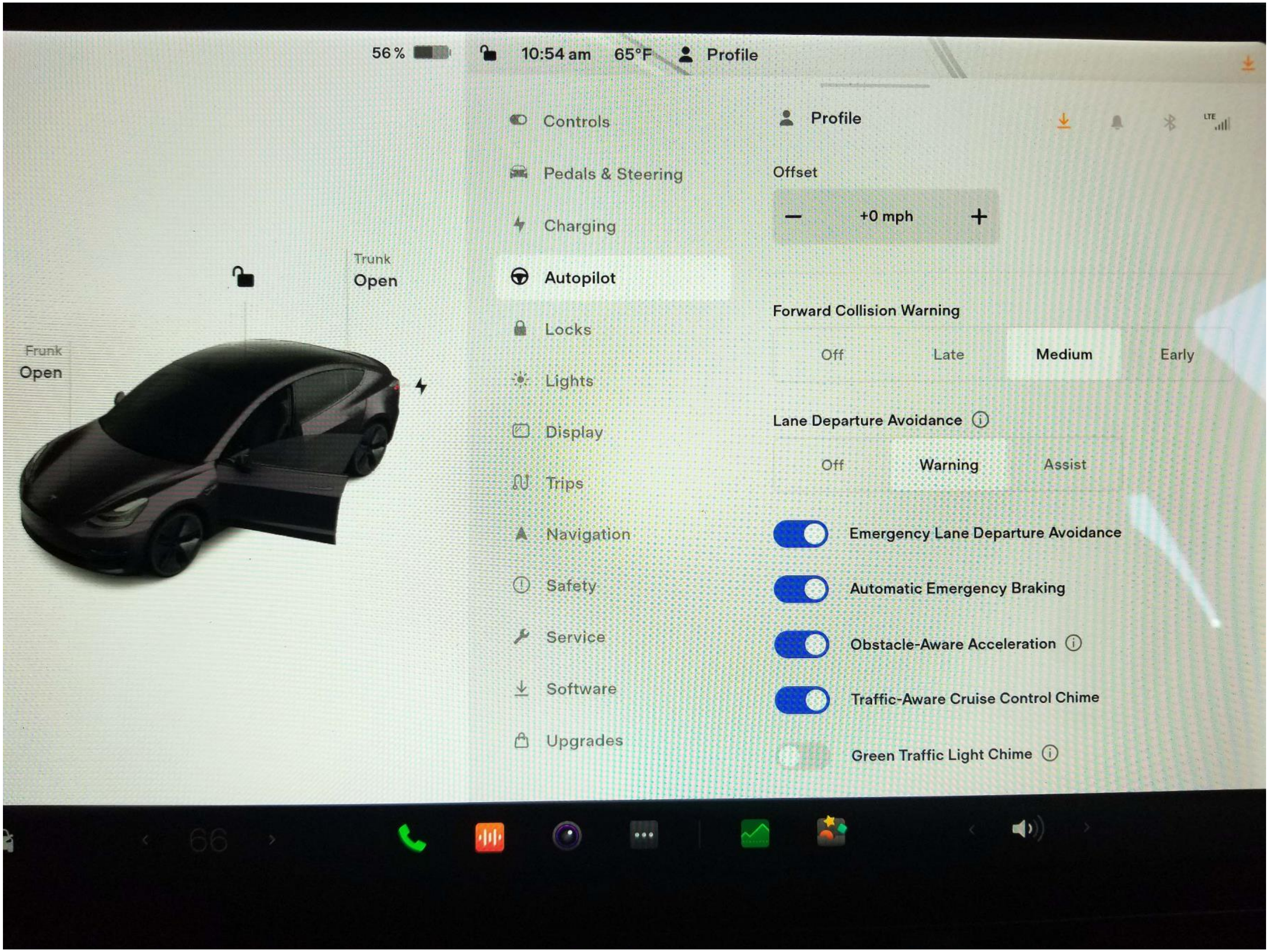


Figure A15. AEB System and Forward Collision Warning Setup Menu

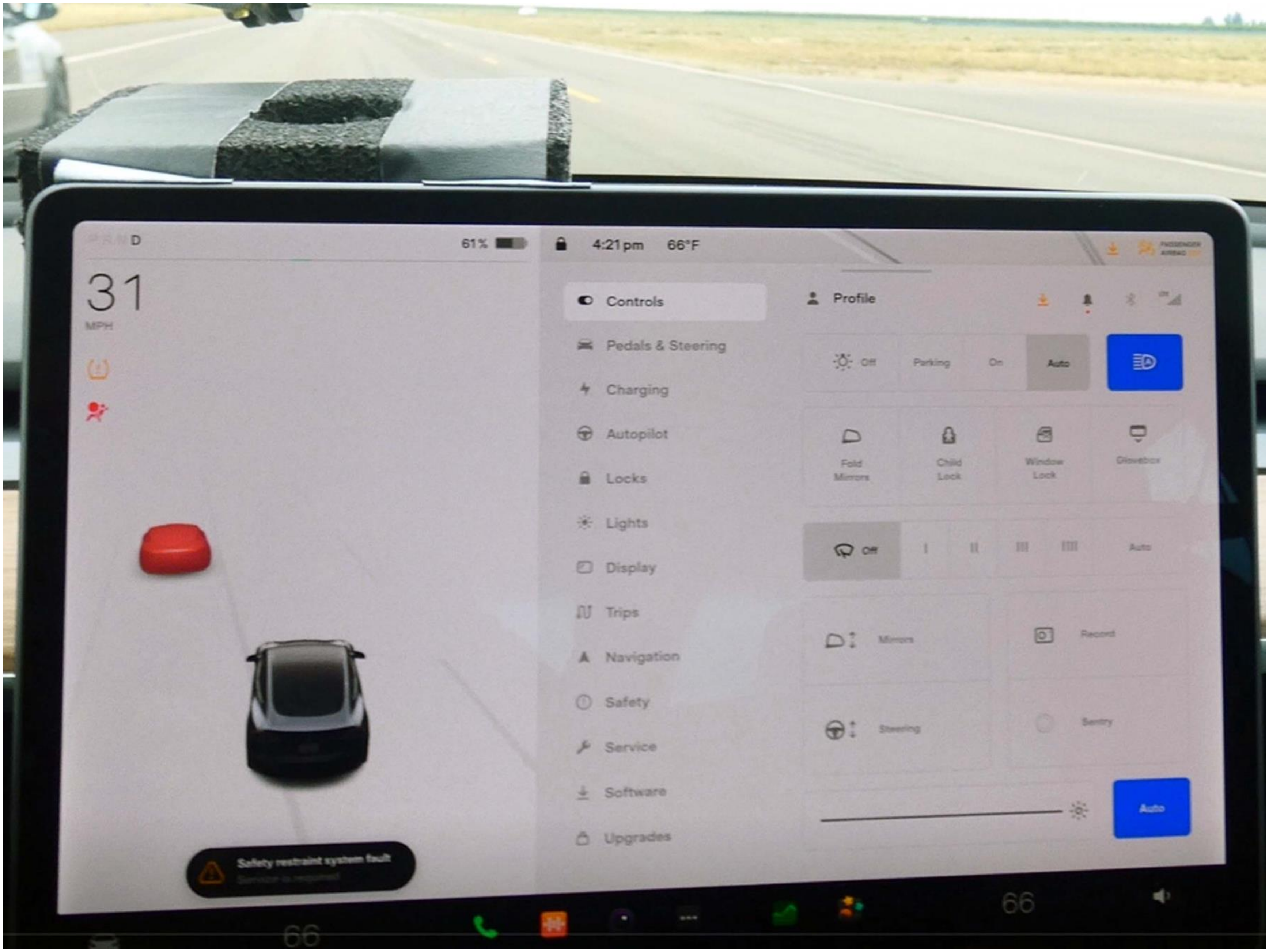


Figure A16. Visual Alert

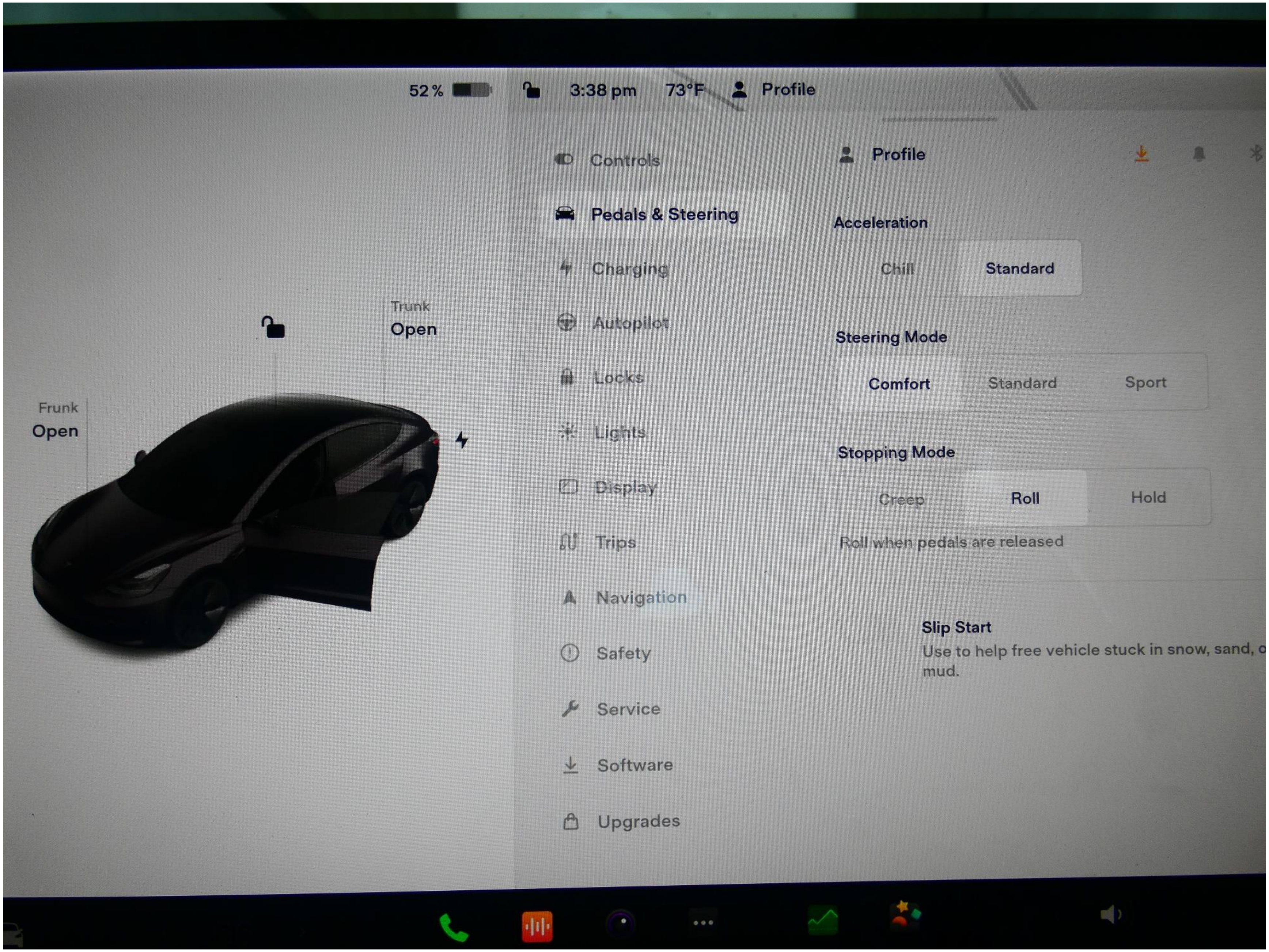


Figure A17. Stopping Mode Setting Menu - Roll

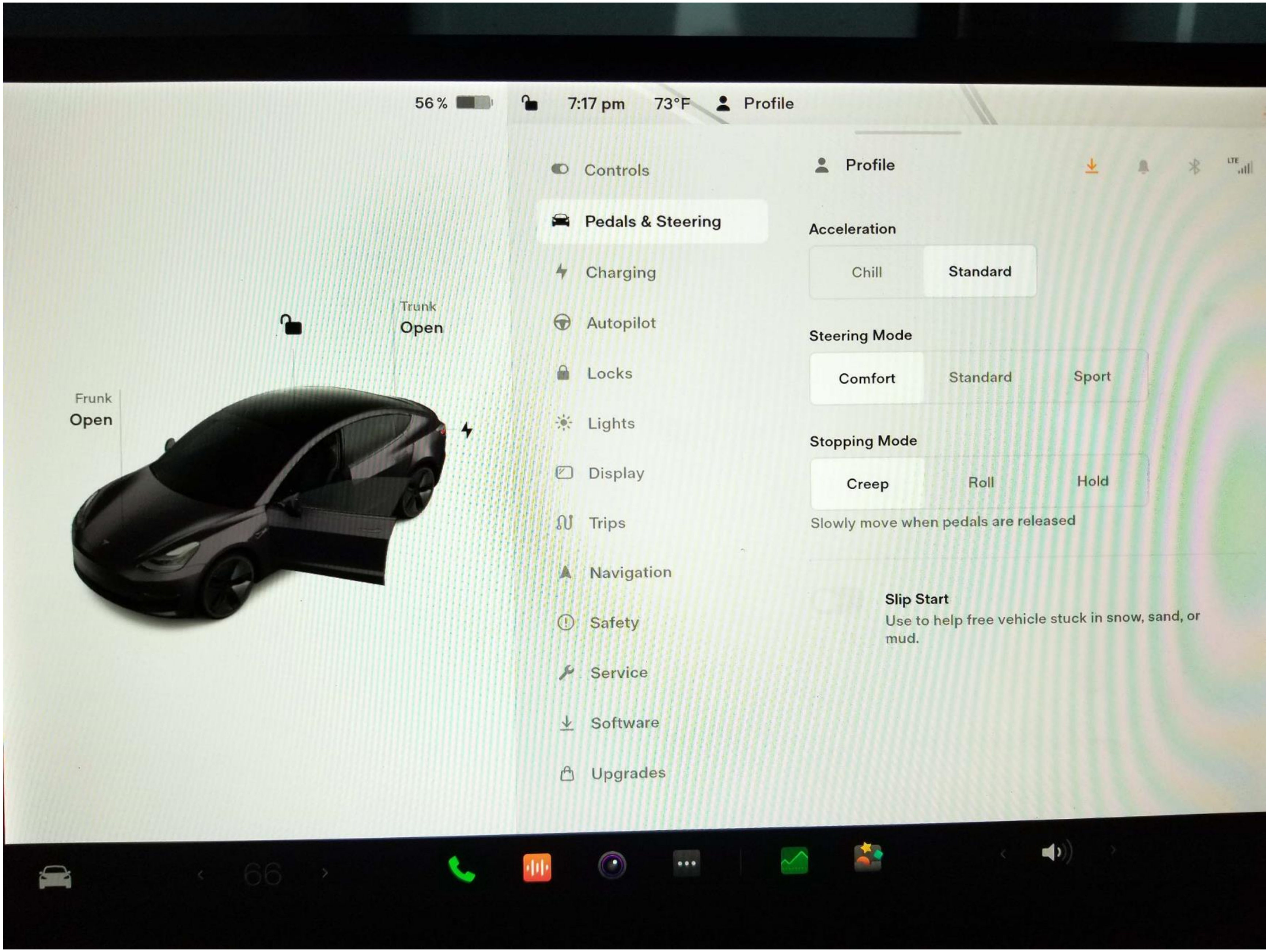


Figure A18. Stopping Mode Setting Menu - Creep

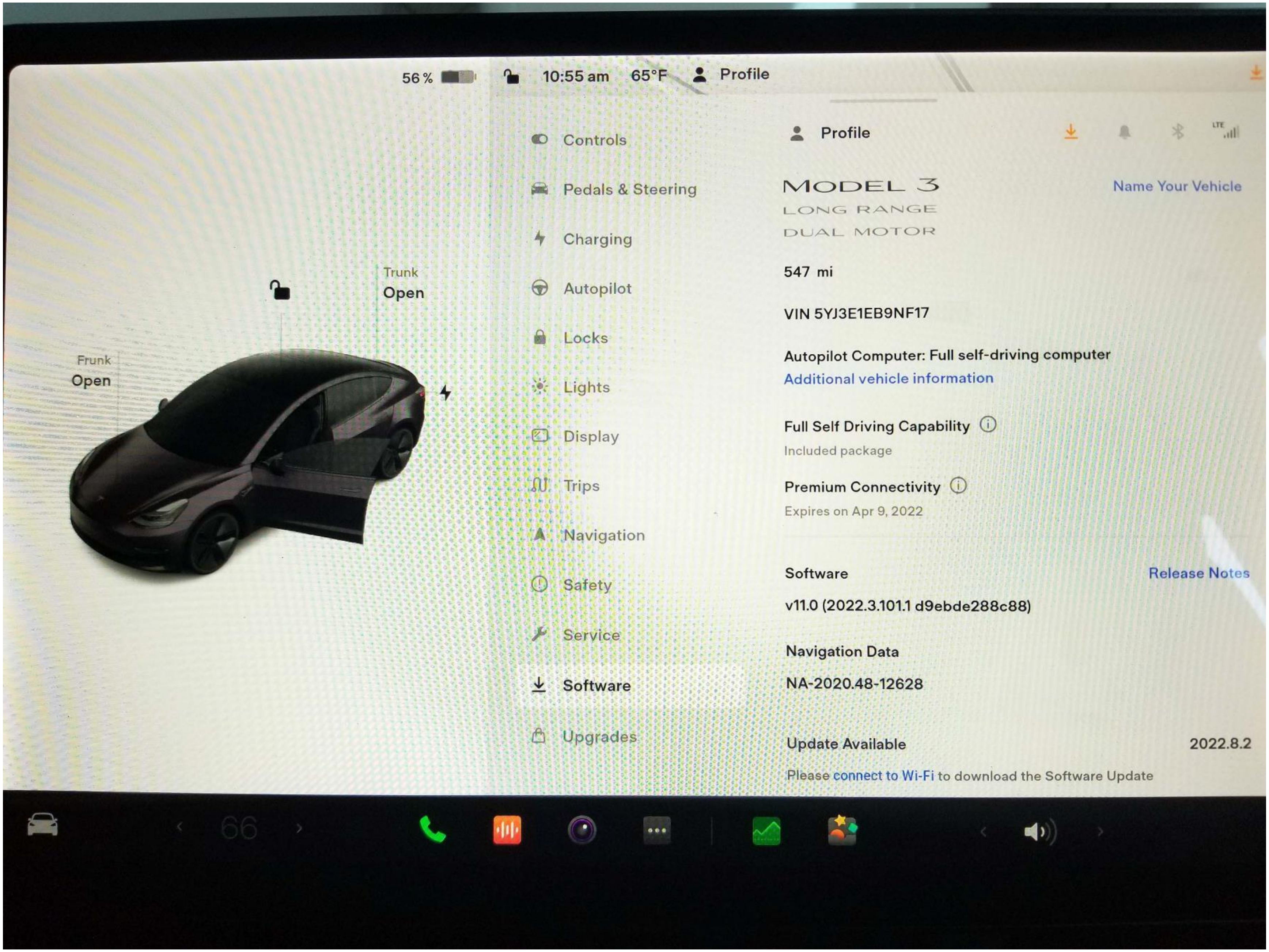


Figure A19. Software Version

APPENDIX B

Excerpts from Owner's Manual

Collision Avoidance Assist

The following collision avoidance features are designed to increase the safety of you and your passengers:

- **Forward Collision Warning** - provides visual and audible warnings in situations when Model 3 detects that there is a high risk of a frontal collision (see Forward Collision Warning on page 112).
- **Automatic Emergency Braking** - automatically applies braking to reduce the impact of a frontal collision (see Automatic Emergency Braking on page 113).
- **Obstacle-Aware Acceleration** - reduces acceleration if Model 3 detects an object in its immediate driving path (see Obstacle-Aware Acceleration on page 113).

CAUTION: Ensure all cameras and sensors are clean. Dirty cameras and sensors, as well as environmental conditions such as rain and faded lane markings, can affect performance.

WARNING: Forward Collision Warning is for guidance purposes only and is not a substitute for attentive driving and sound judgment. Keep your eyes on the road when driving and never depend on Forward Collision Warning to warn you of a potential collision. Several factors can reduce or impair performance, causing either unnecessary, invalid, inaccurate, or missed warnings. Depending on Forward Collision Warning to warn you of a potential collision can result in serious injury or death.

WARNING: Automatic Emergency Braking is not designed to prevent all collisions. In certain situations, it can minimize the impact of a frontal collision by attempting to reduce your driving speed. Depending on Automatic Emergency Braking to avoid a collision can result in serious injury or death.

WARNING: Obstacle-Aware Acceleration is not designed to prevent a collision. In certain situations, it can minimize the impact of a collision. Depending on Obstacle-Aware Acceleration to avoid a collision can result in serious injury or death.

Forward Collision Warning

Model 3 monitors the area in front of it for the presence of an object such as a vehicle, motorcycle, bicycle, or pedestrian. If a collision is considered likely unless you take immediate corrective action, Forward Collision Warning is designed to sound a chime and highlight the vehicle in front of you in red on the touchscreen. If this happens, **TAKE IMMEDIATE CORRECTIVE ACTION!**

Warnings cancel automatically when the risk of a collision has been reduced (for example, you have decelerated or stopped Model 3, or the object in front of your vehicle has moved out of your driving path).

If immediate action is not taken when Model 3 issues a Forward Collision Warning, Automatic Emergency Braking (if enabled) may automatically apply the brakes if a collision is considered imminent (see Automatic Emergency Braking on page 113).

By default, Forward Collision Warning is turned on. To turn it off or adjust its sensitivity, touch **Controls** > **Autopilot** > **Forward Collision Warning**. Instead of the default warning level of **Medium**, you can turn the warning **Off**, or you can choose to be warned **Late** or **Early**.

NOTE: Your chosen setting for Forward Collision Warning is retained until you manually change it.

WARNING: The camera(s) and sensors associated with Forward Collision Warning are designed to monitor an approximate area of up to 525 feet (160 meters) in your driving path. The area being monitored by Forward Collision Warning can be adversely affected by road and weather conditions. Use appropriate caution when driving.

WARNING: Forward Collision Warning is designed only to provide visual and audible alerts. It does not attempt to apply the brakes or decelerate Model 3. When seeing and/or hearing a warning, it is the driver's responsibility to take immediate corrective action.

WARNING: Forward Collision Warning may provide a warning in situations where the likelihood of collision may not exist. Stay alert and always pay attention to the area in front of Model 3 so you can anticipate whether any action is required.

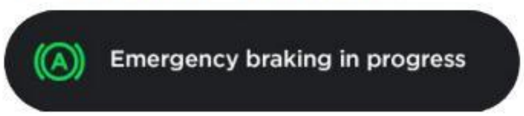
Forward Collision Warning operates only when driving between approximately 3 mph (5 km/h) and 90 mph (150 km/h).

WARNING: Forward Collision Warning does not provide a warning when the driver is already applying the brake.

Automatic Emergency Braking

Model 3 is designed to determine the distance from a detected object traveling in front of it. When a frontal collision is considered unavoidable, Automatic Emergency Braking is designed to apply the brakes to reduce the vehicle's speed and therefore, the severity of the impact. The amount of speed that is reduced depends on many factors, including driving speed and environment.

When Automatic Emergency Braking applies the brakes, the touchscreen displays a visual warning and sounds a chime. You may also notice abrupt downward movement of the brake pedal. The brake lights turn on to alert other road users that you are slowing down.



Automatic Emergency Braking operates only when driving between approximately 3 mph (5 km/h) and 90 mph (150 km/h).

Automatic Emergency Braking does not apply the brakes, or stops applying the brakes, when:

- You turn the steering wheel sharply.
- You press and release the brake pedal while Automatic Emergency Braking is applying the brakes.
- You accelerate hard while Automatic Emergency Braking is applying the brakes.
- The vehicle, motorcycle, bicycle, or pedestrian is no longer detected ahead.

Automatic Emergency Braking is always enabled when you start Model 3. To disable it for your current drive, touch **Controls** > **Autopilot** > **Automatic Emergency Braking**.

WARNING: It is strongly recommended that you do not disable Automatic Emergency Braking. If you disable it, Model 3 does not automatically apply the brakes in situations where a collision is considered likely.

WARNING: Automatic Emergency Braking is designed to reduce the severity of an impact. It is not designed to avoid a collision.

WARNING: Several factors can affect the performance of Automatic Emergency Braking, causing either no braking or inappropriate or untimely braking, such as when a vehicle is partially in the path of travel or there is road debris. It is the driver's responsibility to drive safely and remain in control of the vehicle at all times. Never depend on Automatic Emergency Braking to avoid or reduce the impact of a collision.

WARNING: Automatic Emergency Braking is designed to reduce the impact of frontal collisions only and does not function when Model 3 is in Reverse.

WARNING: Automatic Emergency Braking is not a substitute for maintaining a safe traveling distance between you and the vehicle in front of you.

WARNING: The brake pedal moves downward abruptly during automatic braking events. Always ensure that the brake pedal can move freely. Do not place material under or on top of the driver's floor mat (including an additional mat) and always ensure that the driver's floor mat is properly secured. Failure to do so can impede the ability of the brake pedal to move freely.

Obstacle-Aware Acceleration

Obstacle-Aware Acceleration is designed to reduce the impact of a collision by reducing motor torque and in some cases applying the brakes, if Model 3 detects an object in its driving path. The touchscreen displays a visual warning and sounds a chime when the brakes are automatically applied. For example, Model 3, while parked in front of a closed garage door with the Drive gear engaged, detects that you have pressed hard on the accelerator pedal. Although Model 3 still accelerates and hits the garage door, the reduced torque may result in less damage.

Obstacle-Aware Acceleration is designed to operate only when all of these conditions are simultaneously met:

- A driving gear is engaged (Drive or Reverse).
- Model 3 is stopped or traveling less than 10 mph (16 km/h).
- Model 3 detects an object in its immediate driving path.

To disable Obstacle-Aware Acceleration, touch **Controls** > **Autopilot** > **Obstacle-Aware Acceleration**.

Collision Avoidance Assist

WARNING: Obstacle-Aware Acceleration is designed to reduce the severity of an impact. It is not designed to avoid a collision.

WARNING: Obstacle-Aware Acceleration may not limit torque in all situations. Several factors, including environmental conditions, distance from an obstacle, and a driver's actions, can limit, delay, or inhibit Obstacle-Aware Acceleration.

WARNING: Obstacle-Aware Acceleration may not limit torque when performing a sharp turn, such as into a parking space.

WARNING: Do not rely on Obstacle-Aware Acceleration to control acceleration or to avoid, or limit, the severity of a collision, and do not attempt to test Obstacle-Aware Acceleration. Doing so can result in serious property damage, injury, or death.

WARNING: Several factors can affect the performance of Obstacle-Aware Acceleration, causing an inappropriate or untimely reduction in motor torque. It is the driver's responsibility to drive safely and remain in control of Model 3 at all times.

Limitations and Inaccuracies

Collision Avoidance features cannot always detect all objects, vehicles, bikes, or pedestrians, and you may experience unnecessary, inaccurate, invalid, or missed warnings for many reasons, particularly if:

- The road has sharp curves.
- Visibility is poor (due to heavy rain, snow, fog, etc.).
- Bright light (such as from oncoming headlights or direct sunlight) is interfering with the view of the camera(s).
- The camera or radar sensor (if equipped) is obstructed (dirty, covered, fogged over, covered by a sticker, etc.).
- One or more of the ultrasonic sensors is damaged, dirty, or obstructed (such as by mud, ice, or snow, or by a vehicle bra, excessive paint, or adhesive products such as wraps, stickers, rubber coating, etc.).
- Weather conditions (heavy rain, snow, fog, or extremely hot or cold temperatures) are interfering with sensor operation.
- The sensors are affected by other electrical equipment or devices that generate ultrasonic waves.

WARNING: The limitations previously described do not represent an exhaustive list of situations that may interfere with proper operation of Collision Avoidance Assist features. These features may fail to provide their intended function for many other reasons. It is the driver's responsibility to avoid collisions by staying alert, paying attention, and taking corrective action as early as possible.

CAUTION: If a fault occurs with a Collision Avoidance Assist feature, Model 3 displays an alert. Contact Tesla Service.

APPENDIX C

Run Log

Subject Vehicle: **2022 Tesla Model 3 AWD** Test start date: **3/23/2022**

Principal Other Vehicle: **SSV** Test end date: **3/29/2022**

Run	Test Type	Stopping Mode	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
	Test Start 3/23/2022							
1-12	Brake characterization and confirmation							See Appendix D
13	Static Run							
14	**Stopped POV**	Creep	Y	2.63	0.00	0.58	Fail	Test stopped due to unusual deceleration profile. Charge Level: 78%
	Start of Research Test 3/25/2022							
15-39	Brake characterization and confirmation							See Appendix D
40	Static Run							
41	**Stopped POV**	Roll	Y	2.62	0.70	0.55	Pass	
42		Roll	Y	2.65	1.33	0.58	Pass	
43		Creep	N					Yaw Rate
44		Creep	N					Throttle Drop
45		Creep	Y	2.60	2.59	0.58	Pass	
46		Creep	Y	2.61	2.20	0.58	Pass	
47		Creep	Y	2.65	0.43	0.54	Pass	

Run	Test Type	Stopping Mode	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
48		Creep	Y	2.59	0.56	0.54	Pass	
49		Creep	Y	2.64	0.82	0.52	Pass	
50	Static Run							Charge Level: 51%
51	Brake Confirmation							See Appendix D
52	Static Run							
53	**Stopped POV**	Roll	N					Throttle Drop
54		Roll	N					Throttle Drop
55		Roll	Y	2.49	4.57	0.74	Pass	
56		Roll	Y	2.59	1.68	0.63	Pass	
57	Brake Confirmation							See Appendix D
58		Creep	Y	2.55	1.92	0.64	Pass	
59		Creep	Y	2.54	3.36	0.67	Pass	
60		Creep	N					Brake Force
61		Creep	Y	2.58	0.00	0.56	Fail	
62		Creep	Y	2.66	0.00	0.59	Fail	
63		Creep	Y	2.62	0.00	0.61	Fail	
64	Static Run							Charge Level: 83%
65		Creep	N					SV Lateral Offset

Run	Test Type	Stopping Mode	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
66	**Slower POV, 25 vs 10**	Creep	Y	2.62	16.37	0.64	Pass	
67		Creep	Y	2.76	17.42	0.66	Pass	
68		Creep	Y	2.73	16.15	0.61	Pass	
69		Creep	Y	2.70	16.96	0.61	Pass	
70		Creep	Y	2.63	16.72	0.68	Pass	
71		Roll	Y	2.73	18.06	0.66	Pass	
72		Roll	Y	2.72	15.93	0.72	Pass	
73	Static Run							Charge Level: 81%
74-78	Brake Confirmation							See Appendix D
79	**Slower POV, 45 vs 20**	Creep	Y	2.90	11.36	0.66	Pass	
80		Creep	Y	2.93	12.89	0.64	Pass	
81		Creep	Y	3.05	15.73	0.69	Pass	
82		Creep	Y	3.06	14.82	0.64	Pass	
83		Creep	Y	2.98	11.24	0.63	Pass	
84		Roll	Y	2.67	4.38	0.64	Pass	
85		Roll	Y	2.87	6.82	0.62	Pass	
86	Static Run							Charge Level: 75%
87-89	Brake confirmation							See Appendix D

Run	Test Type	Stopping Mode	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
90	Static Run							
91	**Decelerating POV, 35**	Roll	N					Brake Force
92		Roll	Y	2.30	12.71	0.86	Pass	
93		Roll	N					Yaw Rate, Brake Force
94		Roll	Y	2.48	11.99	0.83	Pass	
95		Creep	Y	2.39	11.19	0.82	Pass	
96		Creep	Y	2.24	14.71	1.01	Pass	
97		Creep	Y	2.54	14.17	0.95	Pass	
98		Creep	N					Yaw Rate, Brake Force, POV Brakes
99		Creep	N					POV Brakes
100		Creep	Y	2.63	13.64	0.89	Pass	
101		Creep	Y	2.51	9.98	0.82	Pass	
102	Static Run							Charge Level: 70%
103	STP - Static run							
104	**Baseline, 25**	Creep	Y			0.59		
105		Creep	N					SV Speed
106		Creep	Y			0.66		
107		Creep	Y			0.63		
108		Creep	Y			0.56		

Run	Test Type	Stopping Mode	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
109		Creep	Y			0.57		
110		Roll	Y			0.65		
111		Roll	Y			0.61		
112	Static Run							Charge Level: 70%
113	**Baseline, 45**	Creep	N					Throttle Drop, Brake Force
114		Creep	N					Throttle Drop
115		Creep	Y			0.59		
116		Creep	Y			0.56		
117		Creep	Y			0.59		
118		Creep	Y			0.54		
119		Creep	Y			0.63		
120		Roll	N					SV Speed
121		Roll	N					Throttle Drop, Brake Force
122		Roll	Y			0.57		
123		Roll	Y			0.62		
124	Static Run							Charge Level: 70%
125	**STP False Positive, 25**	Creep	Y			0.59	Pass	
126		Creep	Y			0.67	Pass	

Run	Test Type	Stopping Mode	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
127		Creep	Y			0.63	Pass	
128		Creep	Y			0.57	Pass	
129		Creep	Y			0.56	Pass	
130		Roll	Y			0.59	Pass	
131		Roll	Y			0.58	Pass	
124	Static Run							Charge Level: 64%
133	**STP False Positive, 45**	Creep	Y			0.59	Pass	
134		Creep	Y			0.58	Pass	
135		Creep	Y			0.57	Pass	
136		Creep	Y			0.59	Pass	
137		Creep	Y			0.60	Pass	
138		Roll	Y			0.61	Pass	
139		Roll	Y			0.61	Pass	
140	Static Run							Charge Level: 62%

APPENDIX D

Brake Characterization

Subject Vehicle: **2022 Tesla Model 3 AWD**

Test start date: **3/23/2022**

Test end date: **3/29/2022**

DBS Initial Brake Characterization					
Run Number	**Stopping Mode**	**Stroke at 0.4 g (in)**	**Force at 0.4 g (lb)**	**Slope**	**Intercept**
1	Creep	1.24	17.25	0.833	-0.147
2		1.27	17.52	0.887	-0.123
3		1.22	17.94	0.868	-0.119

Run	DBS Mode	Stopping 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	Creep	35	Y	0.374	1.26		1.35	
5		Creep	35	Y	0.329	1.30		1.58	
6		Creep	35	Y	0.403	1.35		1.34	
7		Creep	25	Y	0.383	1.35		1.41	
8		Creep	45	Y	0.422	1.35		1.28	
9	Hybrid	Creep	35	Y	0.497	1.35	17.74	14.28	

Run	DBS Mode	Stopping 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		Creep	35	Y	0.403	1.35	15.25	15.14	
11		Creep	25	Y	0.375	1.35	15.25	16.27	
12		Creep	45	Y	0.424	1.35	15.25	14.39	
15	Hybrid	Hold	25	Y	0.497	1.35	15.25		
16		Creep	25	Y	0.373	1.35	15.25		
17	Hybrid	Creep	35	Y	0.385	1.35	15.25	15.84	
18		Creep	25	Y	0.355	1.35	15.25	17.18	
19		Creep	25	Y	0.391	1.35	16.00	16.37	
20		Creep	45	Y	0.413	1.35	15.25	14.77	

DBS Initial Brake Characterization					
Run	Stopping Mode	Stroke at 0.4 g (in)	Force at 0.4 g (lb)	Slope	Intercept
21	Roll	1.34	18.09	0.885	-0.170
22		1.31	17.65	0.752	-0.065
23		1.24	17.93	0.926	-0.228

Run	DBS Mode	Stopping Mode	Speed	Valid Run	Average Decel. (g)	0.4 g Stroke Value (in)	0.4 g Force Value (lb)	Stroke/Force Calculator (in)	Notes
24	Displacement	Roll	35	N					Brake Rate
25		Roll	35	Y	0.335	1.30		1.55	
26		Roll	35	Y	0.381	1.35		1.42	
27		Roll	25	Y	0.356	1.35		1.52	
28		Roll	25	N					SV Speed
29		Roll	25	Y	0.365	1.40		1.53	
30		Roll	25	Y	0.407	1.45		1.43	
31		Roll	45	Y	0.444	1.45		1.31	
32		Roll	45	Y	0.417	1.40		1.34	
33		Roll	35	Y	0.419	1.40		1.34	
34	Hybrid	Roll	35	Y	0.506	1.40	17.89	14.14	

Run	DBS Mode	Stopping Mode	Speed	Valid Run	Average Decel. (g)	0.4 g Stroke Value (in)	0.4 g Force Value (lb)	Stroke/Force Calculator (in)	Notes
35		Roll	35	Y	0.392	1.40	14.14	14.43	
36		Roll	25	Y	0.365	1.45	14.14	15.50	
37		Roll	25	Y	0.392	1.45	15.00	15.31	
38		Roll	45	Y	0.430	1.40	15.00	13.95	
39		Roll	45	Y	0.407	1.40	14.14	13.90	
51	Hybrid	Roll	25	Y	0.392	1.45	15.00		Check Run
57	Hybrid	Creep	25	Y	0.387	1.35	16.00		Check Run
74	Hybrid	Roll	45	Y	0.411	1.40	14.14		Check Run
75	Displacement	Roll	45	Y	0.447	1.40	14.14		Check Run
76		Roll	45	Y	0.399	1.35	14.14		Check Run
77	Hybrid	Roll	45	Y	0.388	1.35	14.14		Check Run
78		Creep	45	Y	0.393	1.35	15.25		Check Run
87	Hybrid	Creep	35	Y	0.395	1.35	15.25		Check Run

Run	DBS Mode	Stopping Mode	Speed	Valid Run	Average Decel. (g)	0.4 g Stroke Value (in)	0.4 g Force Value (lb)	Stroke/Force Calculator (in)	Notes
88		Roll	35	Y	0.353	1.35	14.14		Check Run
89		Roll	35	Y	0.389	1.35	15.00		Check Run

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. Plots shown herein are grouped by test type and are presented sequentially within a given test type. 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)
- Decelerating 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 auditory, 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 auditory 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 front-most 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 – Position of the accelerator pedal and brake pedal. The units for the brake pedal are inches and the units for the accelerator pedal are percent of full scale divided by 10.

- 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.

Envelopes and Thresholds

Some of the time history plot figures contain either green or yellow envelopes and/or black or red 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.

With the exception of the brake force plots (see description below), 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 Ax plot, 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 0.27 g (the upper edge of the envelope, i.e., 0.30 g ± 0.03 g). A green circle or red asterisk is displayed at the moment the POV brake level achieves 0.27 g. 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.

- If the tests are performed in Displacement mode, the plot shows a short dashed black line above the brake onset period representing the maximum allowable 20% overshoot and 100 ms time period beyond the commanded pedal position.

  Additionally, a green envelope representing ±10% of the target brake pedal position is shown. If the brake pedal position exceeds the boundaries of the envelope, the run is invalid.

- If the tests are performed in Hybrid mode, no other brake pedal position requirements are shown.

For the brake force plots:

- A short, solid black line at 2.5 lbs is displayed representing the required nominal TTC or distance in which the brakes must be applied. If the brakes are applied based on a real-time calculation of TTC (which is standard practice), the tolerance is ±0.05 sec and the TTC of the brake onset is displayed. If the brakes cannot be applied based on a real-time TTC due to regenerative braking or other factors, the brakes are applied based on a distance calculation. The tolerance is ±2 ft and no other values are displayed. If the brakes are applied at the correct TTC or distance, a green dot is displayed. If not, a red asterisk is displayed.

- If the tests are performed in Displacement mode, no other brake force requirements are shown.

- If the tests are performed in Hybrid mode, a long, dashed black line is displayed at 2.5 lbs representing the minimum brake force required while the brake actuator is active. Exceedances of this brake force threshold are indicated by red shading in the area between the measured time-varying data and the dashed threshold line.

  additionally, a blue envelope representing ±10% of the target average brake force is shown along with the calculated average during that time period. Note that the brake force may exceed the boundaries of the envelope as long as the overall average is within tolerance.

In the instance of “last second” braking applied by the brake actuator, a thick vertical red line will appear on the plots at the moment the brake actuator activates. Note that “last second” braking is only done when it has been determined by the onboard computer that test failure cannot be avoided. It is done simply to reduce the collision speed in order to minimize the likelihood of damage to the SSV and to the Subject Vehicle. Therefore, data validity checks are not performed after the red line, and certain values, such as minimum distance or peak deceleration, may not be accurate.

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
    - Blue envelope = visualized target range for the time varying data averaged over a period equal to the length of the envelope
    - 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.
    - Red threshold (Solid) = for reference only – indicates the activation of last-minute braking by the brake robot. Data after the solid red line is not used to determine test validity.

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

Other Notations

- NG – Indicates that the value for that variable was outside of bounds and therefore “No Good”.
- No Wng – No warning was detected.
- POV – Indicates that the value for the Principal Other Vehicle was out of bounds.
- SV – Indicates that the value for the Subject Vehicle was out of bounds.
- SR – Shows the speed reduction value.
- Thr – Indicates that the requirements for the throttle were not met.

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.

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.

Notes

For valid runs, plots are shown for all warning types. In some cases, one of the plots may indicate that a run was invalid, but if the run was valid for either warning type it is considered valid. The companion plots are shown for the sake of completeness.

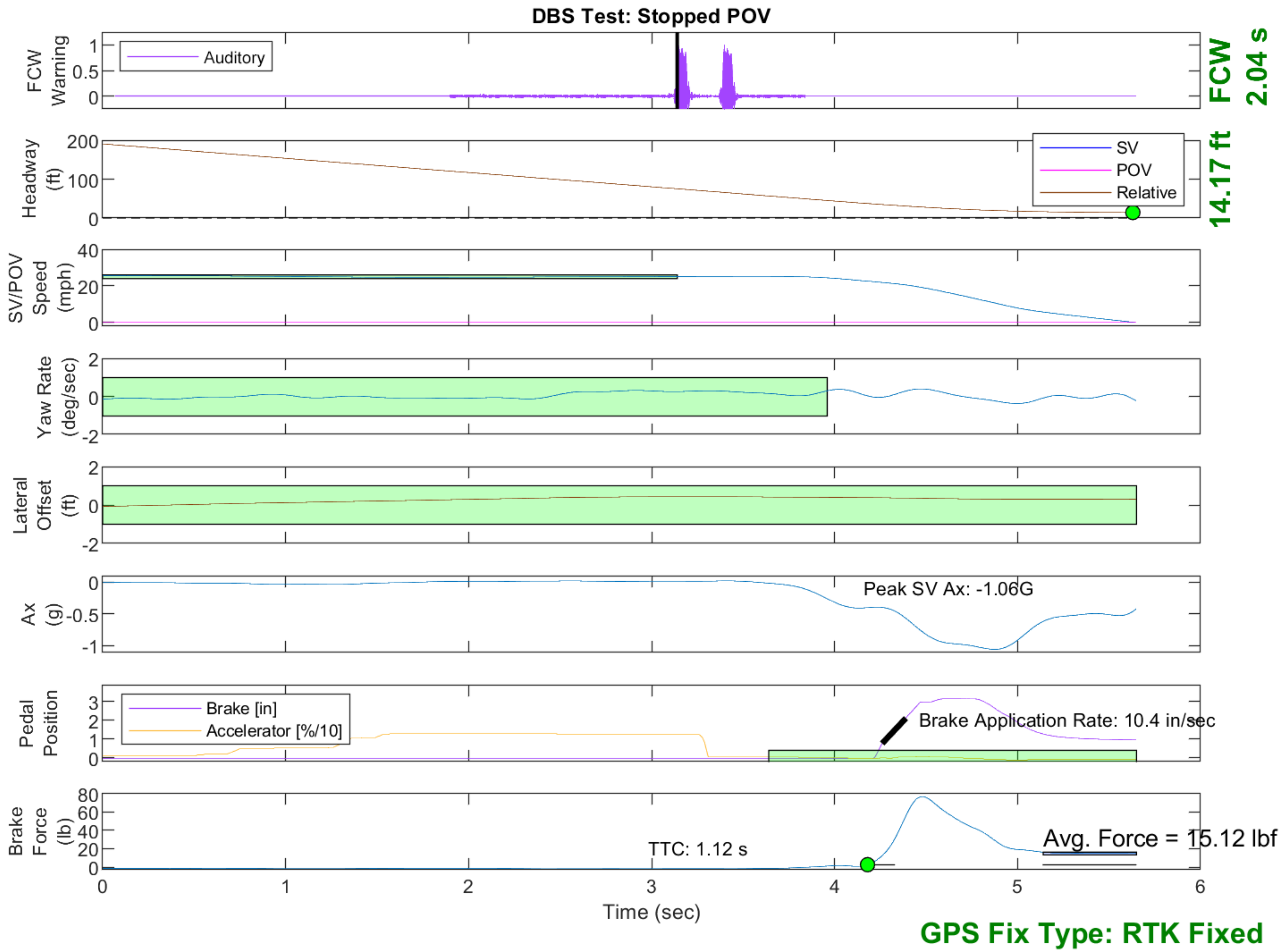


Figure E1. Example Time History for Stopped POV, Passing

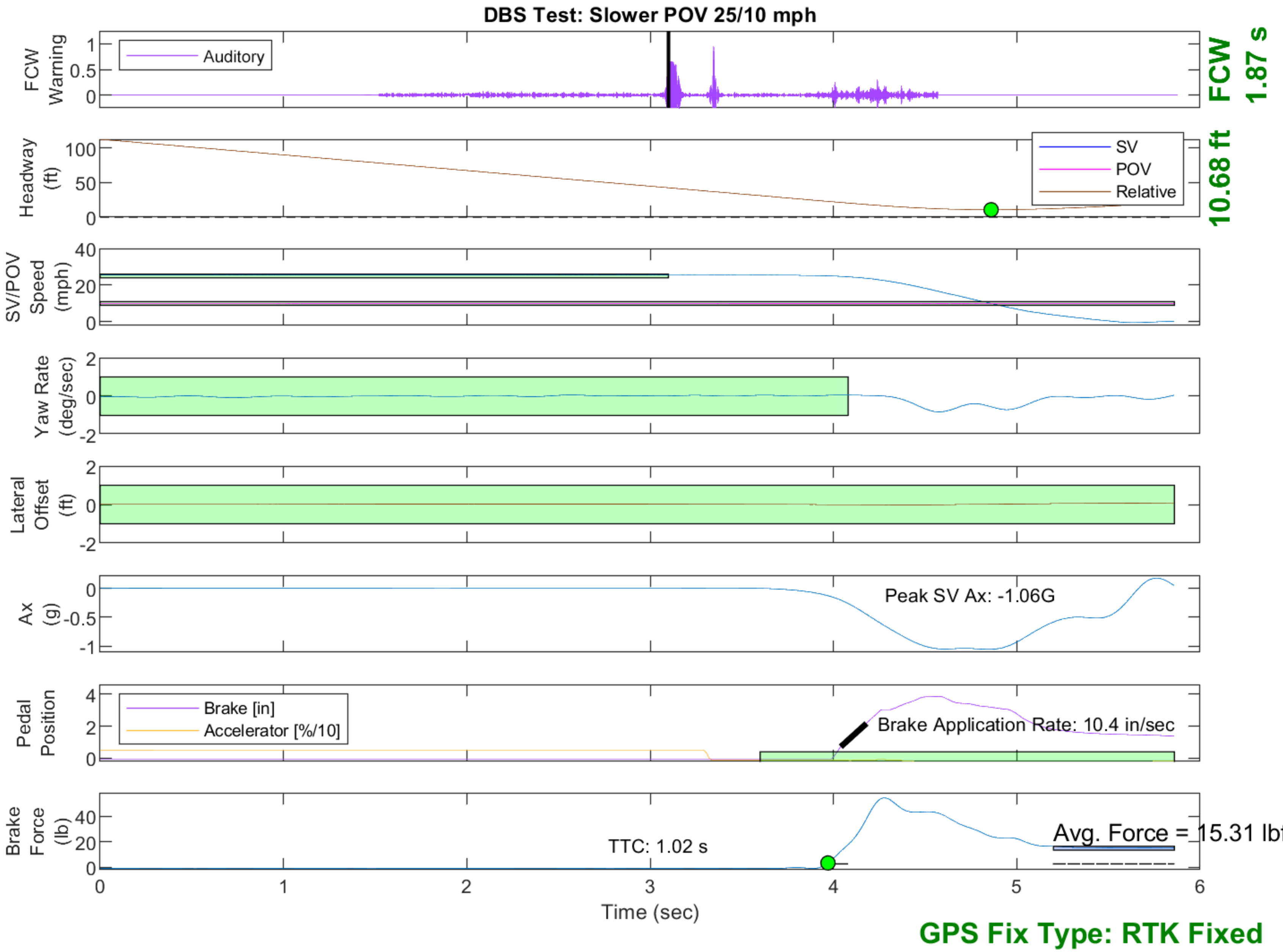


Figure E2. Example Time History for Slower POV 25 vs. 10, Passing

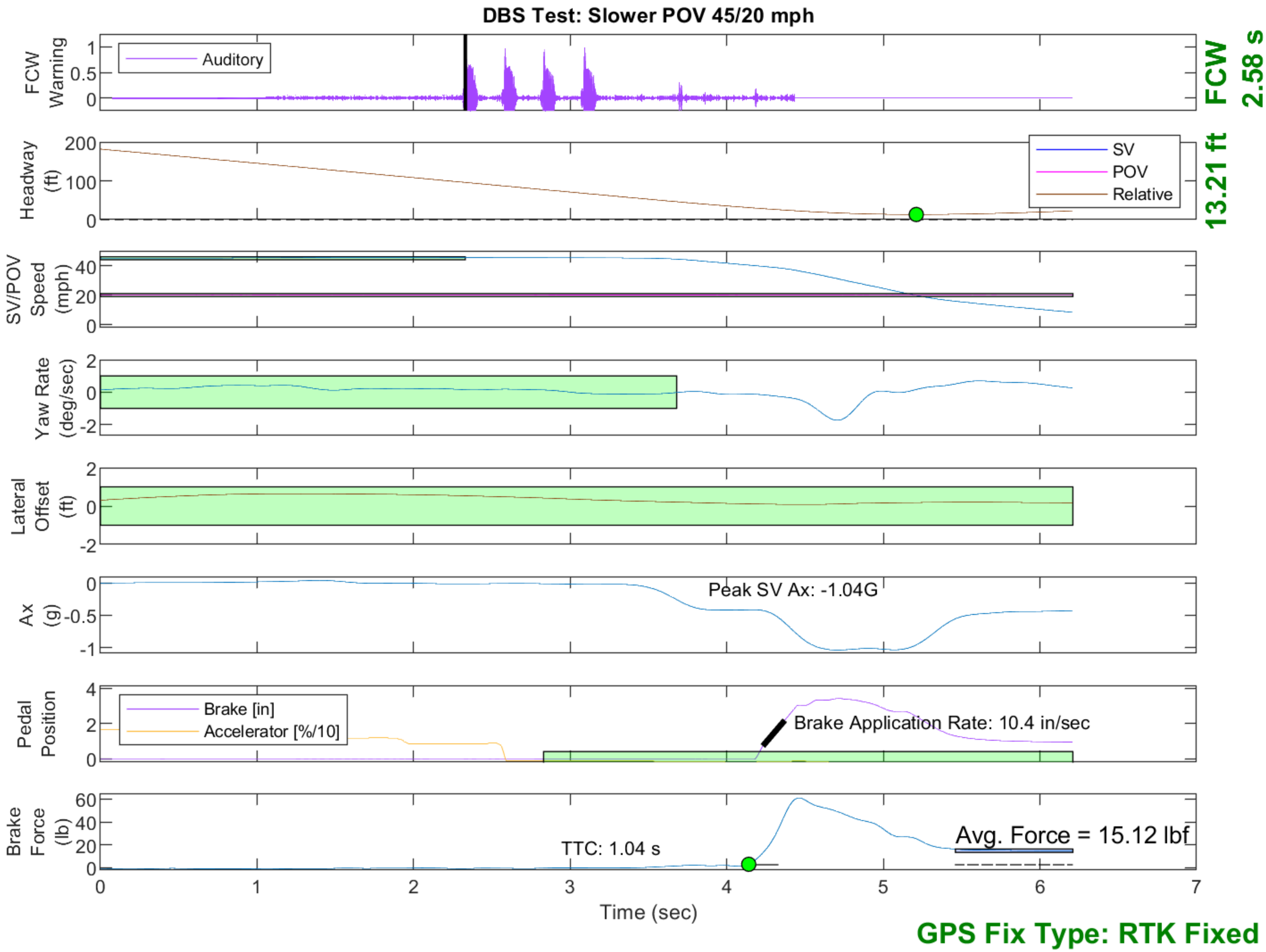


Figure E3. Example Time History for Slower POV 45 vs. 20, Passing

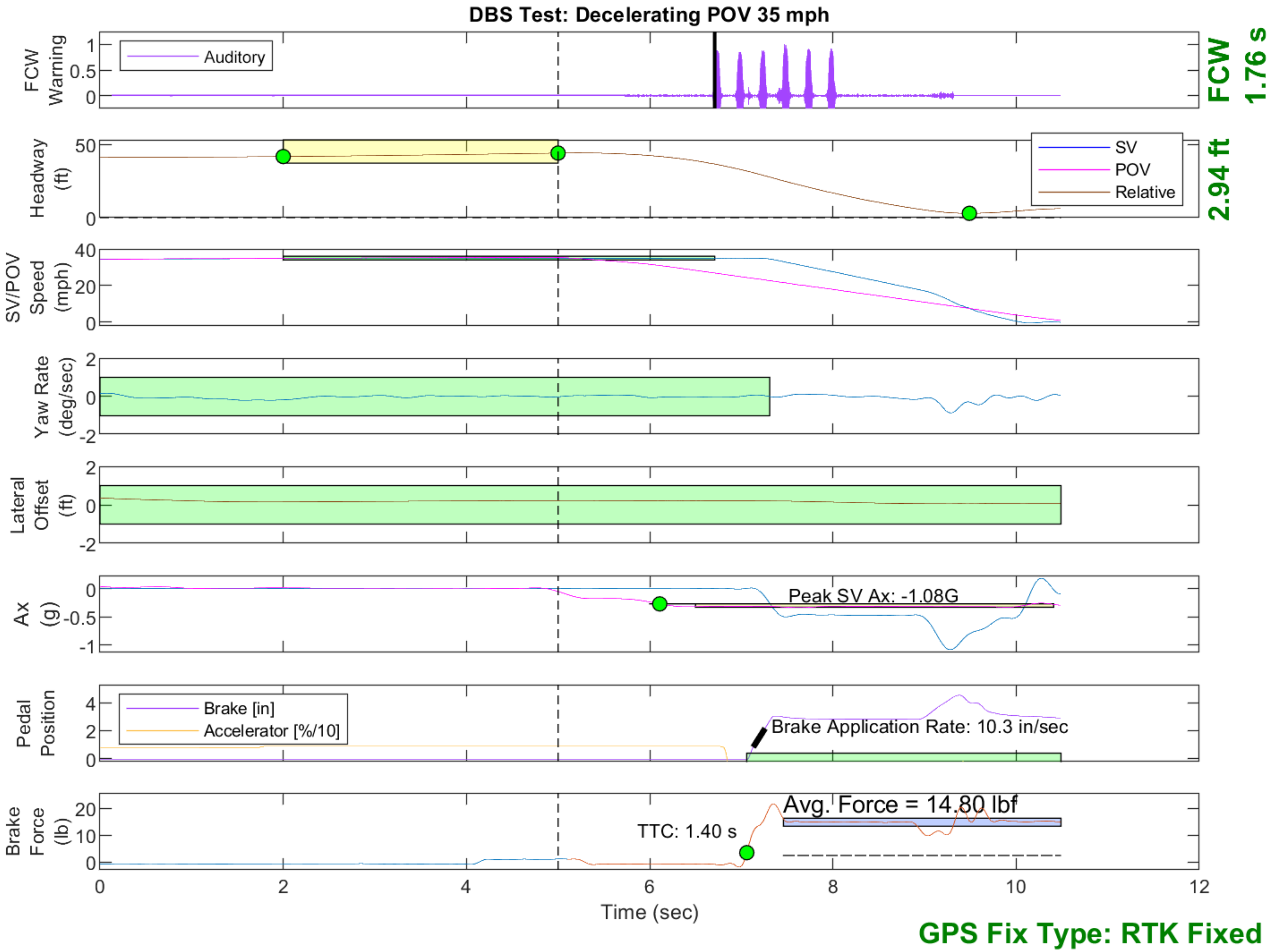


Figure E4. Example Time History for Decelerating POV 35, Passing

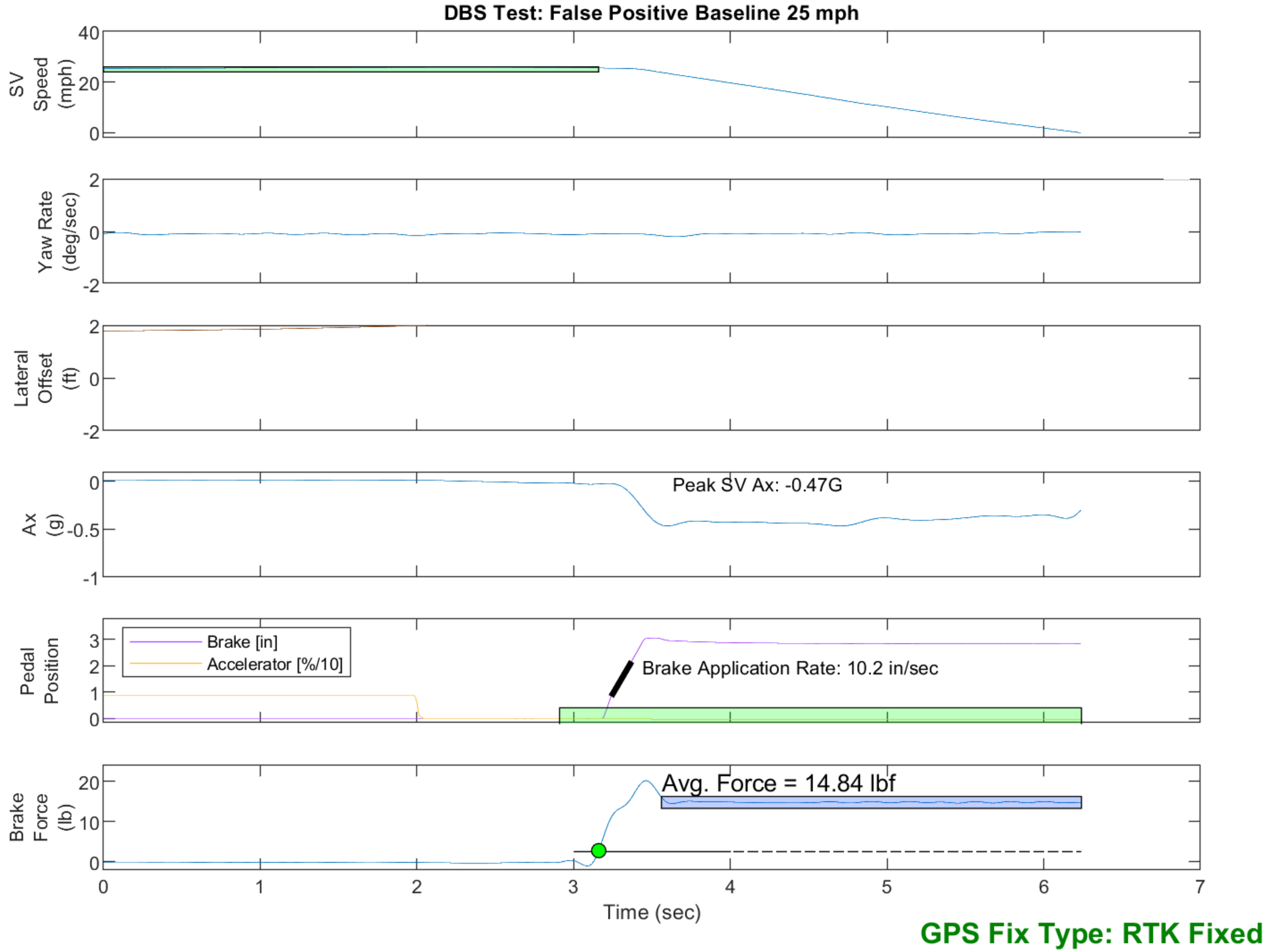


Figure E5. Example Time History for False Positive Baseline 25

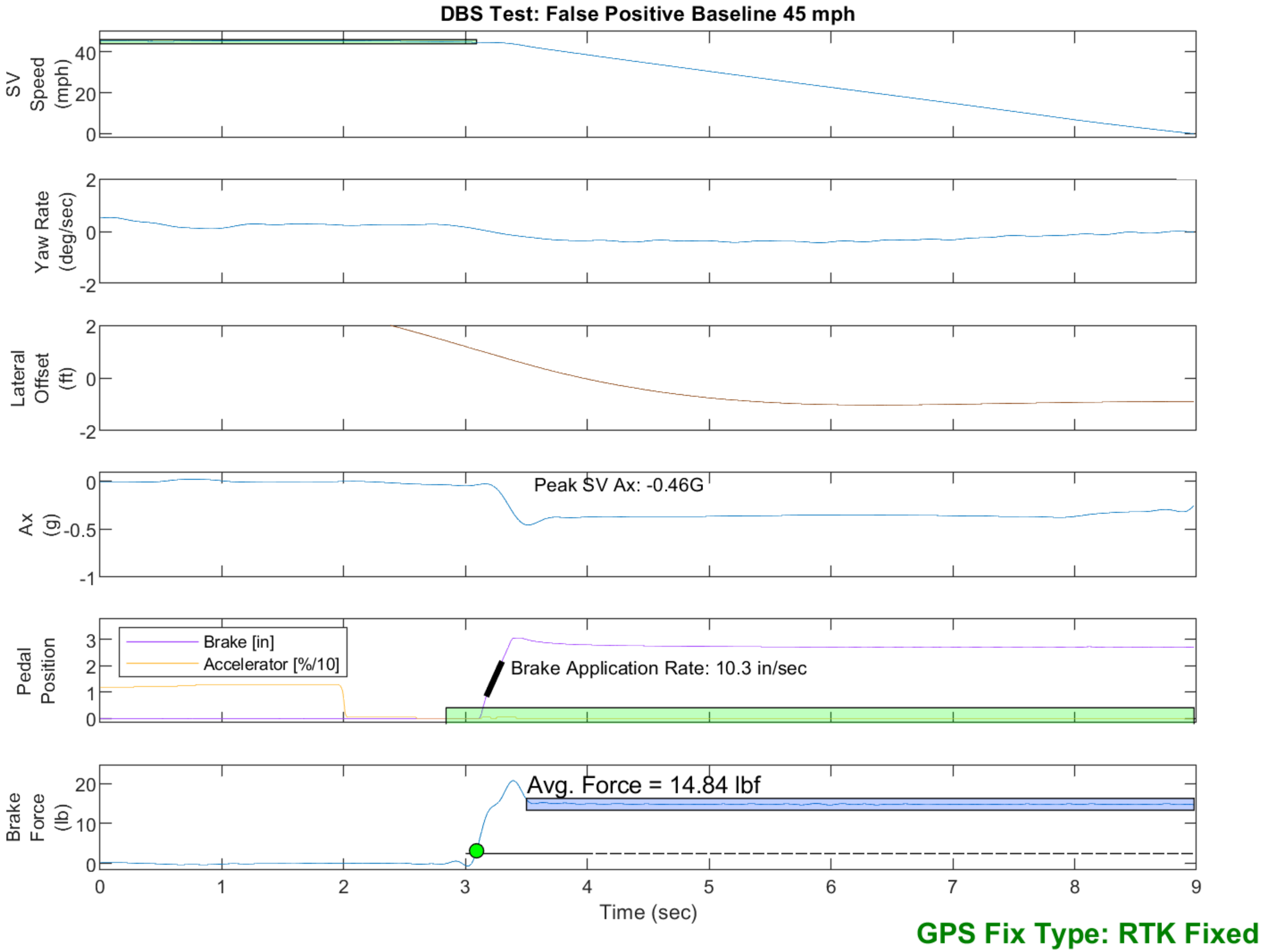


Figure E6. Example Time History for False Positive Baseline 45

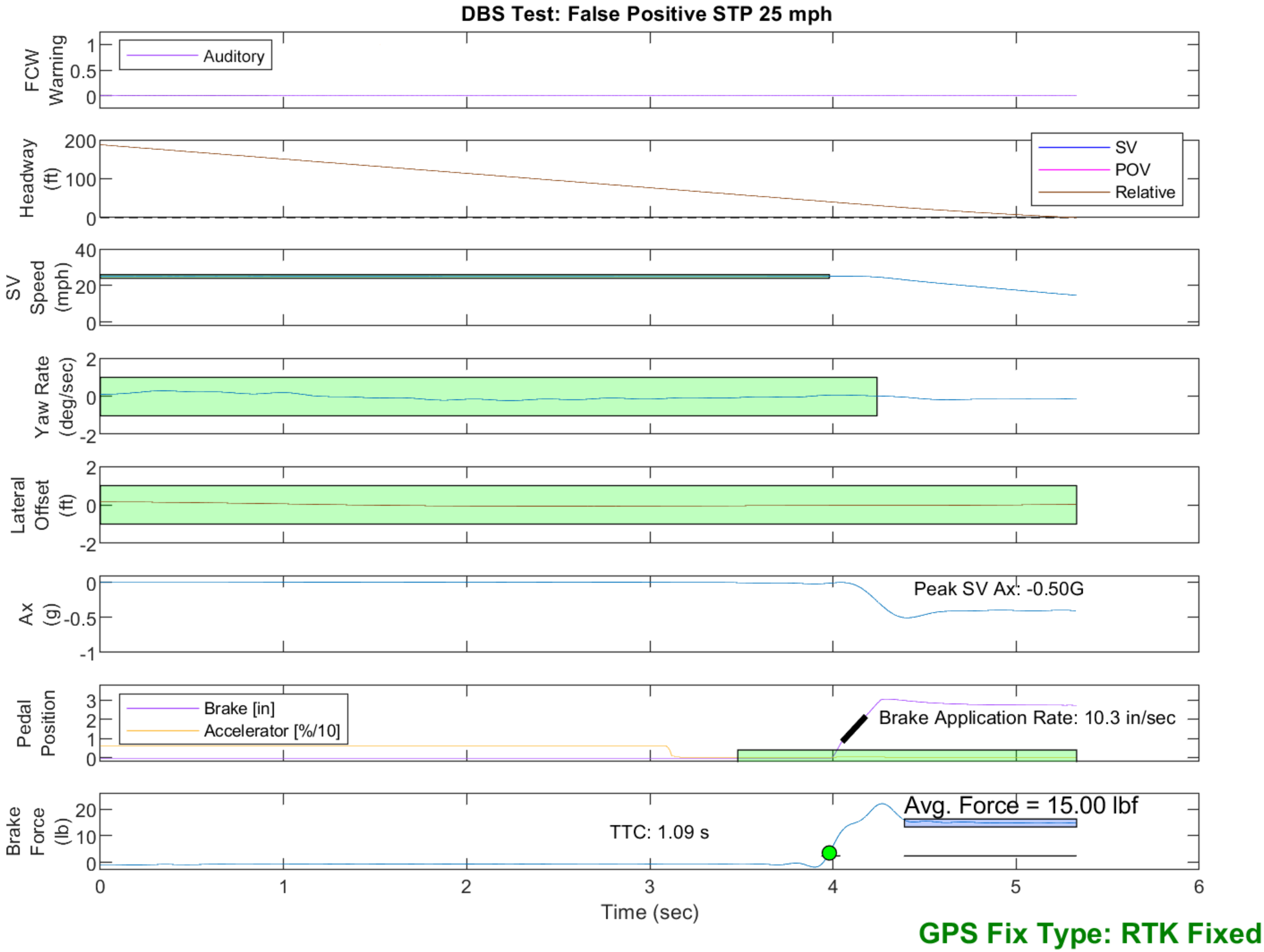


Figure E7. Example Time History for False Positive Steel Plate 25, Passing

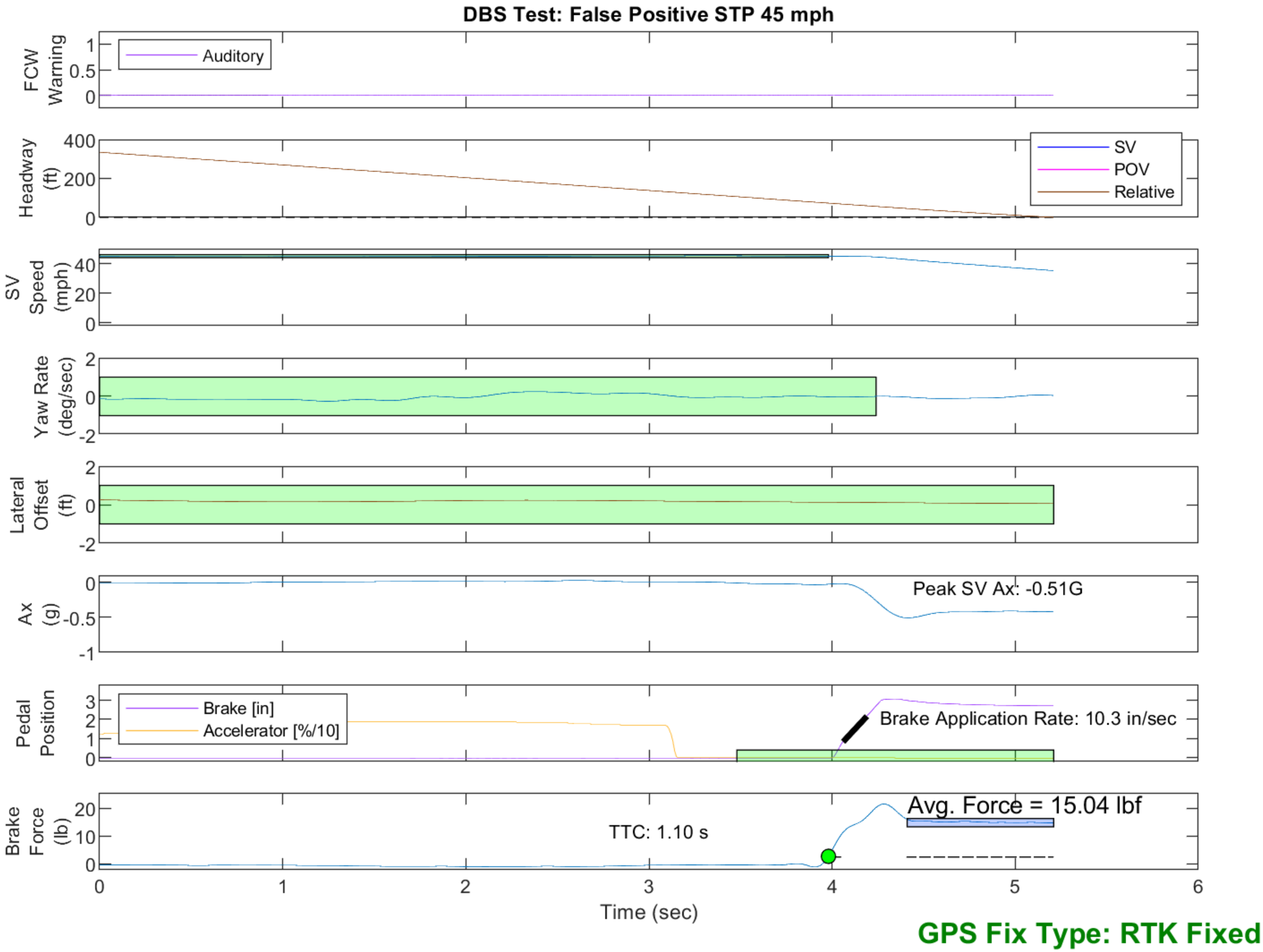


Figure E8. Example Time History for False Positive Steel Plate 45, Passing

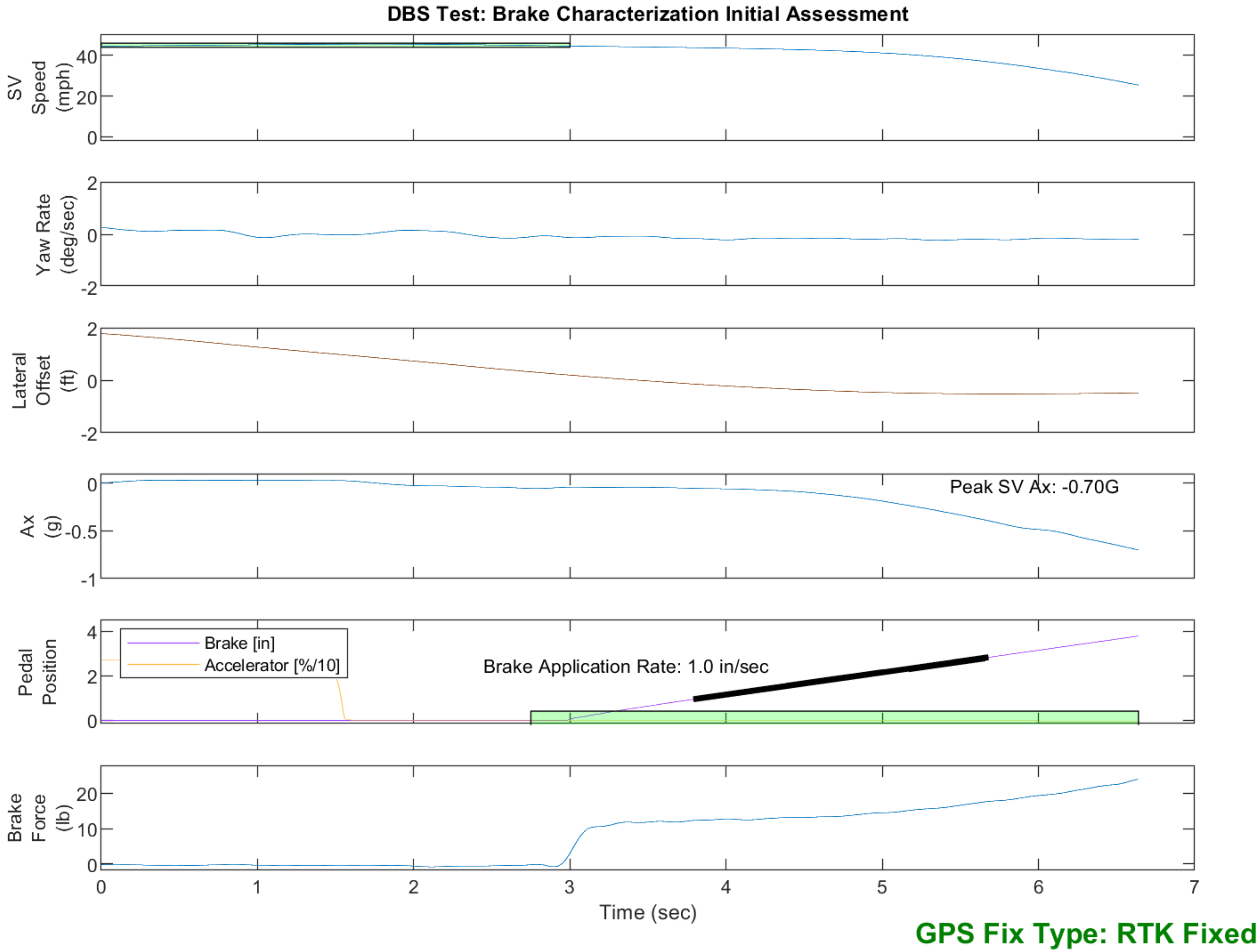


Figure E9. Example Time History for DBS Brake Characterization, Passing

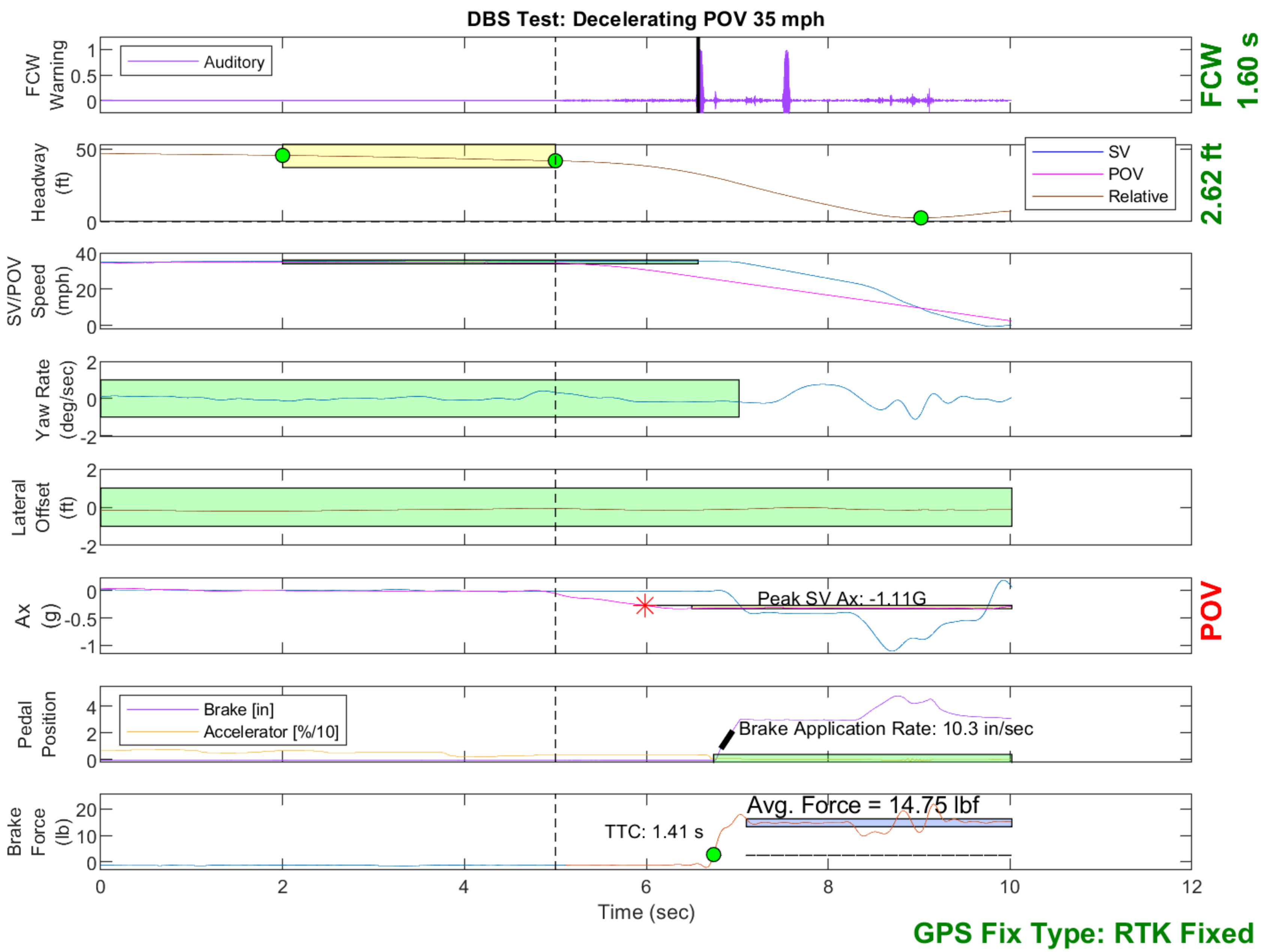


Figure E10. Example Time History Displaying Invalid POV Acceleration Criteria

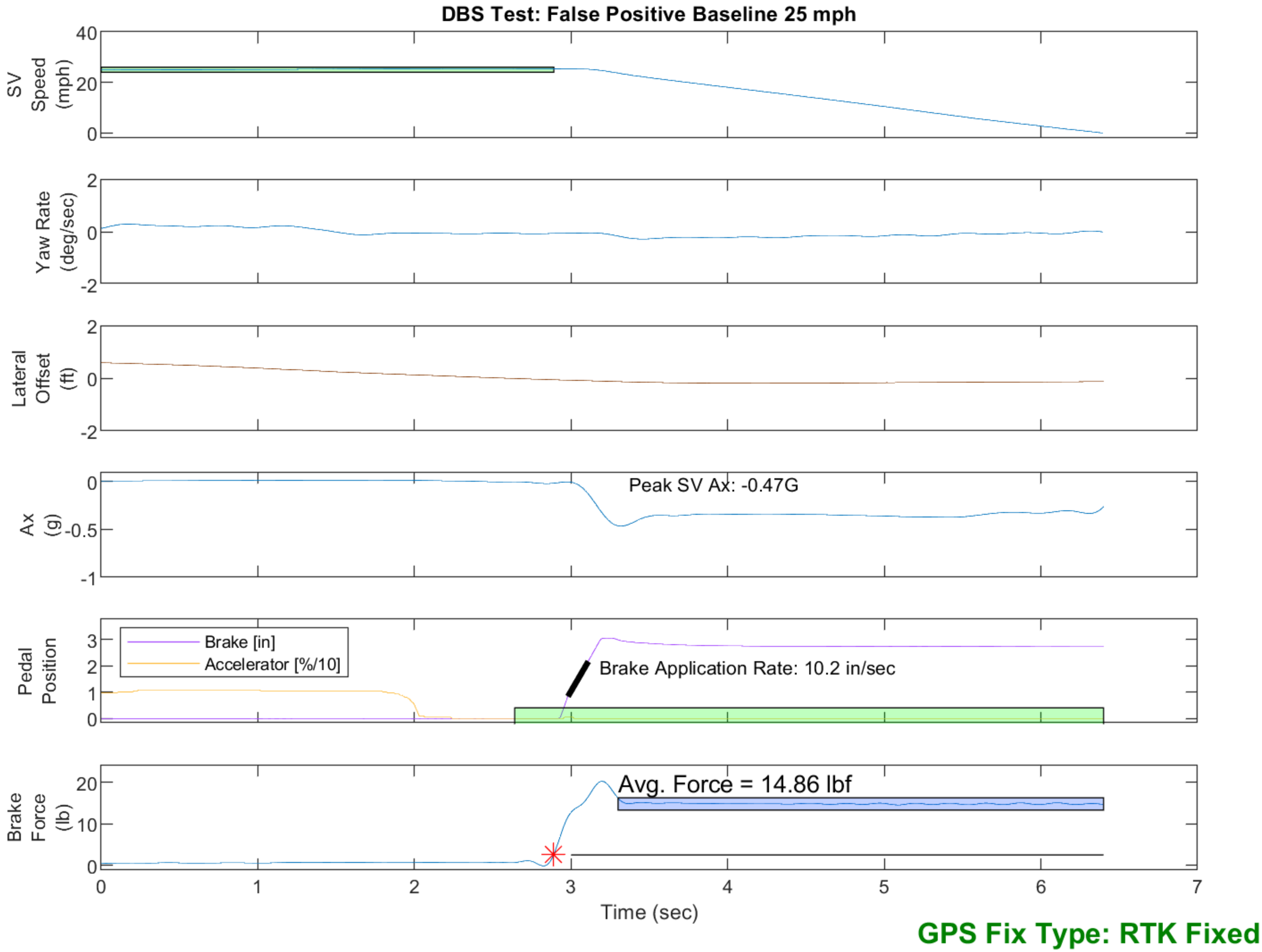


Figure E11. Example Time History Displaying Invalid Brake Force Criteria

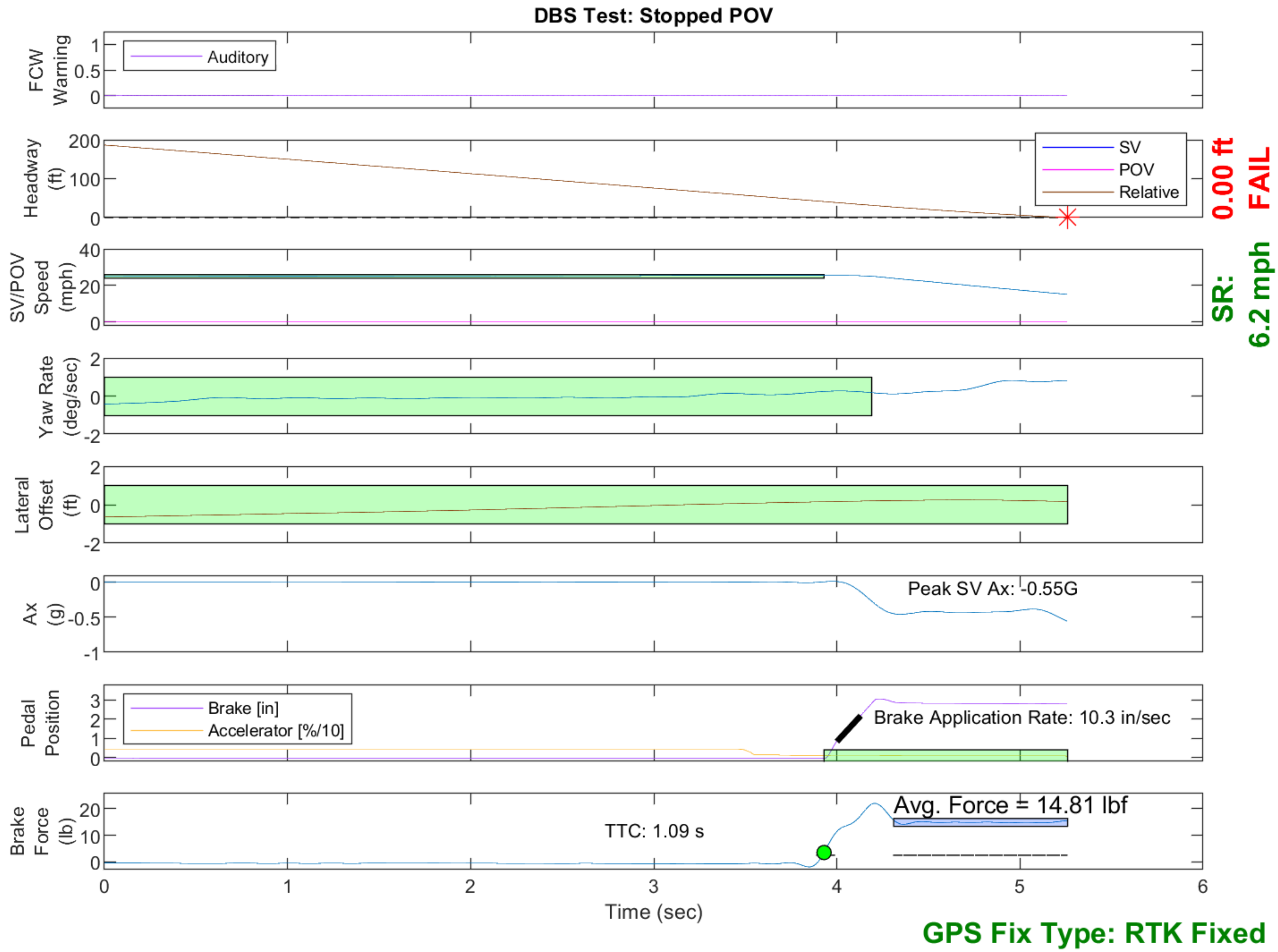


Figure E12. Example Time History for a Failed Run

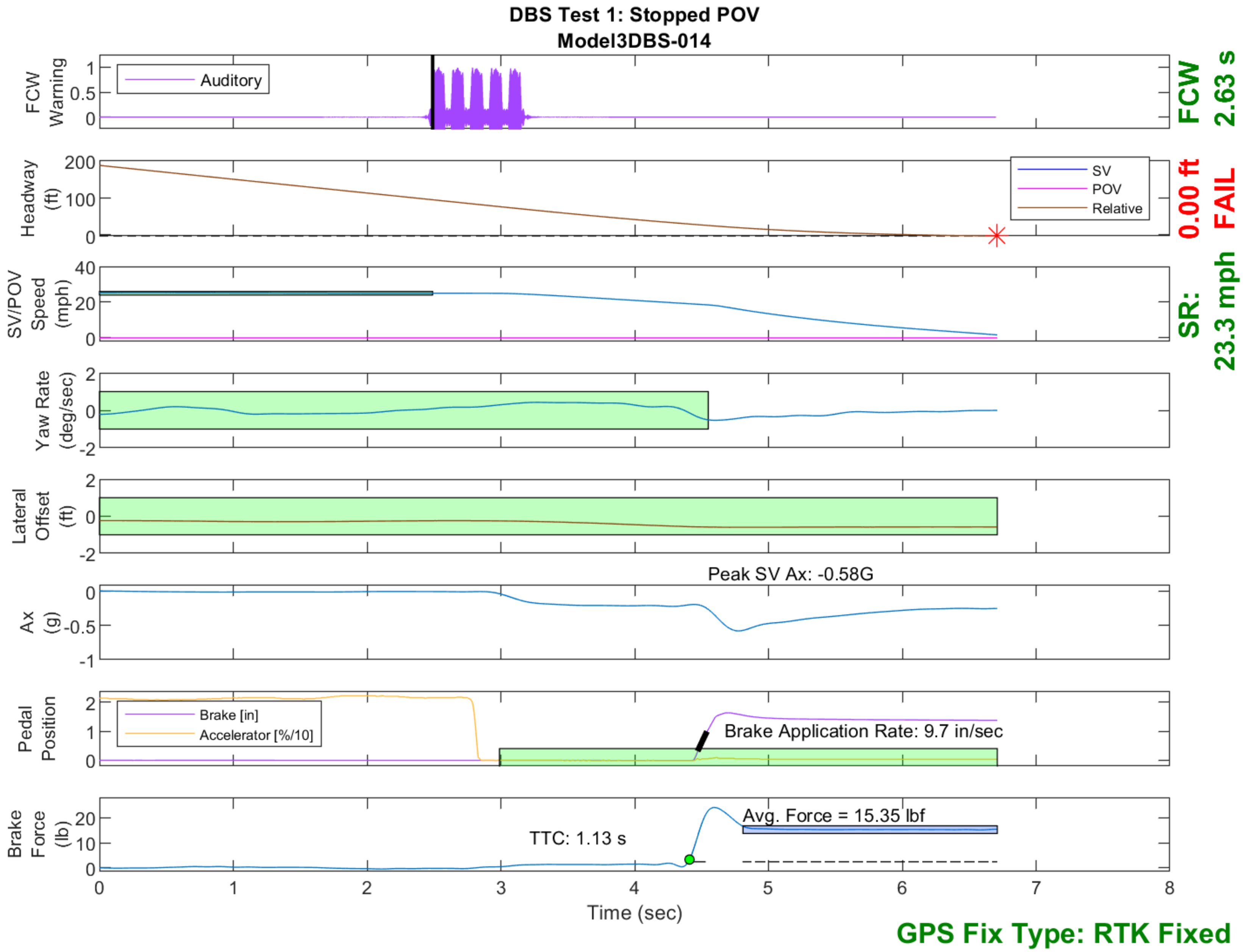


Figure E13. Time History for DBS Run 14, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~78%

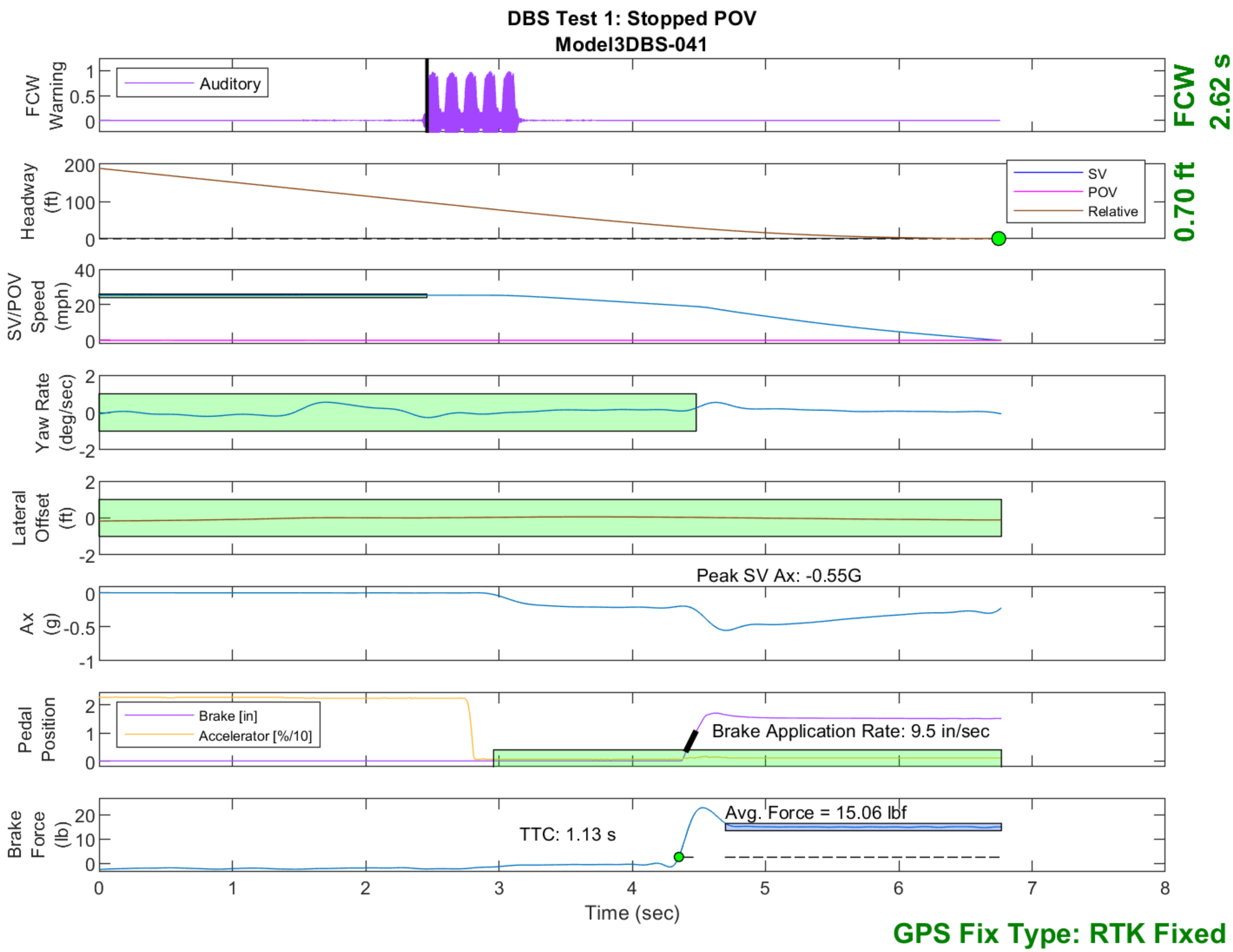


Figure E14. Time History for DBS Run 41, Test 1 - Stopped POV, Roll Mode, Battery SOC = ~51%

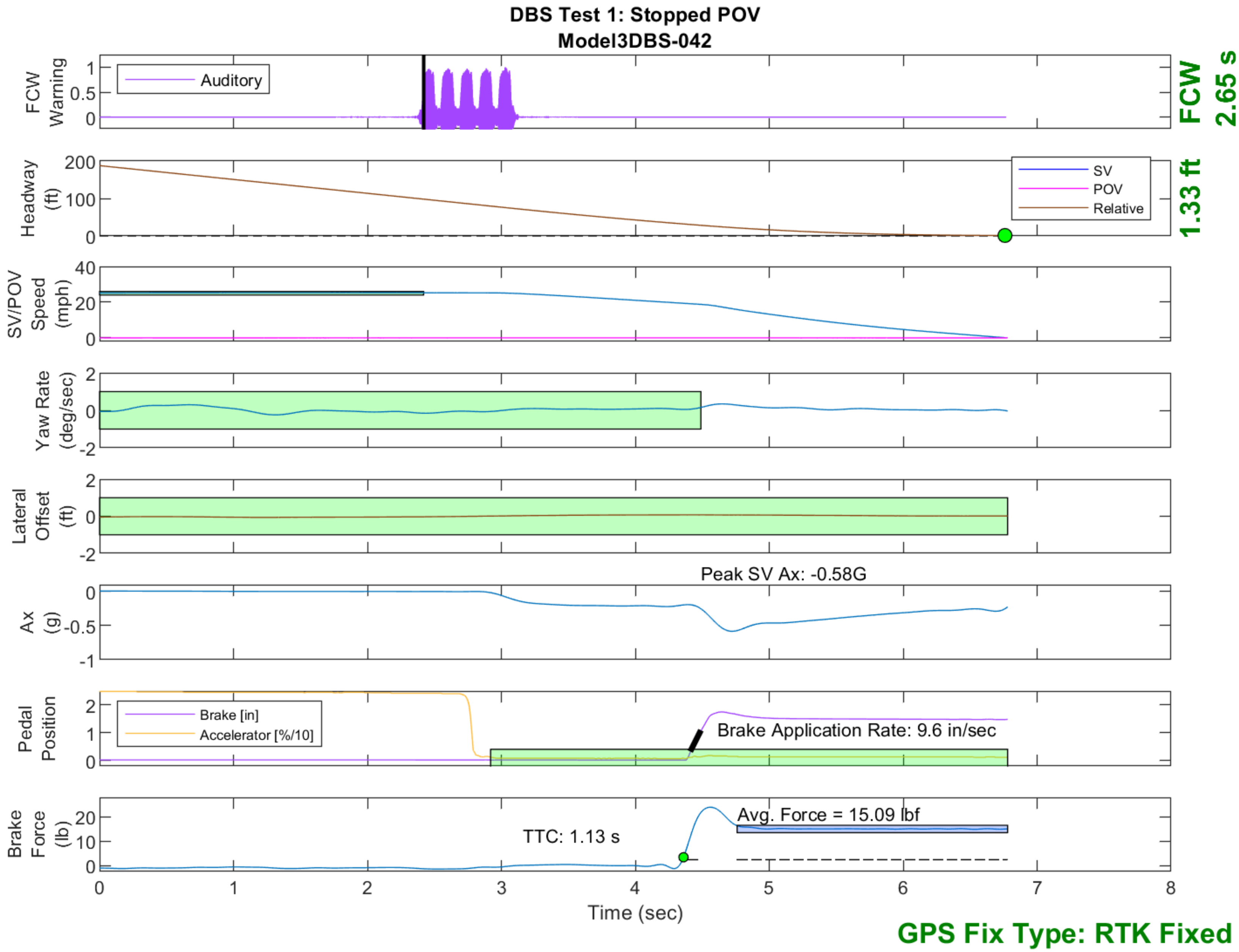


Figure E15. Time History for DBS Run 42, Test 1 - Stopped POV, Roll Mode, Battery SOC = ~51%

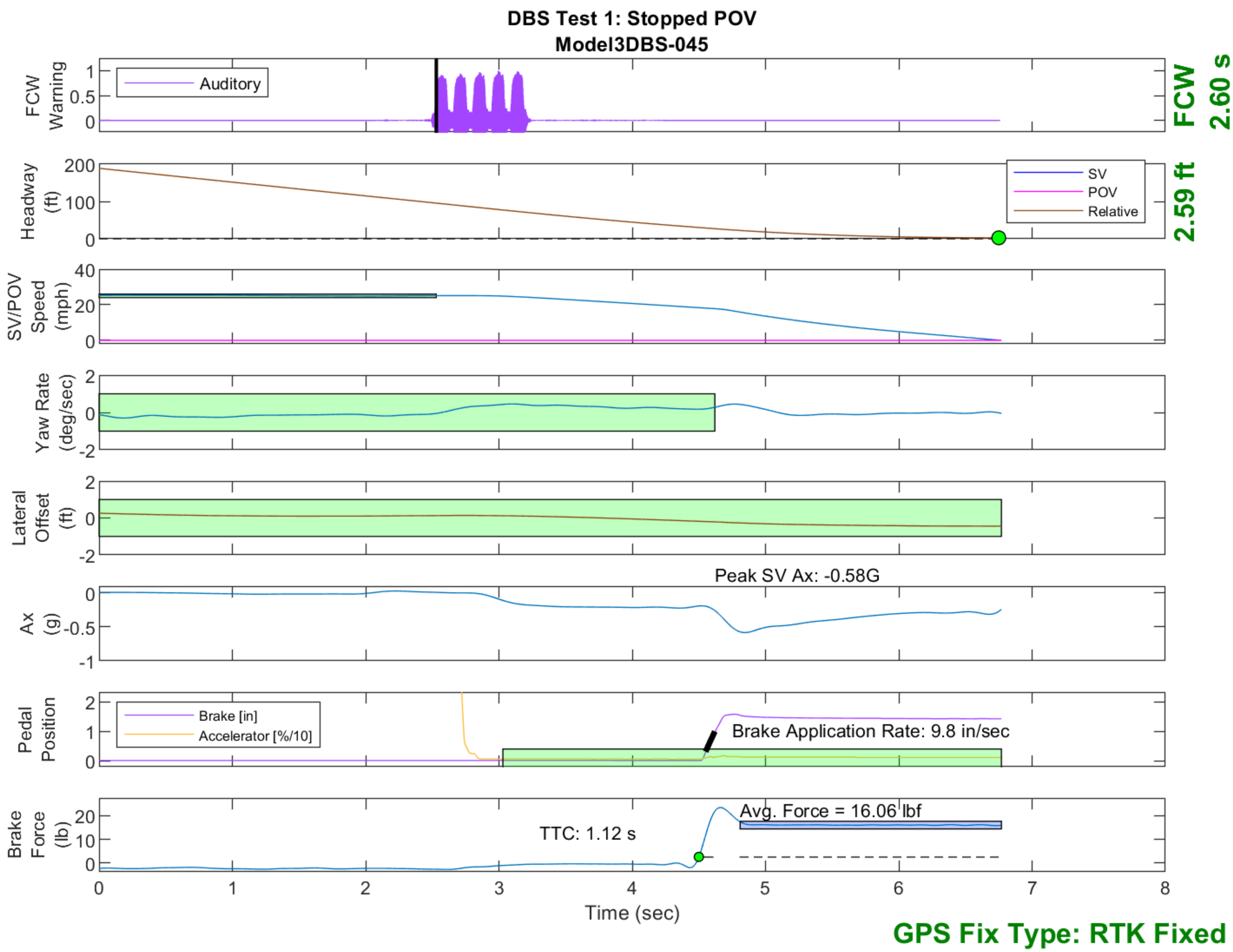


Figure E16. Time History for DBS Run 45, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~51%

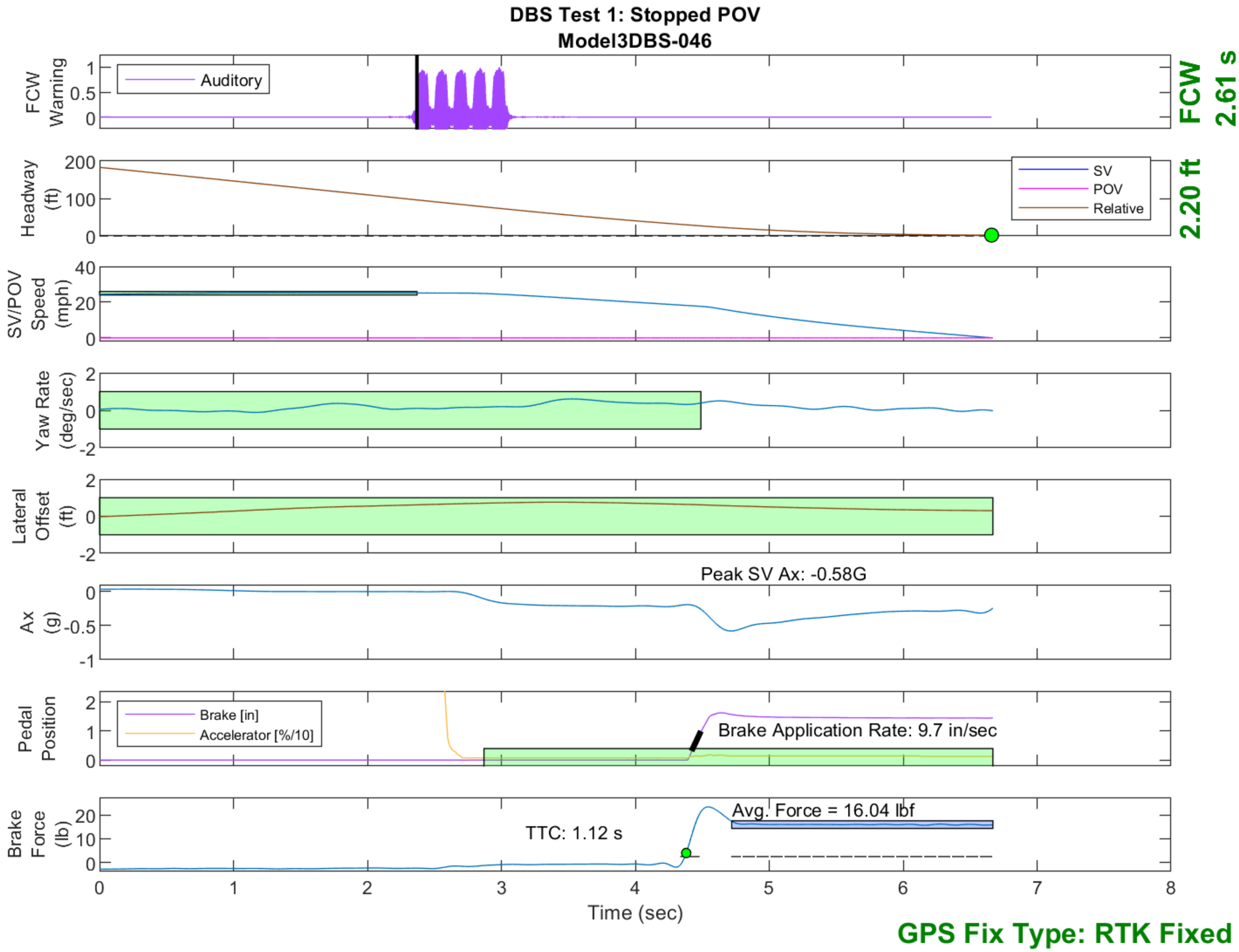


Figure E17. Time History for DBS Run 46, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~51%

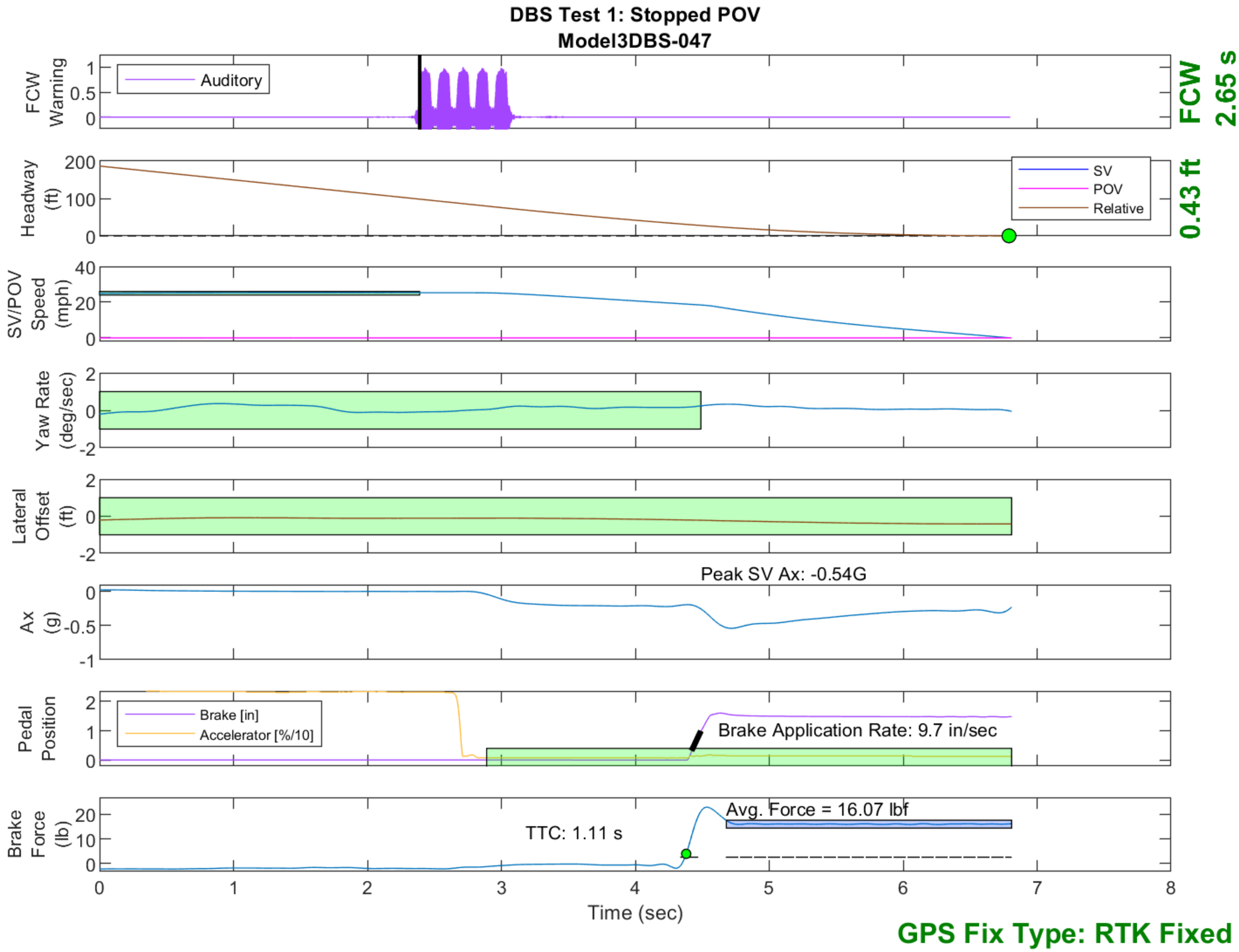


Figure E18. Time History for DBS Run 47, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~51%

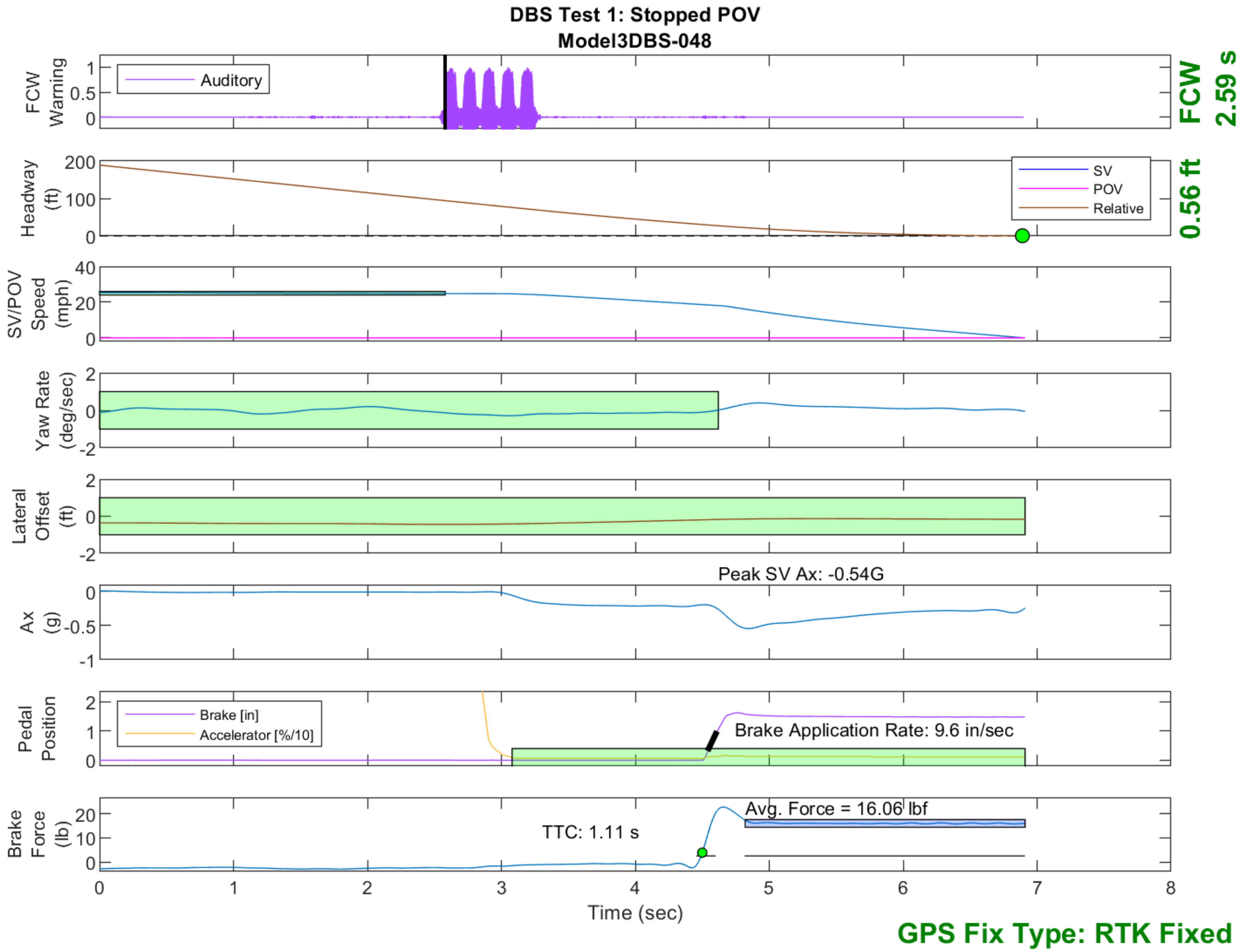


Figure E19. Time History for DBS Run 48, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~51%

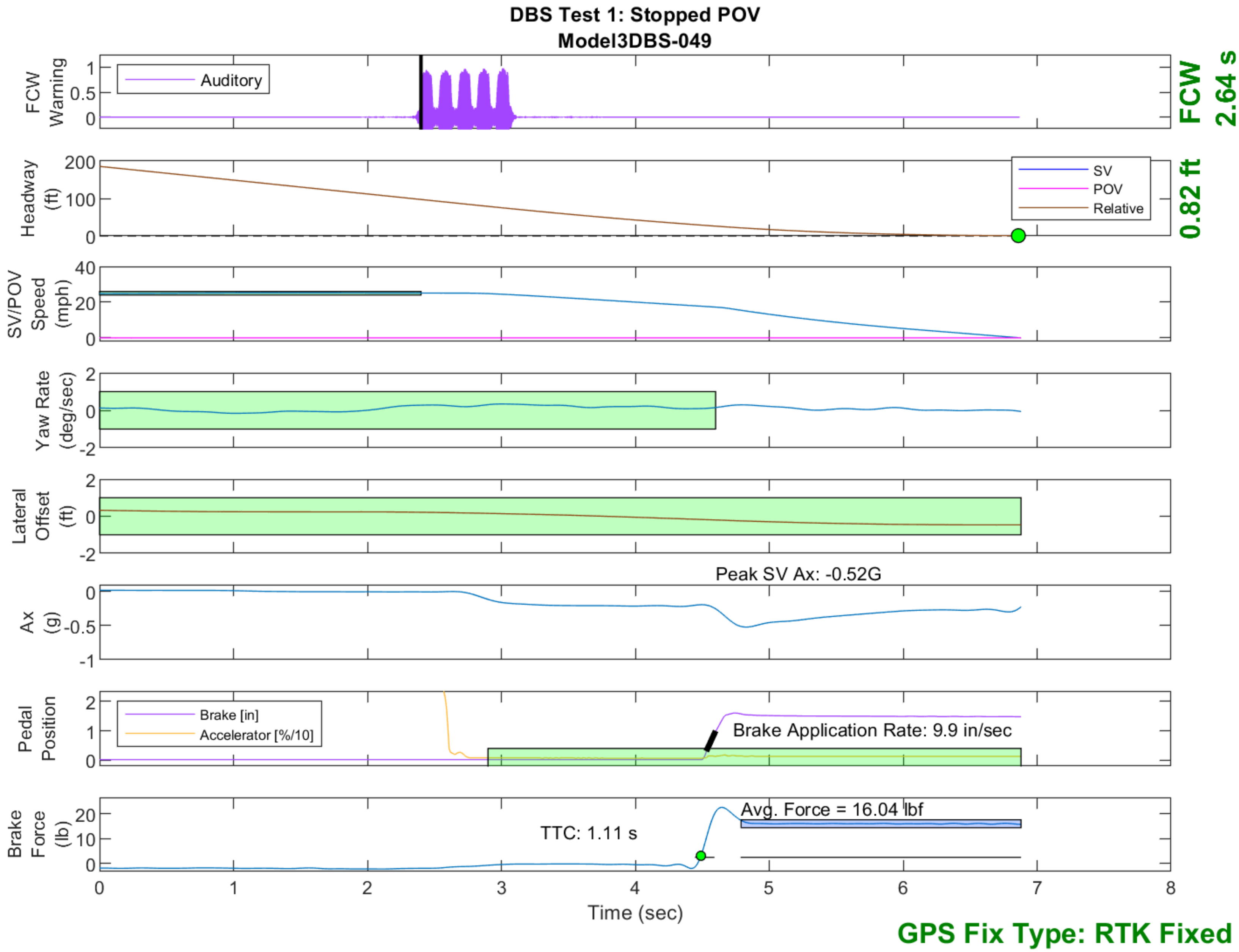


Figure E20. Time History for DBS Run 49, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~51%

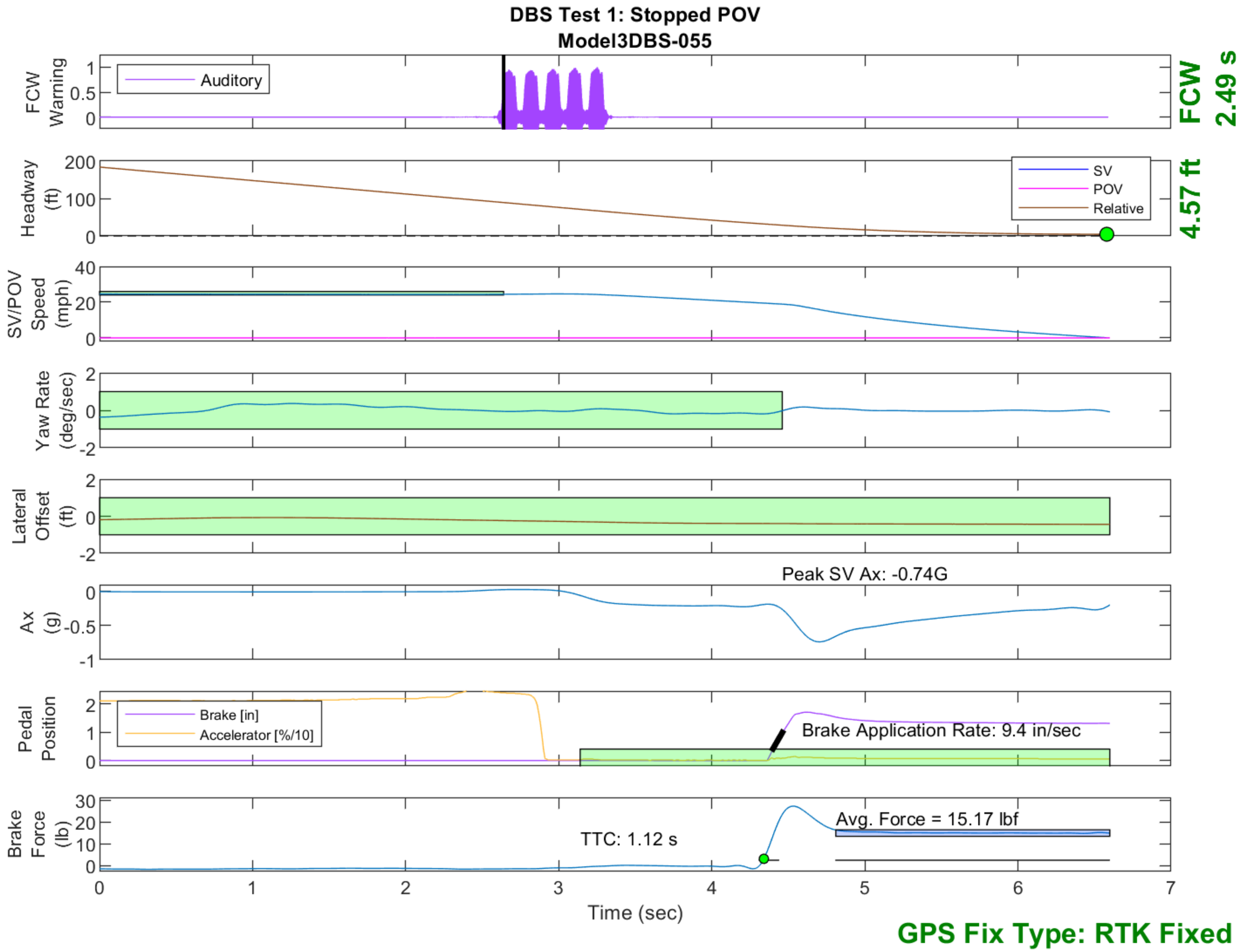


Figure E21. Time History for DBS Run 55, Test 1 - Stopped POV, Roll Mode, Battery SOC = ~83%

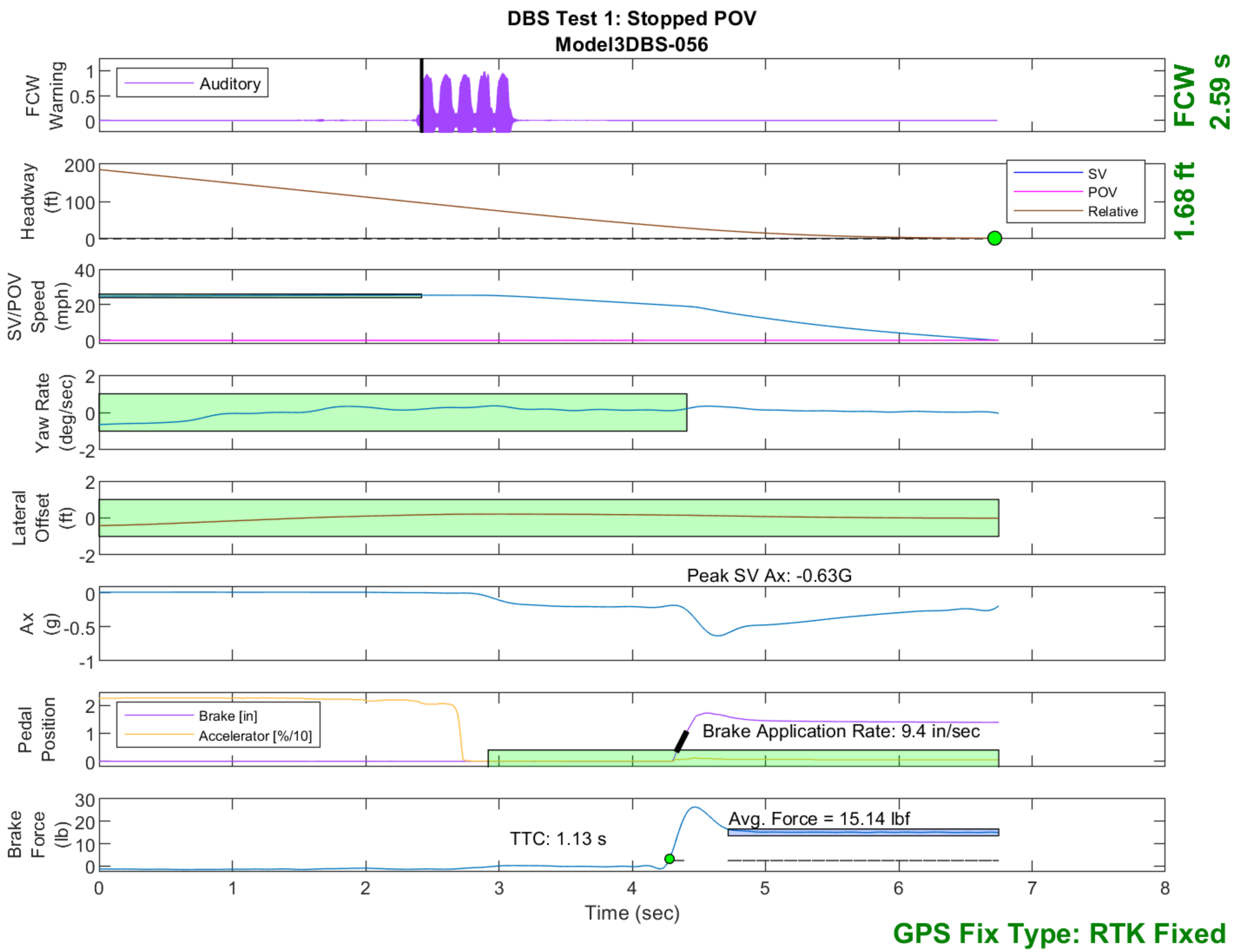


Figure E22. Time History for DBS Run 56, Test 1 - Stopped POV, Roll Mode, Battery SOC = ~83%

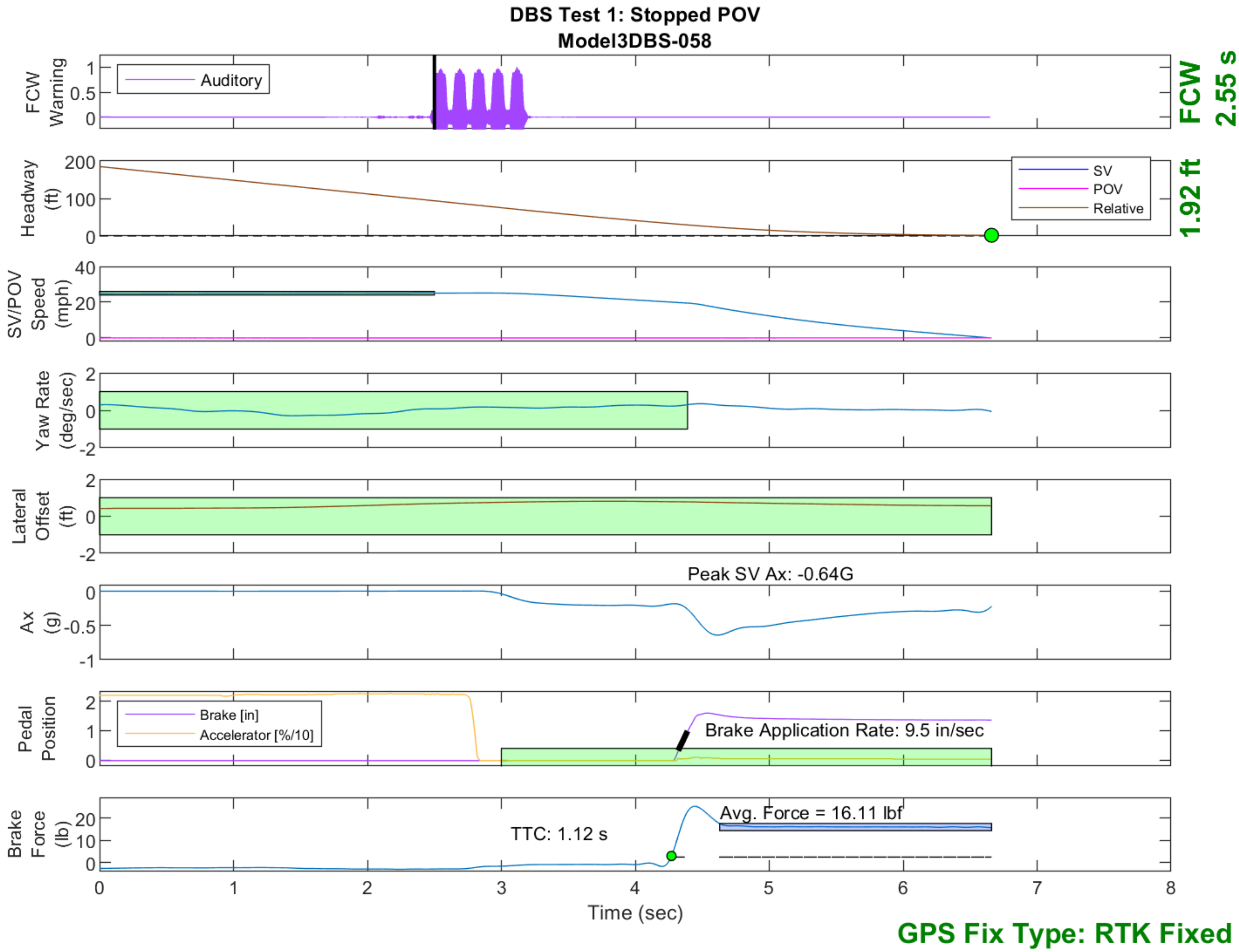


Figure E23. Time History for DBS Run 58, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~83%

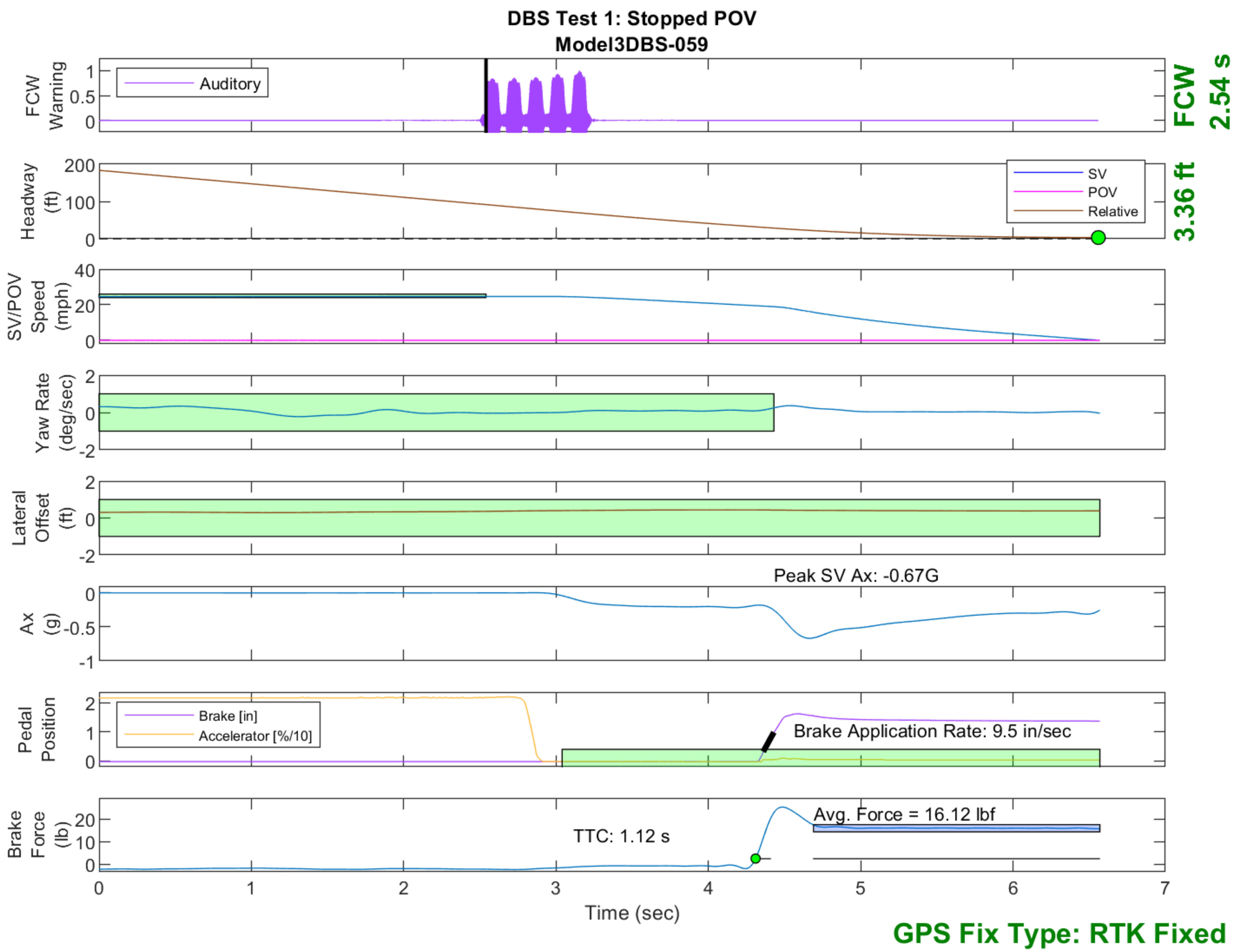


Figure E24. Time History for DBS Run 59, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~83%

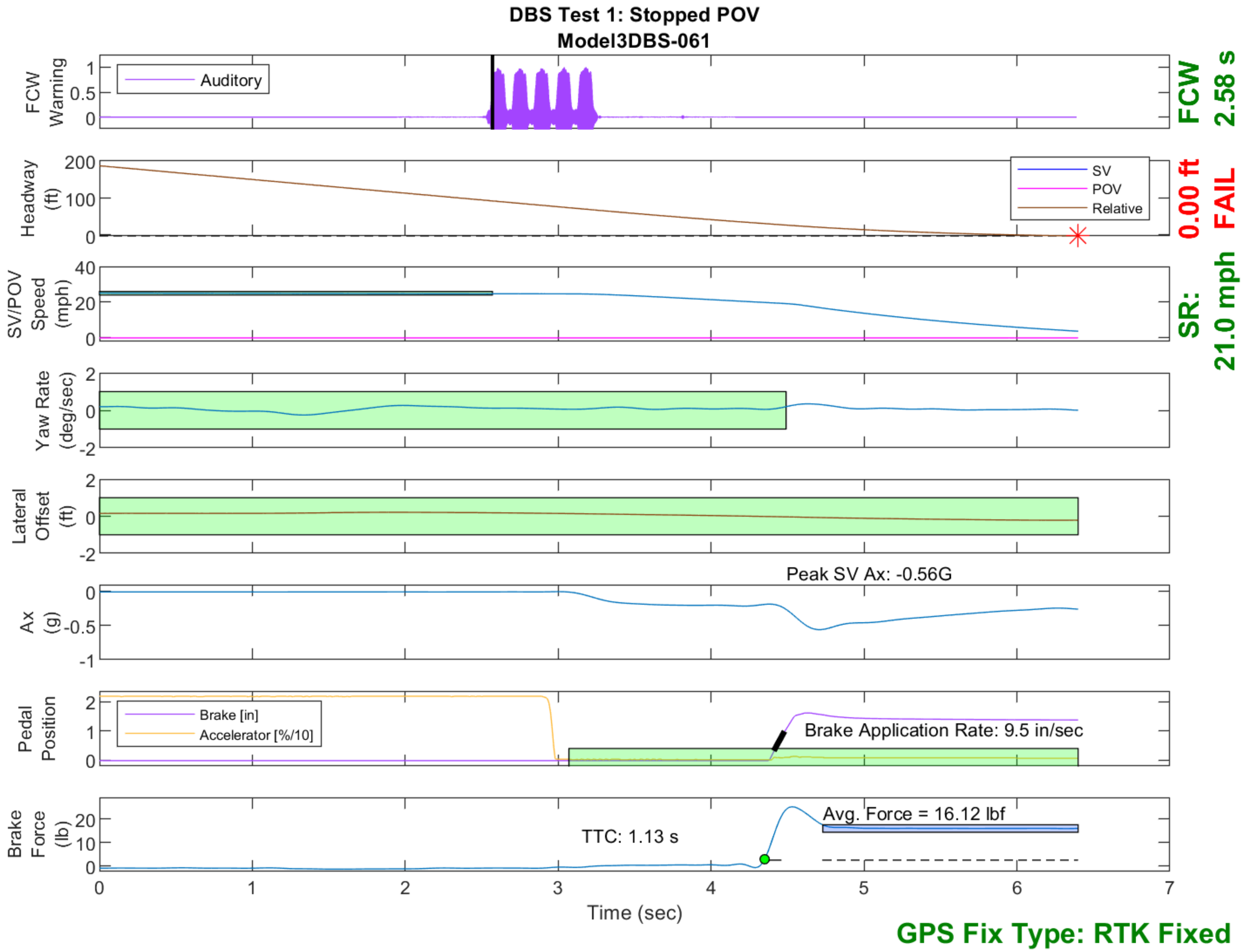


Figure E25. Time History for DBS Run 61, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~83%

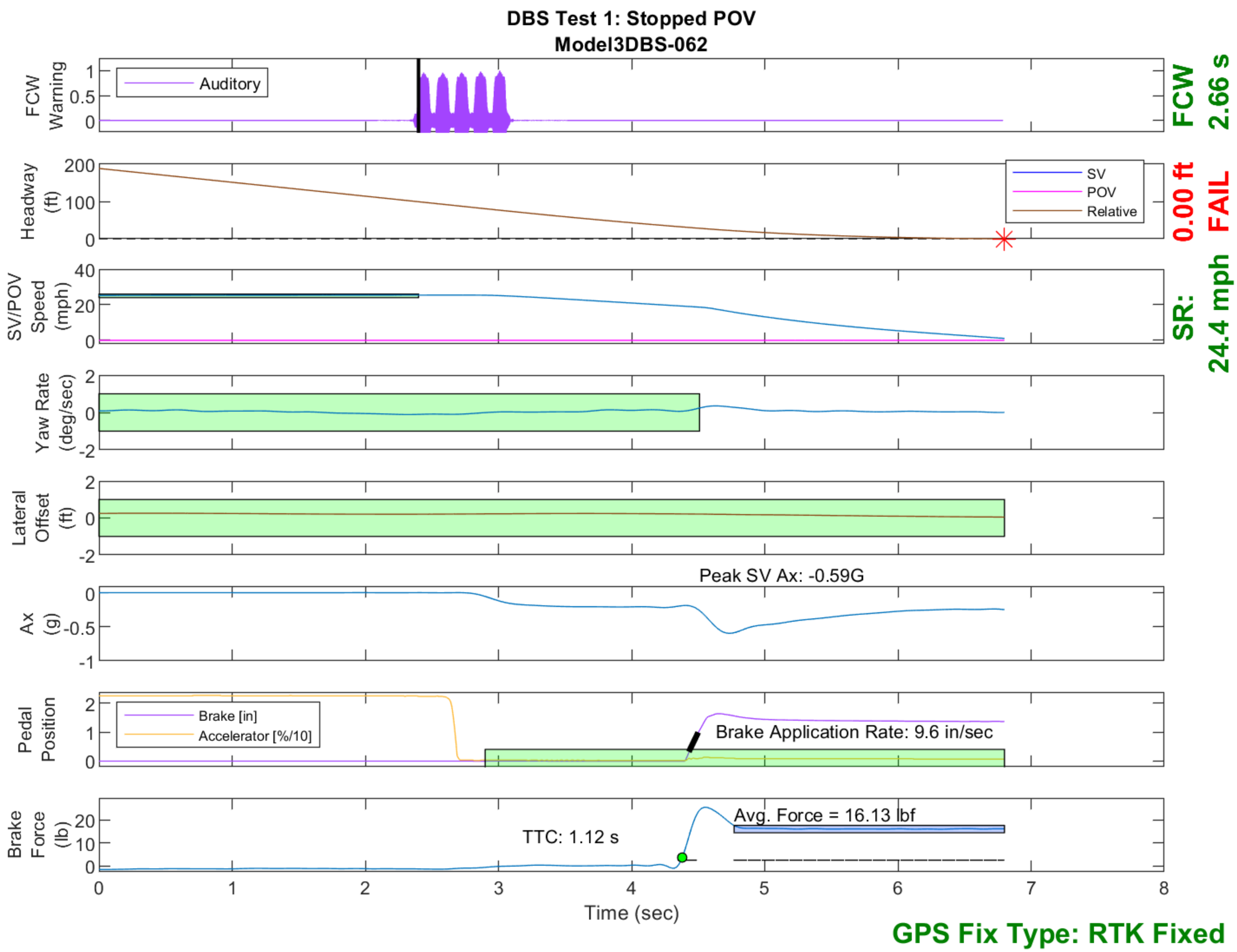


Figure E26. Time History for DBS Run 62, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~83%

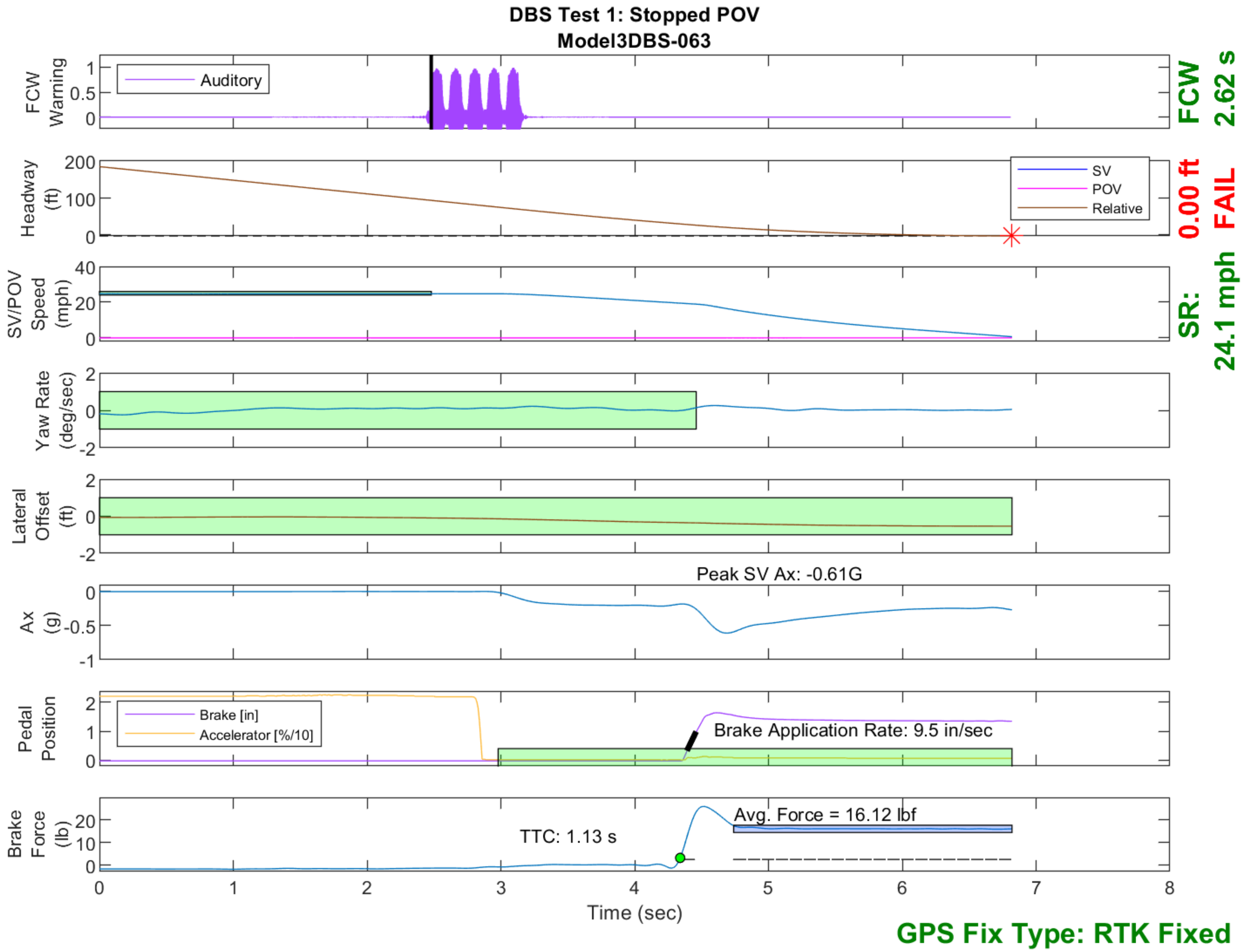


Figure E27. Time History for DBS Run 63, Test 1 - Stopped POV, Creep Mode, Battery SOC = ~83%

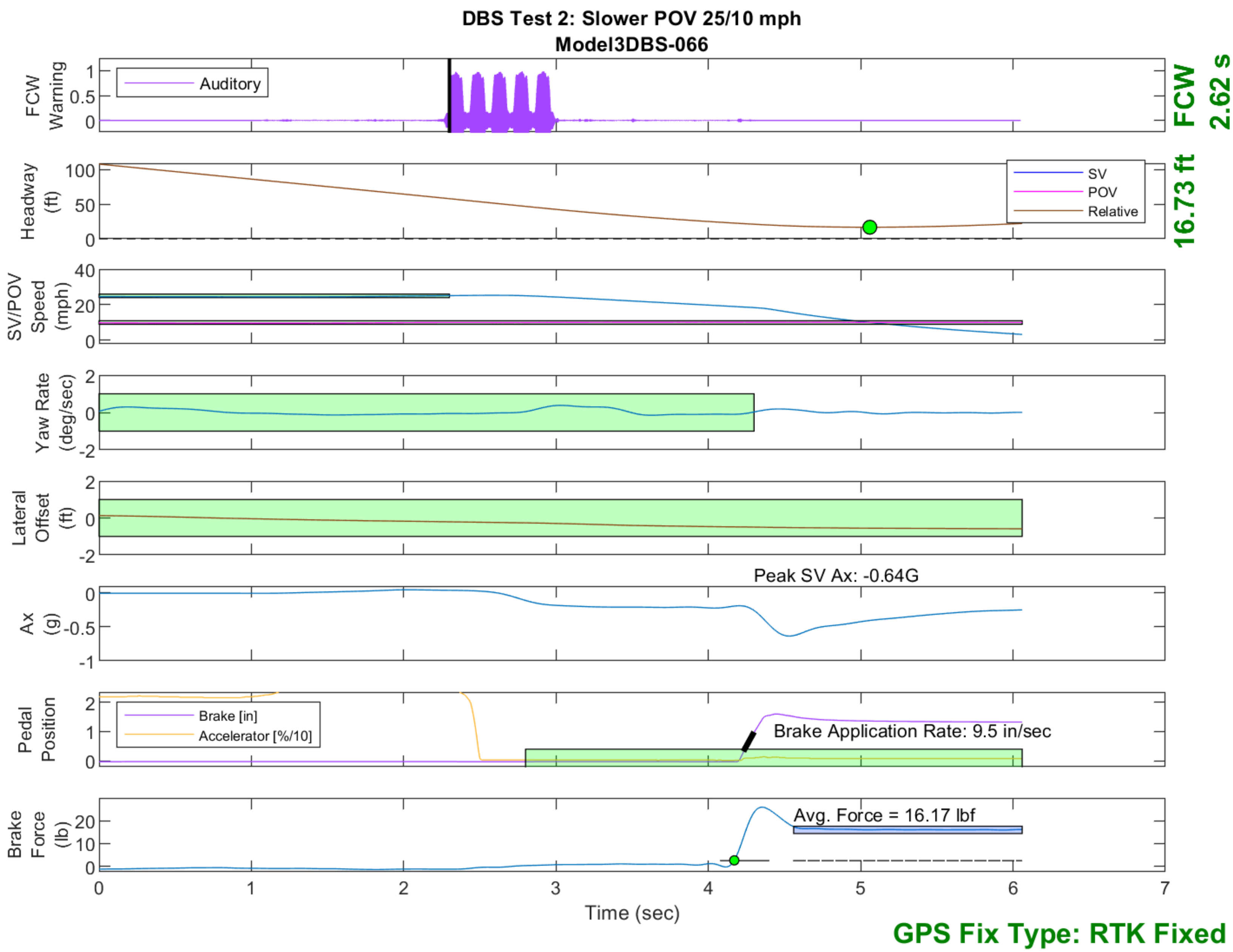


Figure E28. Time History for DBS Run 66, Test 2 - Slower Moving POV 25/10 mph, Creep Mode, Battery SOC = ~81%

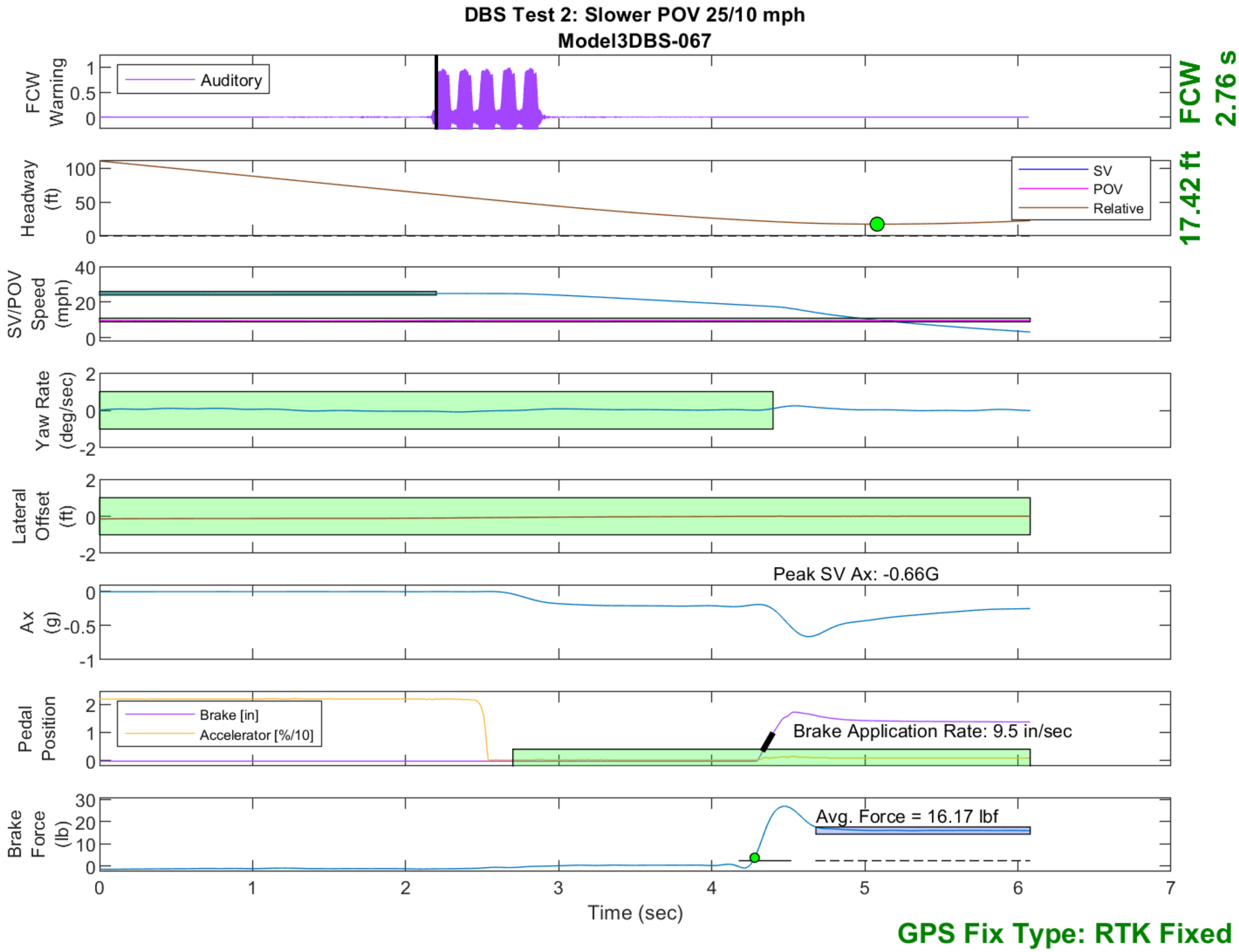


Figure E29. Time History for DBS Run 67, Test 2 - Slower Moving POV 25/10 mph, Creep Mode, Battery SOC = ~81%

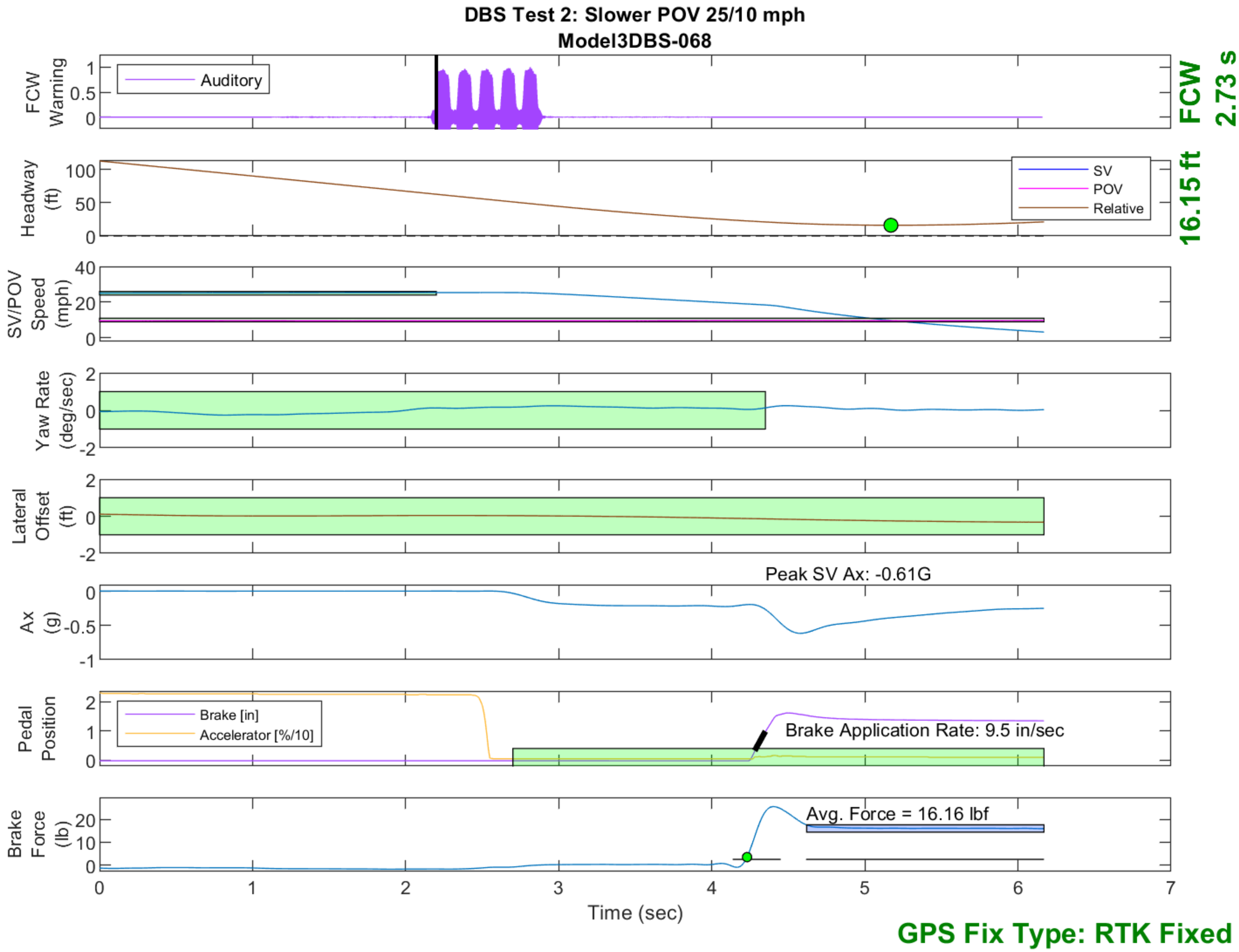


Figure E30. Time History for DBS Run 68, Test 2 - Slower Moving POV 25/10 mph, Creep Mode, Battery SOC = ~81%

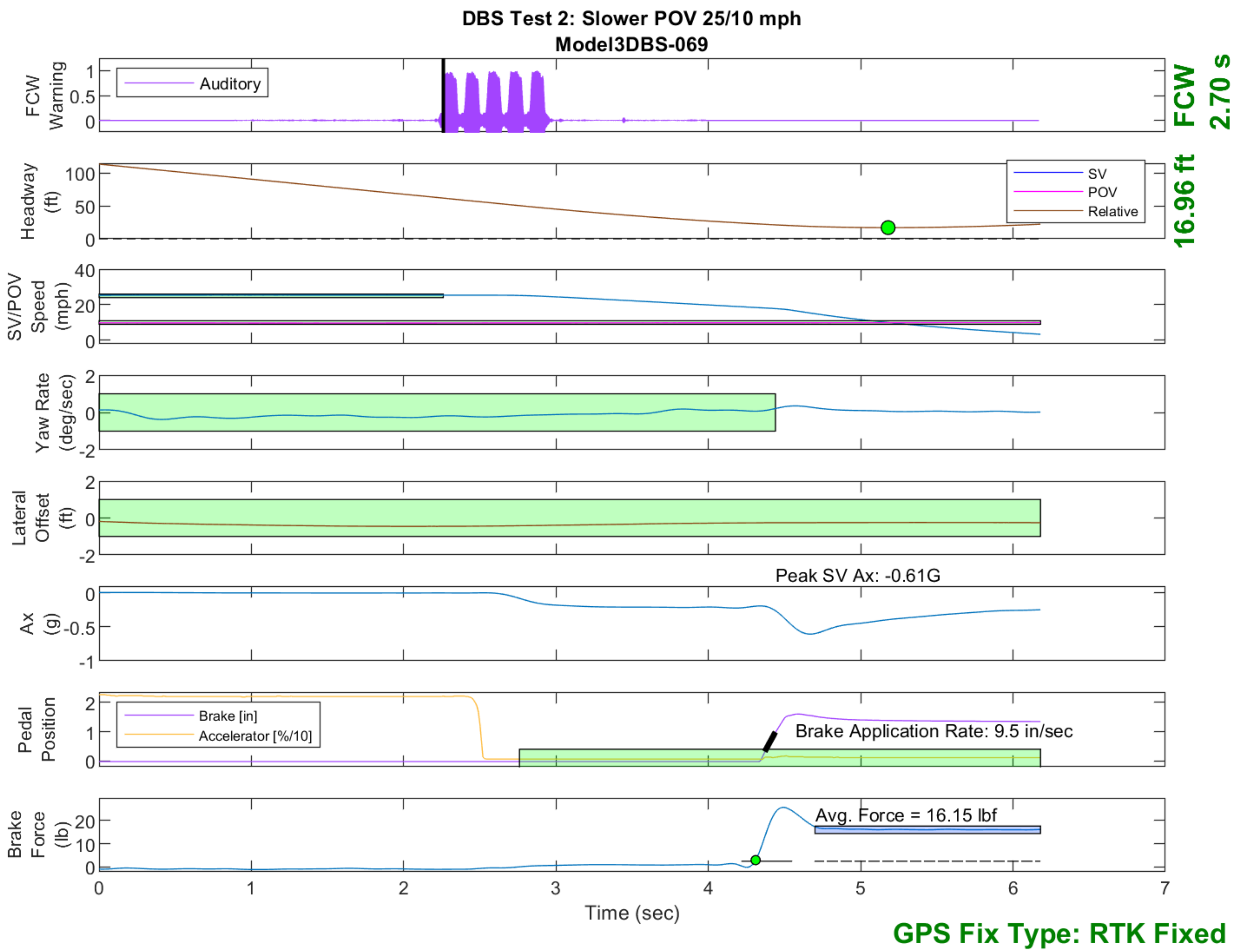


Figure E31. Time History for DBS Run 69, Test 2 - Slower Moving POV 25/10 mph, Creep Mode, Battery SOC = ~81%

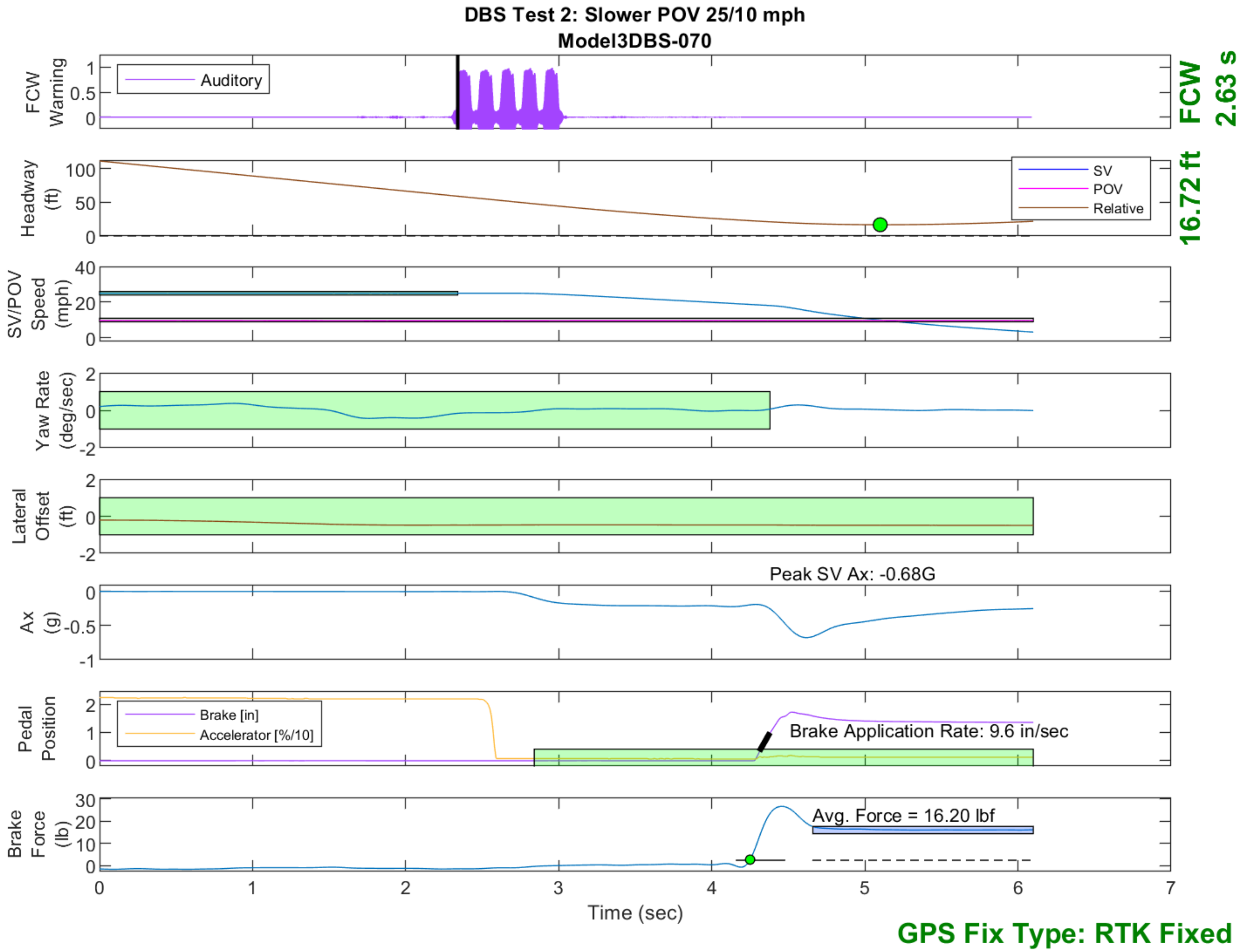


Figure E32. Time History for DBS Run 70, Test 2 - Slower Moving POV 25/10 mph, Creep Mode, Battery SOC = ~81%

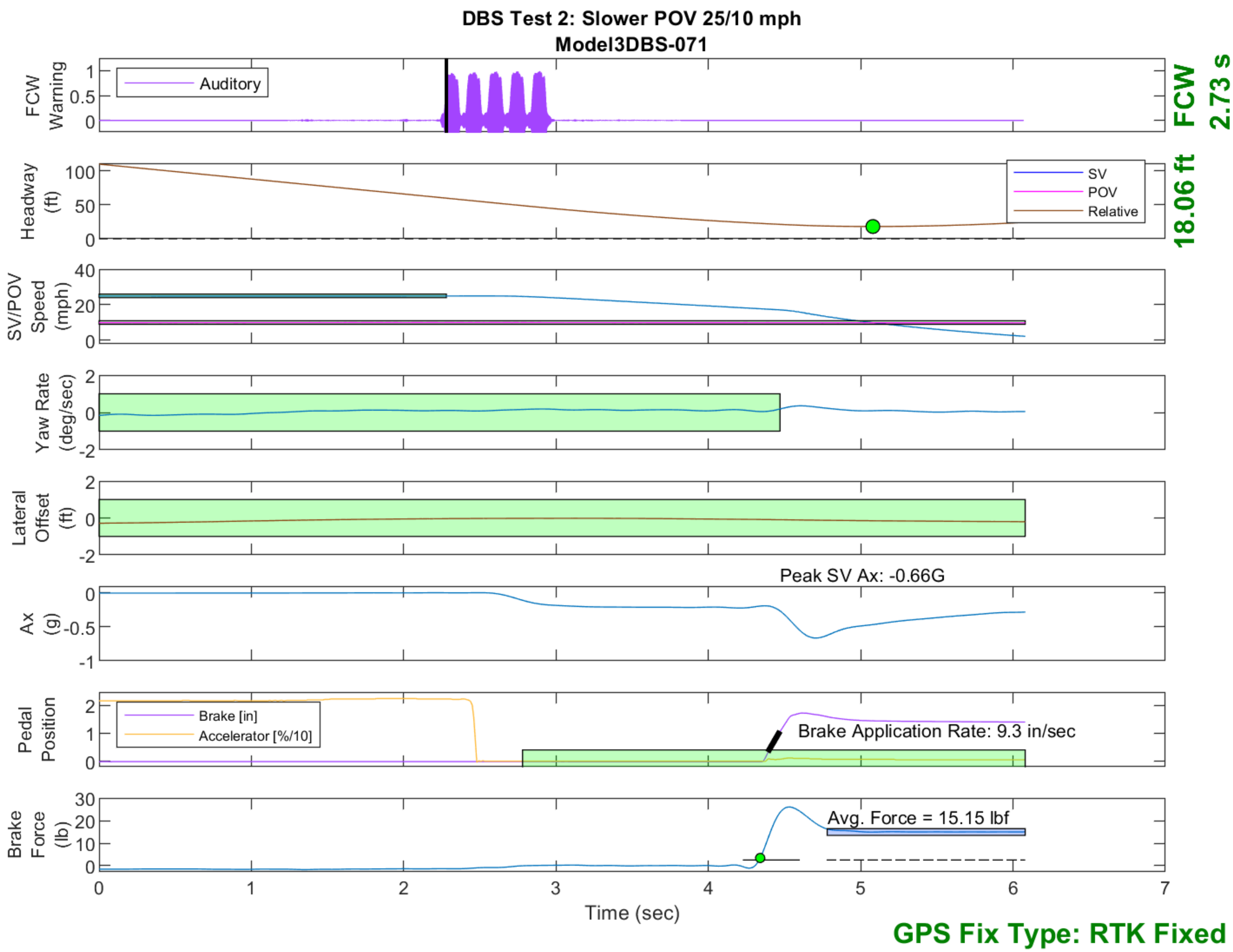


Figure E33. Time History for DBS Run 71, Test 2 - Slower Moving POV 25/10 mph, Roll Mode, Battery SOC = ~81%

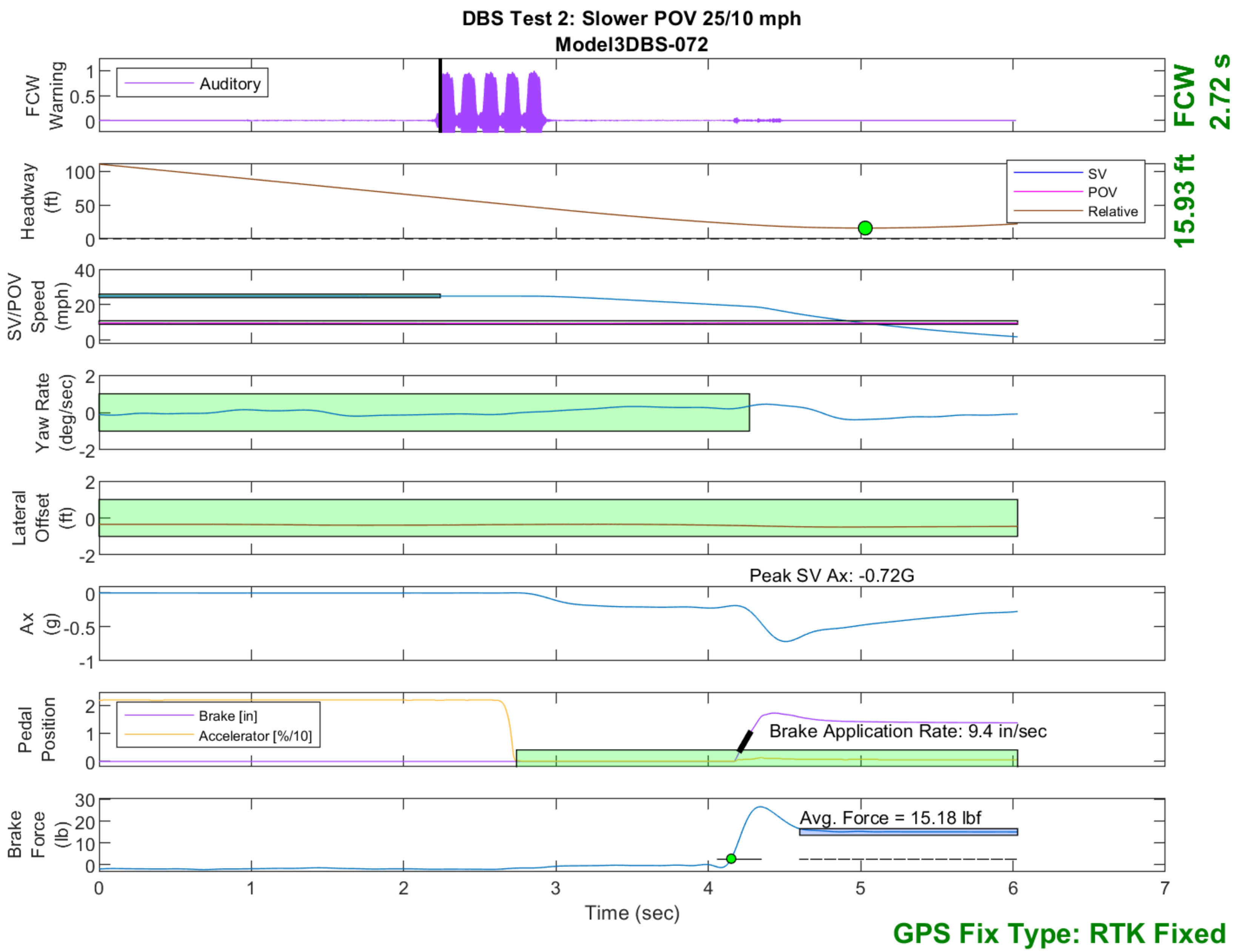


Figure E34. Time History for DBS Run 72, Test 2 - Slower Moving POV 25/10 mph, Roll Mode, Battery SOC = ~81%

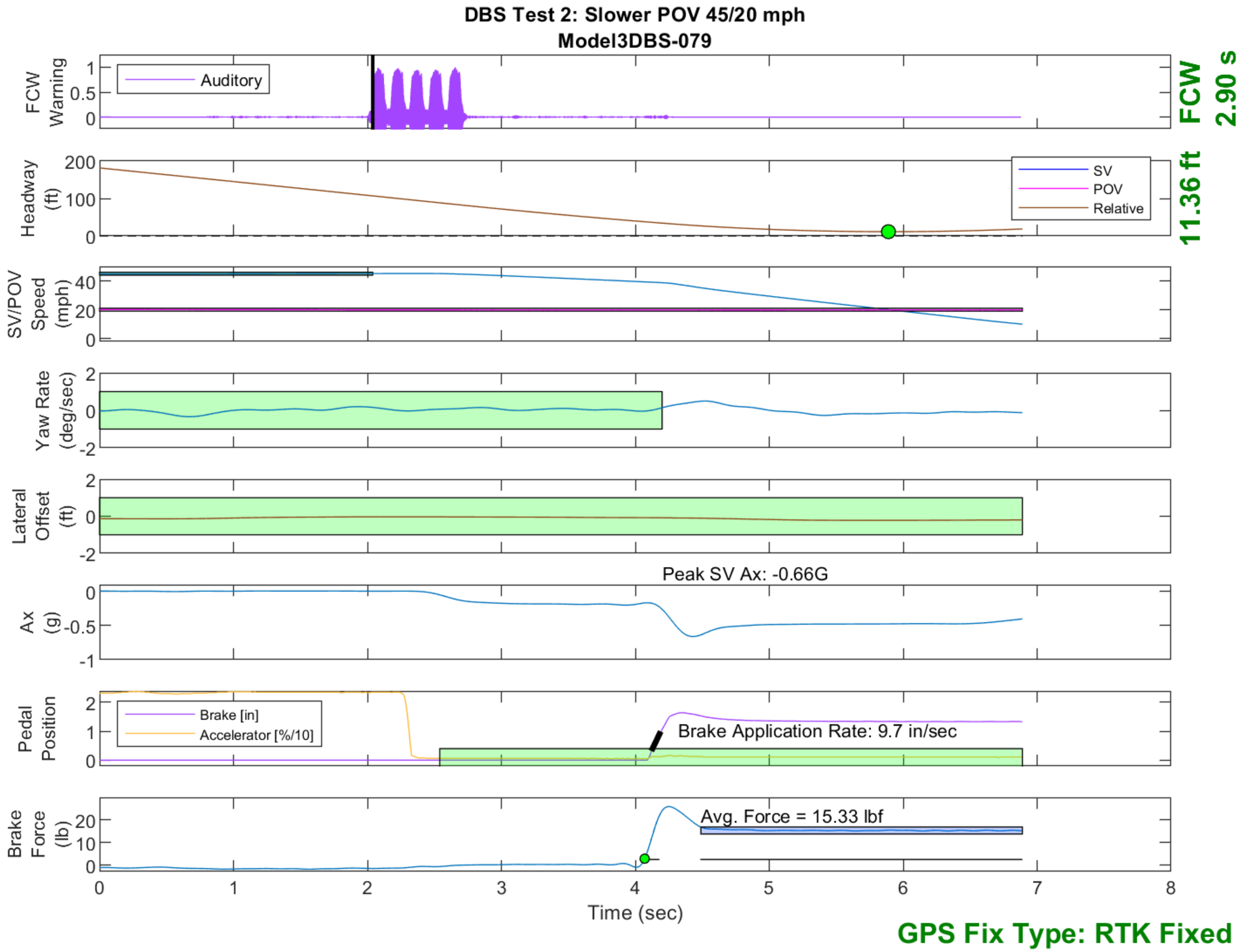


Figure E35. Time History for DBS Run 79, Test 2 - Slower Moving POV 45/20 mph, Creep Mode, Battery SOC = ~75%

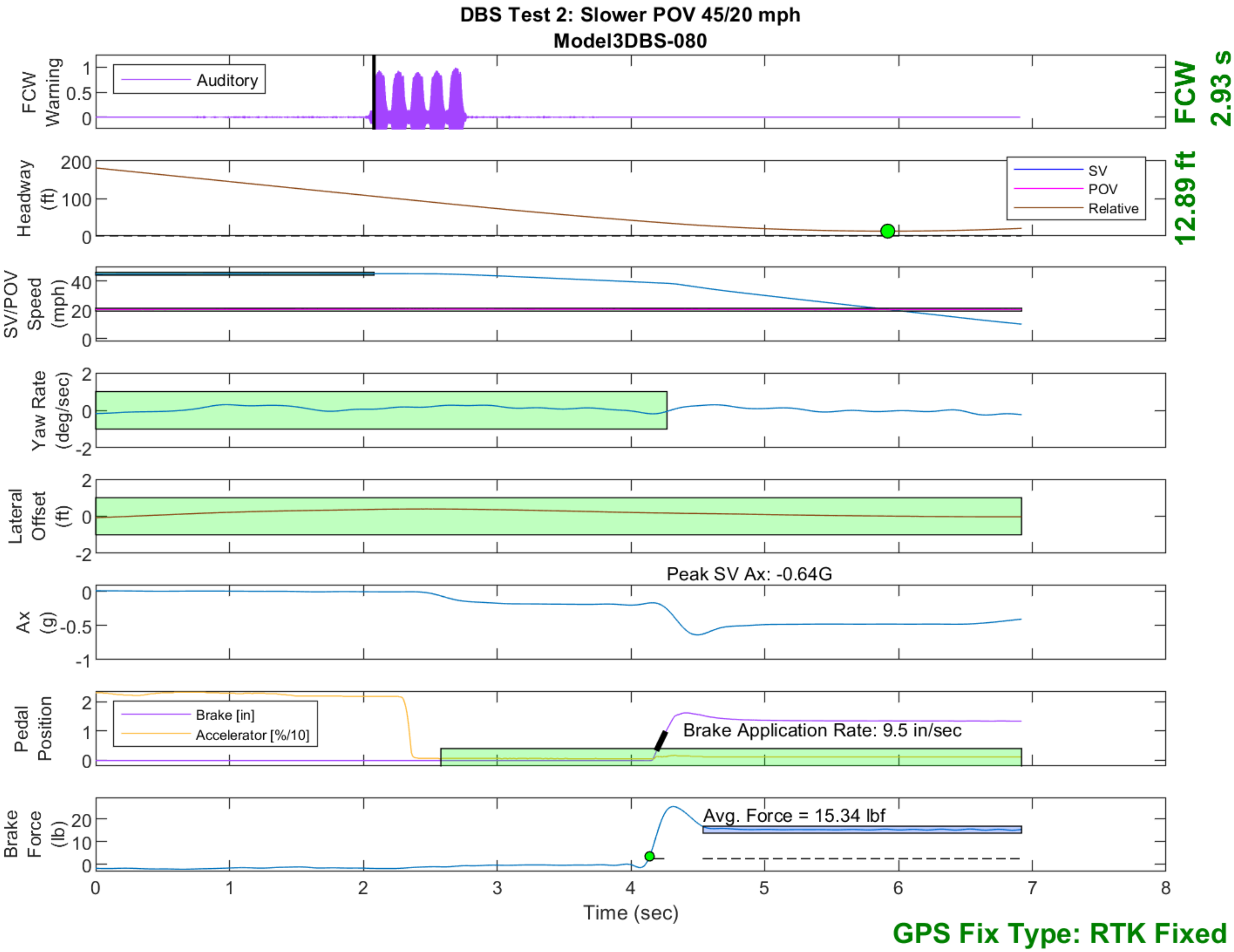


Figure E36. Time History for DBS Run 80, Test 2 - Slower Moving POV 45/20 mph, Creep Mode, Battery SOC = ~75%

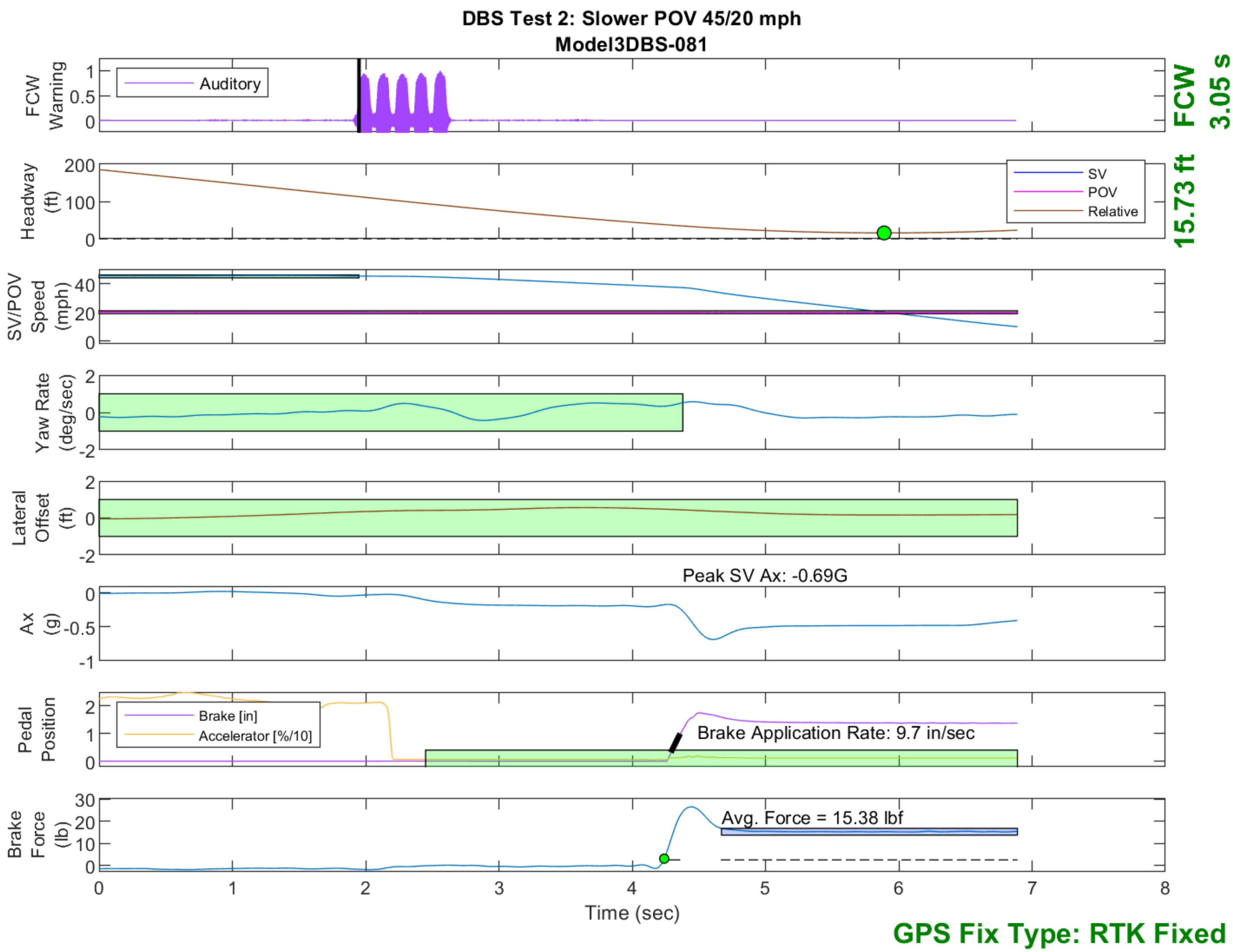


Figure E37. Time History for DBS Run 81, Test 2 - Slower Moving POV 45/20 mph, Creep Mode, Battery SOC = ~75%

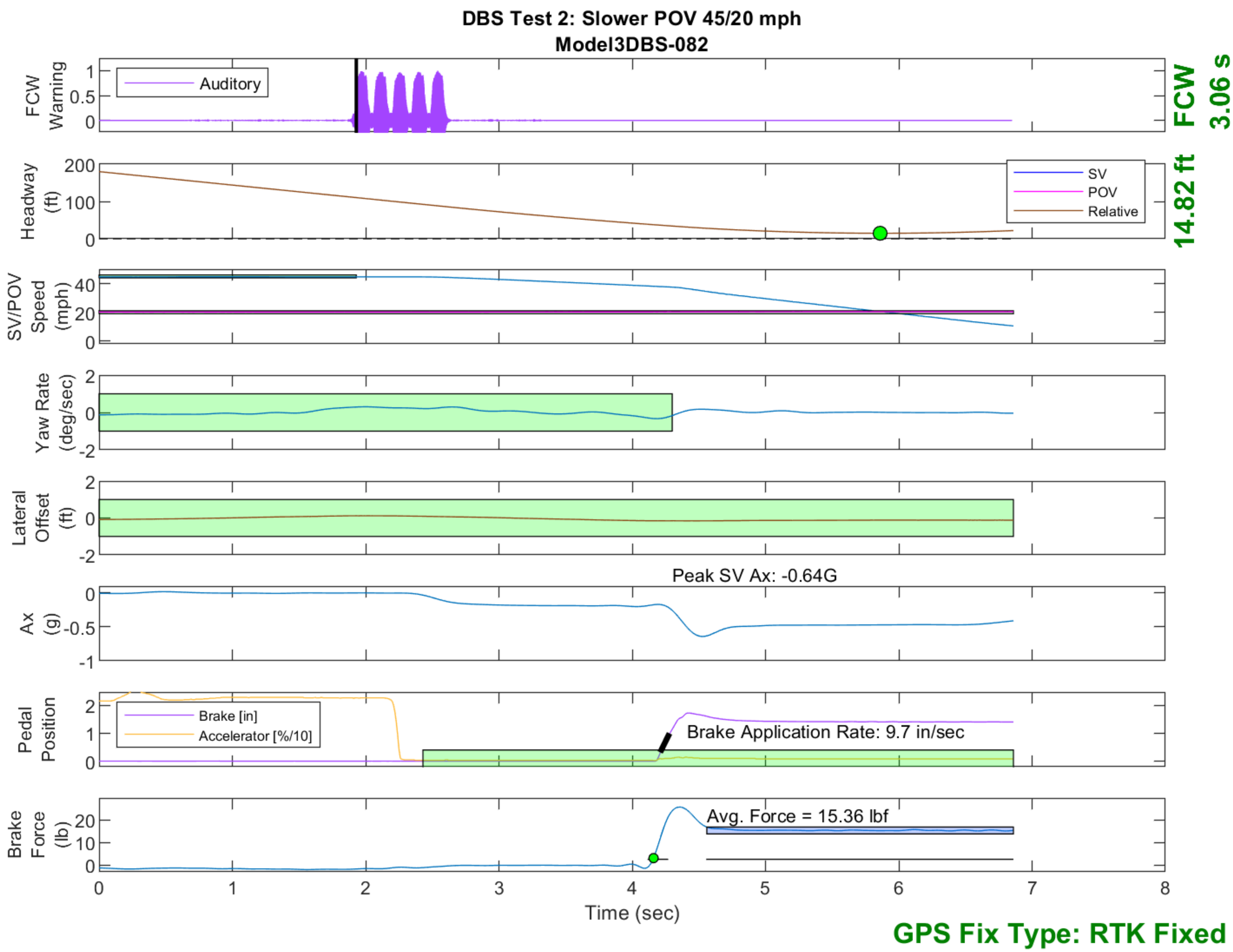


Figure E38. Time History for DBS Run 82, Test 2 - Slower Moving POV 45/20 mph, Creep Mode, Battery SOC = ~75%

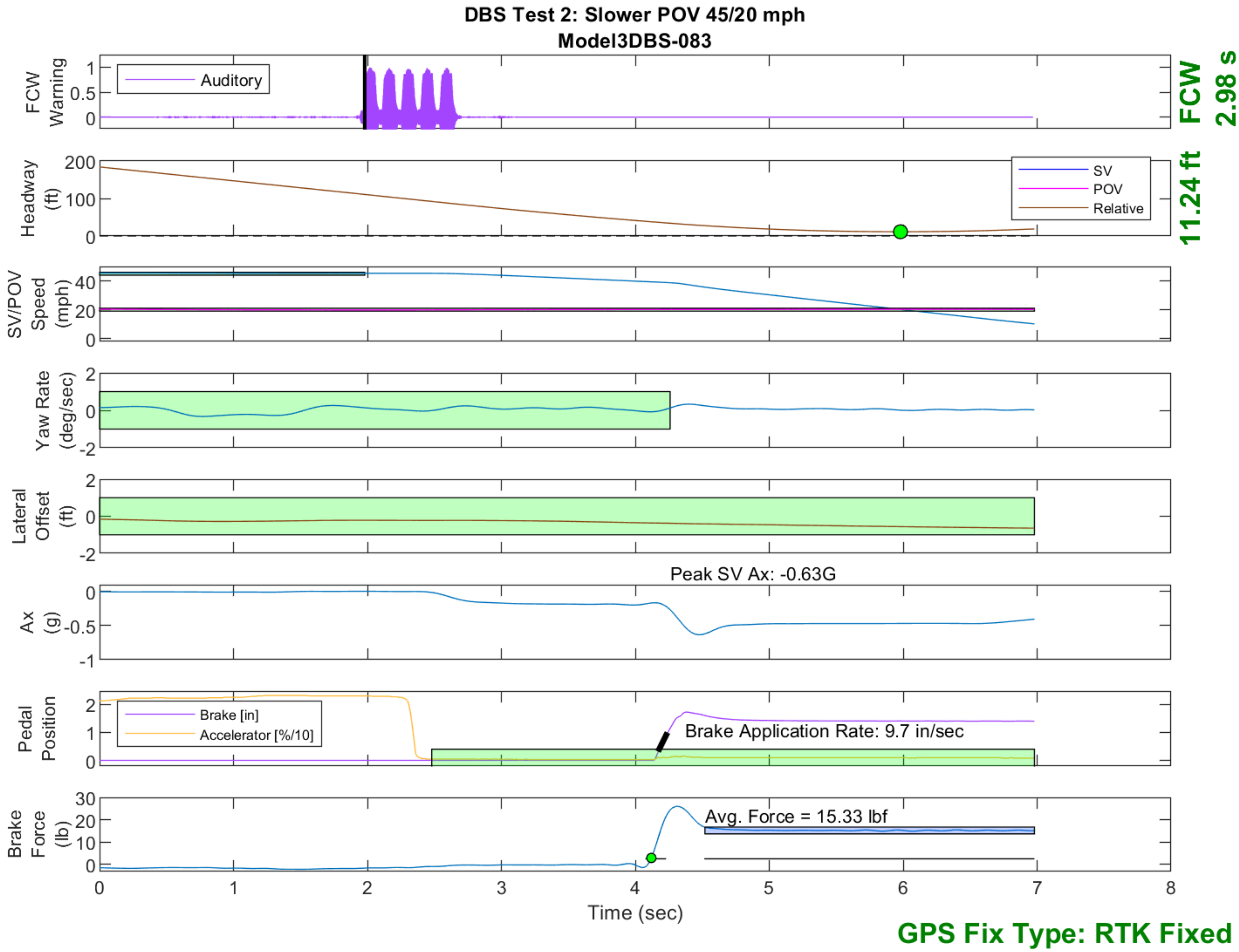


Figure E39. Time History for DBS Run 83, Test 2 - Slower Moving POV 45/20 mph, Creep Mode, Battery SOC = ~75%

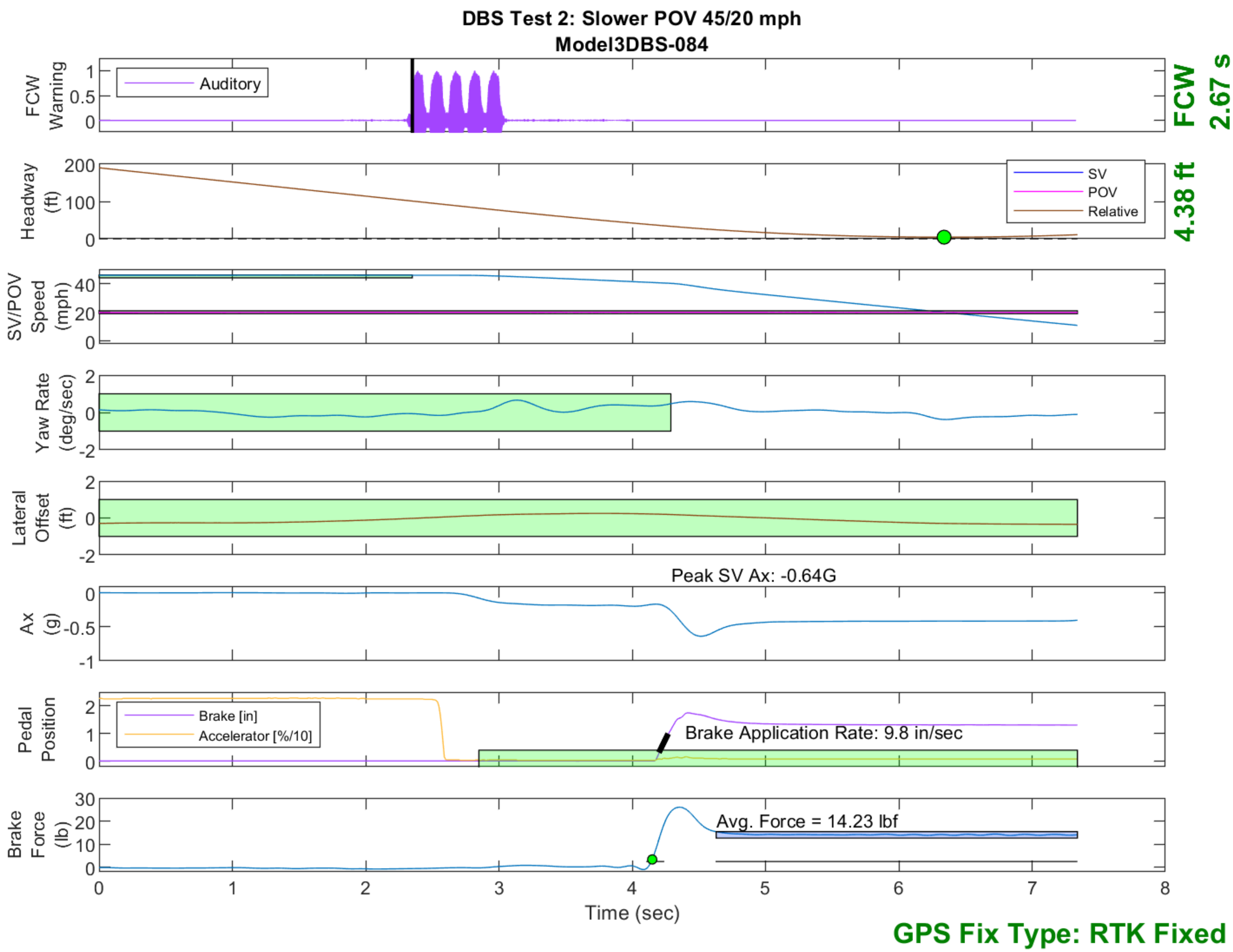


Figure E40. Time History for DBS Run 84, Test 2 - Slower Moving POV 45/20 mph, Roll Mode, Battery SOC = ~75%

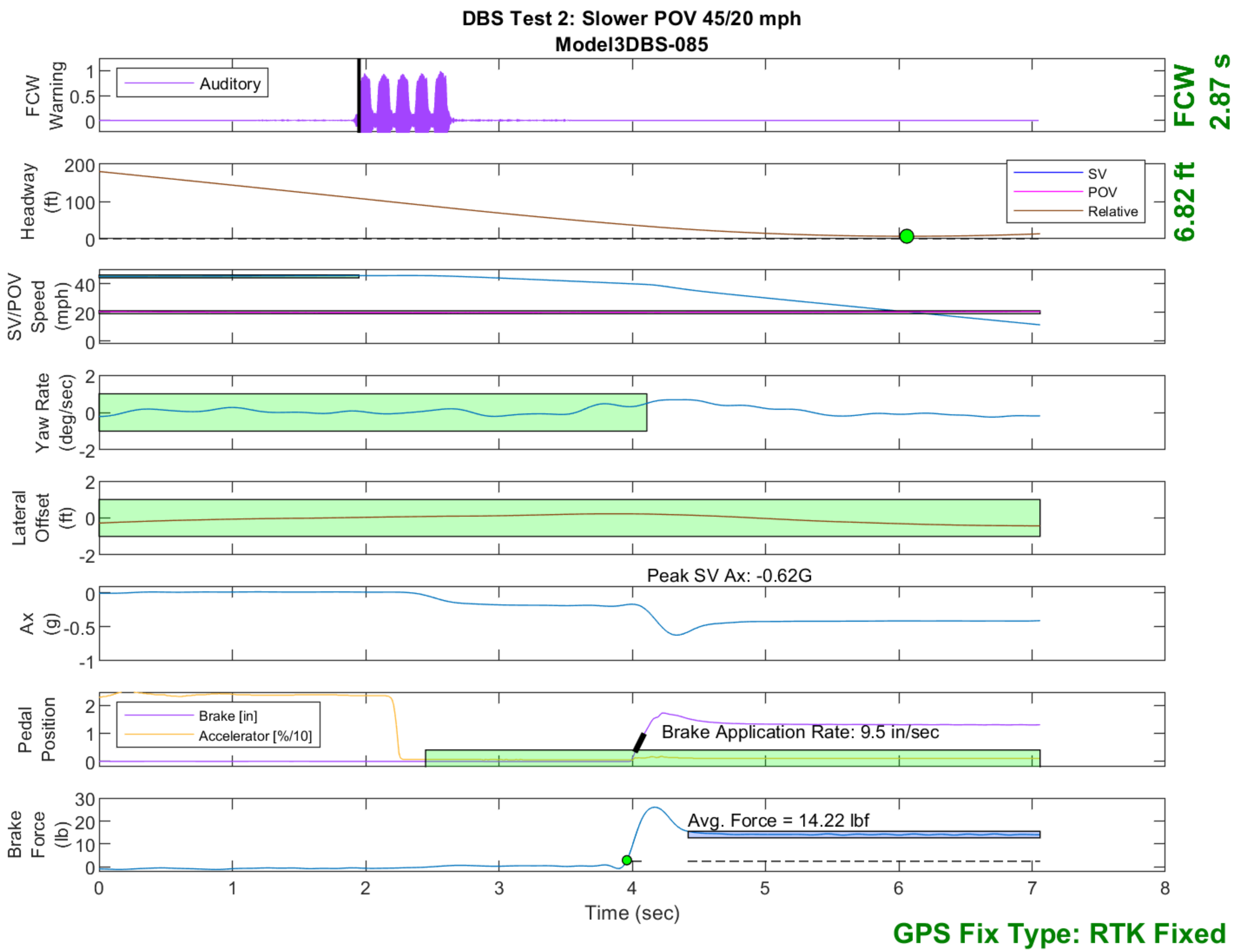


Figure E41. Time History for DBS Run 85, Test 2 - Slower Moving POV 45/20 mph, Roll Mode, Battery SOC = ~75%

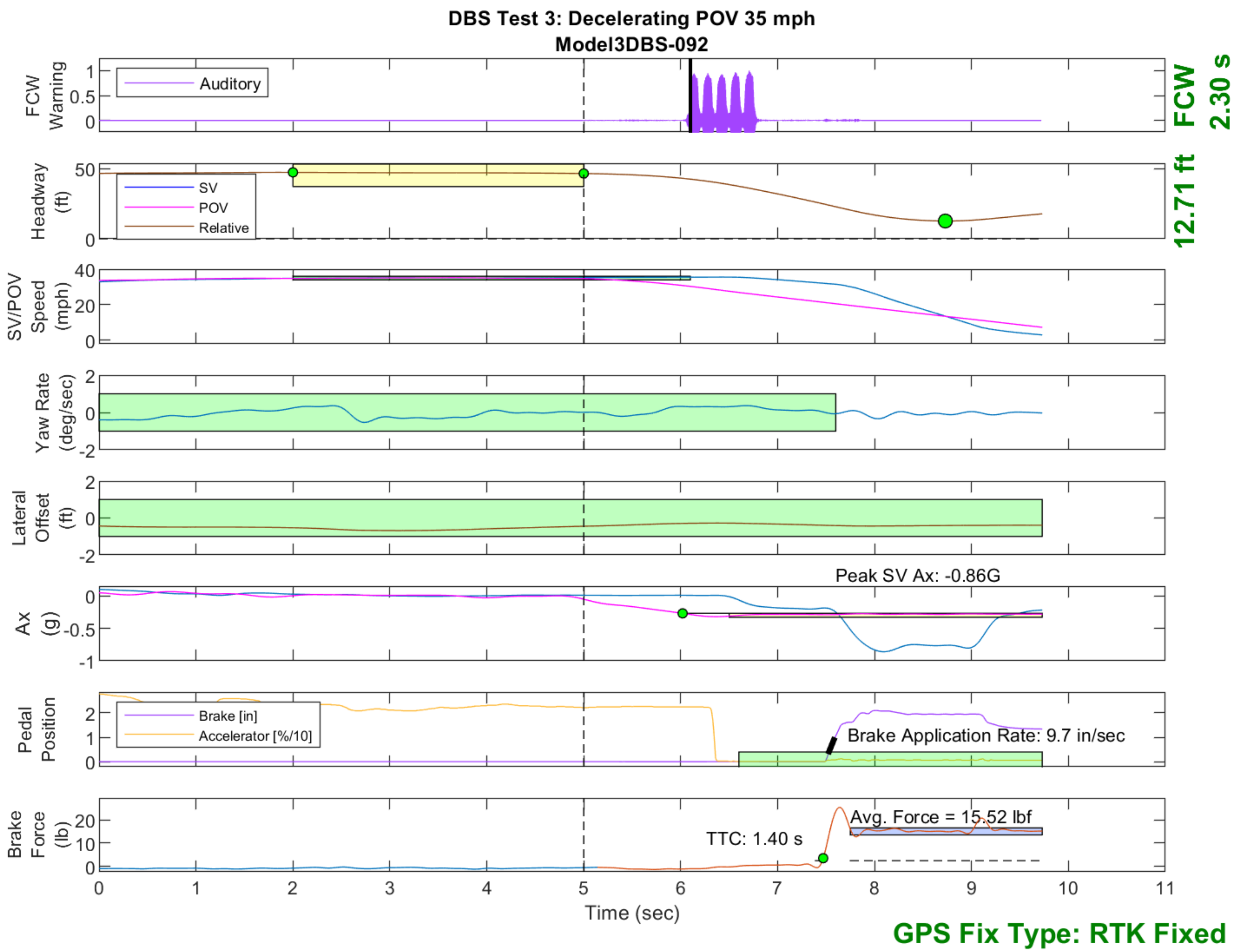


Figure E42. Time History for DBS Run 92, Test 3 - Decelerating POV 35 mph, Roll Mode, Battery SOC = ~70%

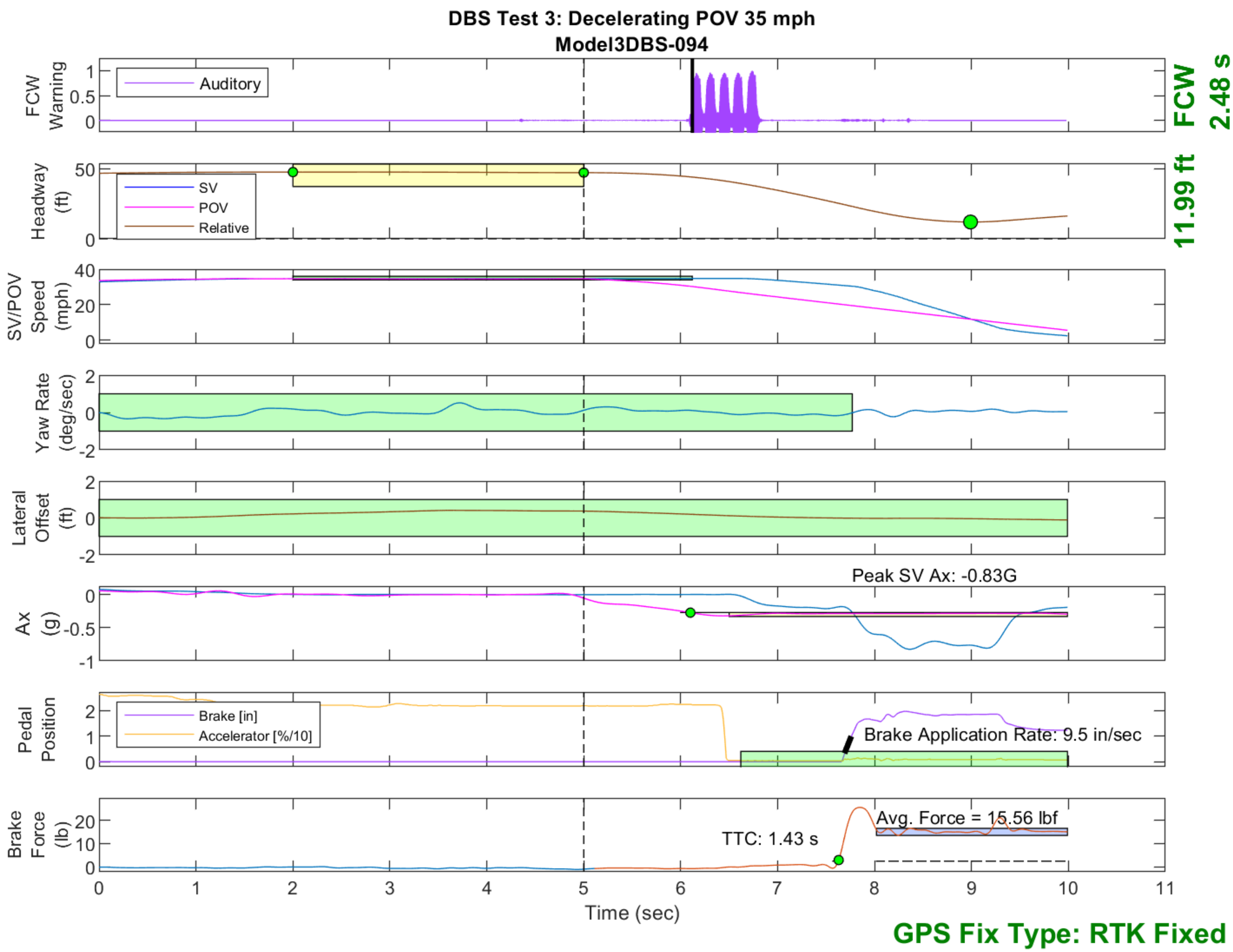


Figure E43. Time History for DBS Run 94, Test 3 - Decelerating POV 35 mph, Roll Mode, Battery SOC = ~70%

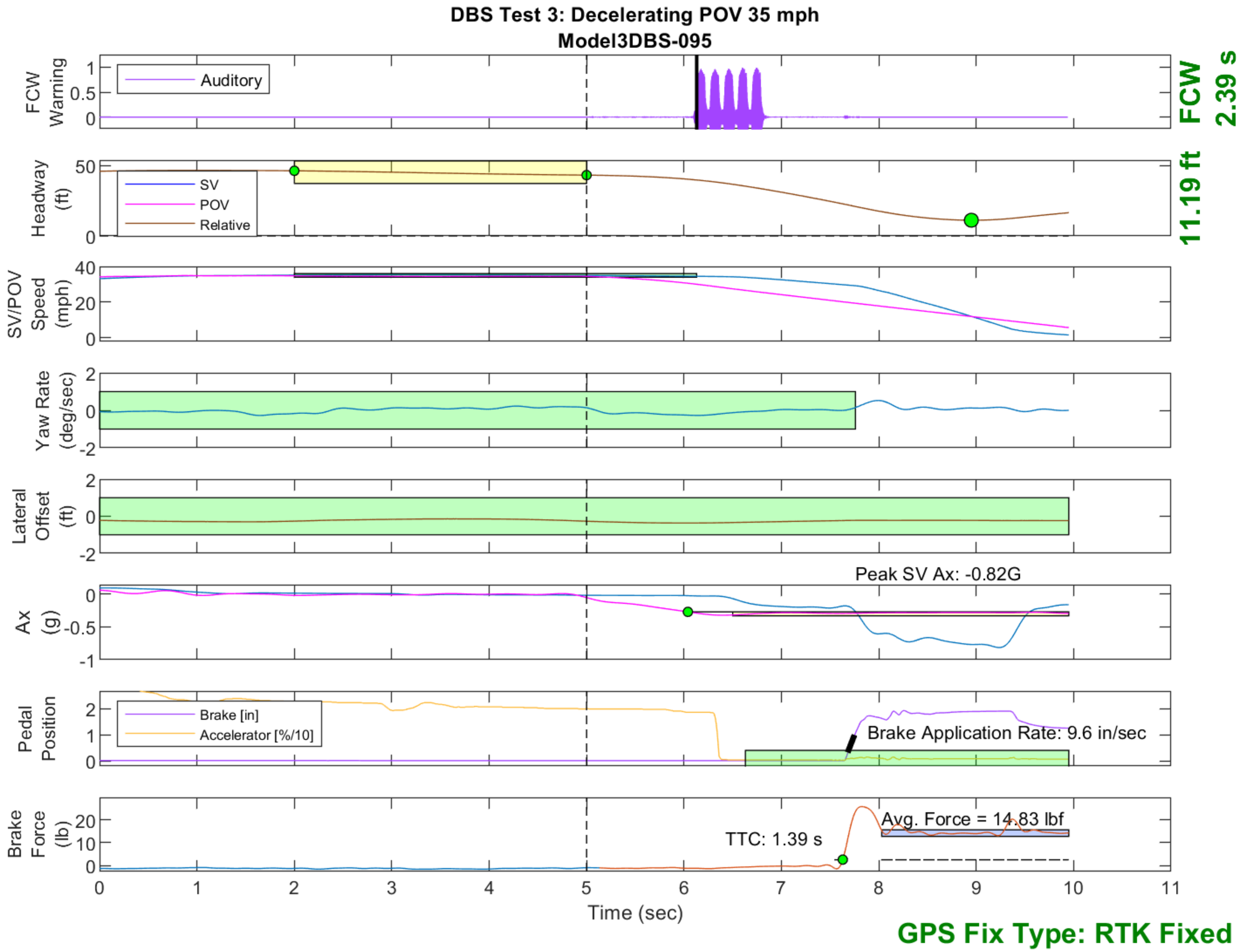


Figure E44. Time History for DBS Run 95, Test 3 - Decelerating POV 35 mph, Creep Mode, Battery SOC = ~70%

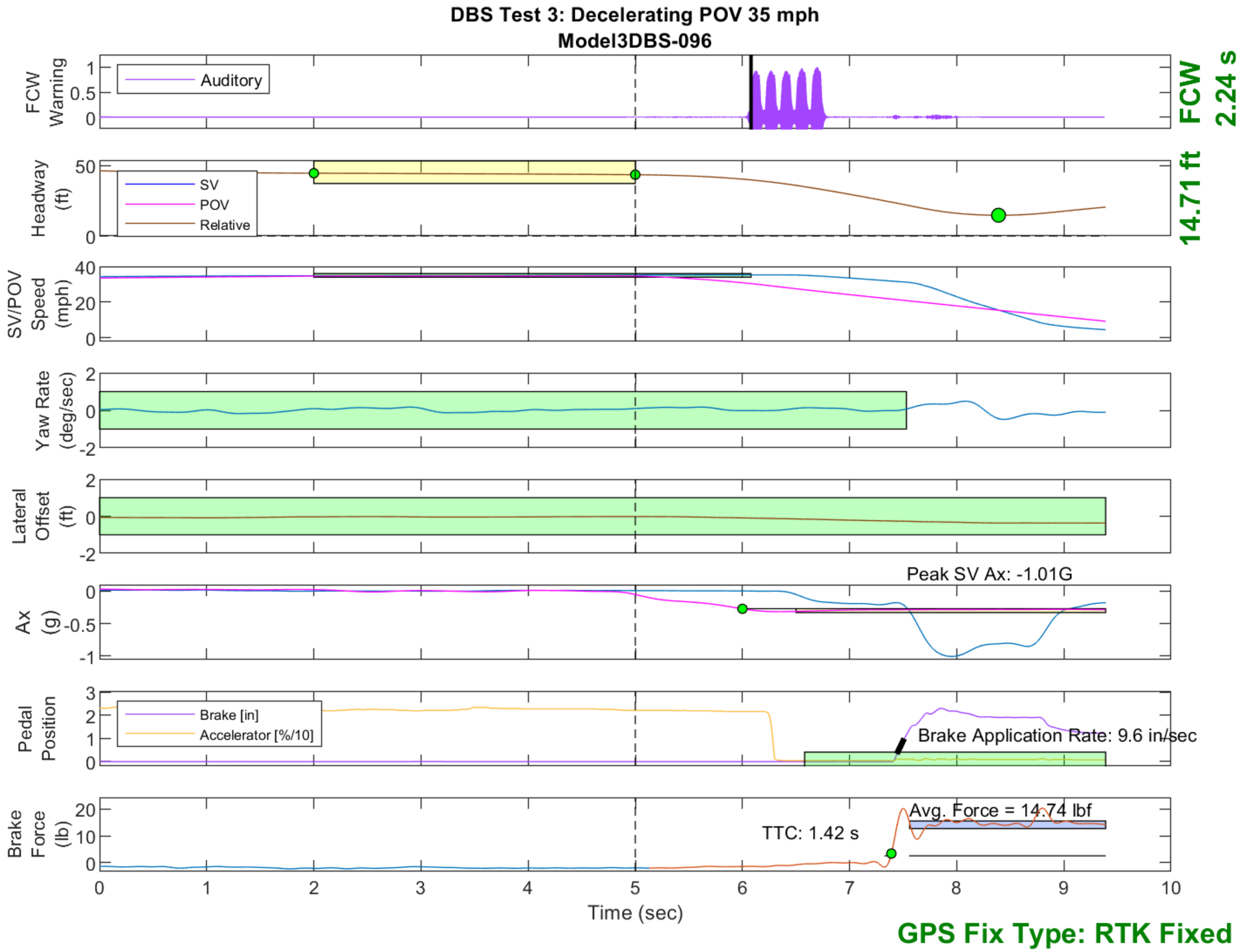


Figure E45. Time History for DBS Run 96, Test 3 - Decelerating POV 35 mph, Creep Mode, Battery SOC = ~70%

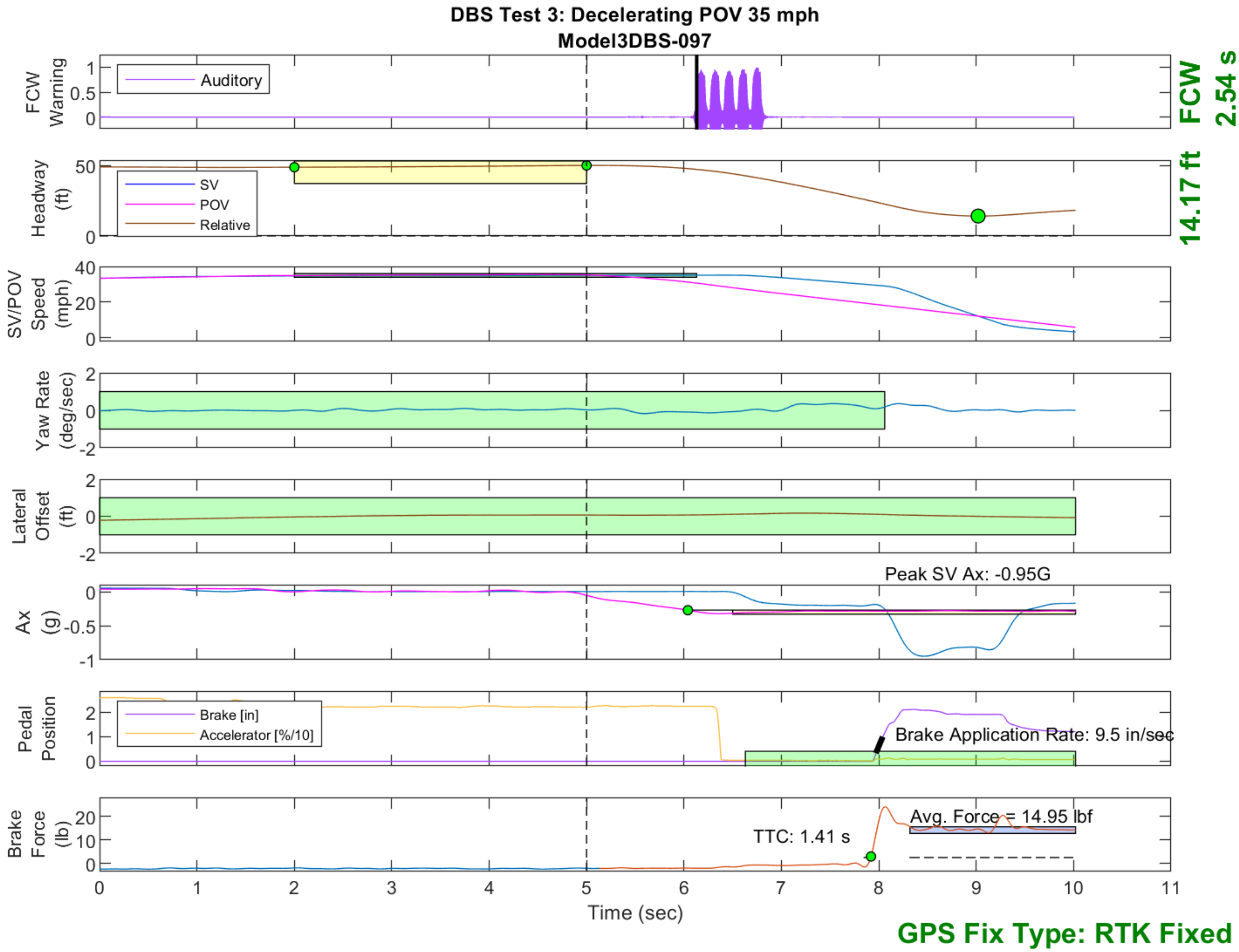


Figure E46. Time History for DBS Run 97, Test 3 - Decelerating POV 35 mph, Creep Mode, Battery SOC = ~70%

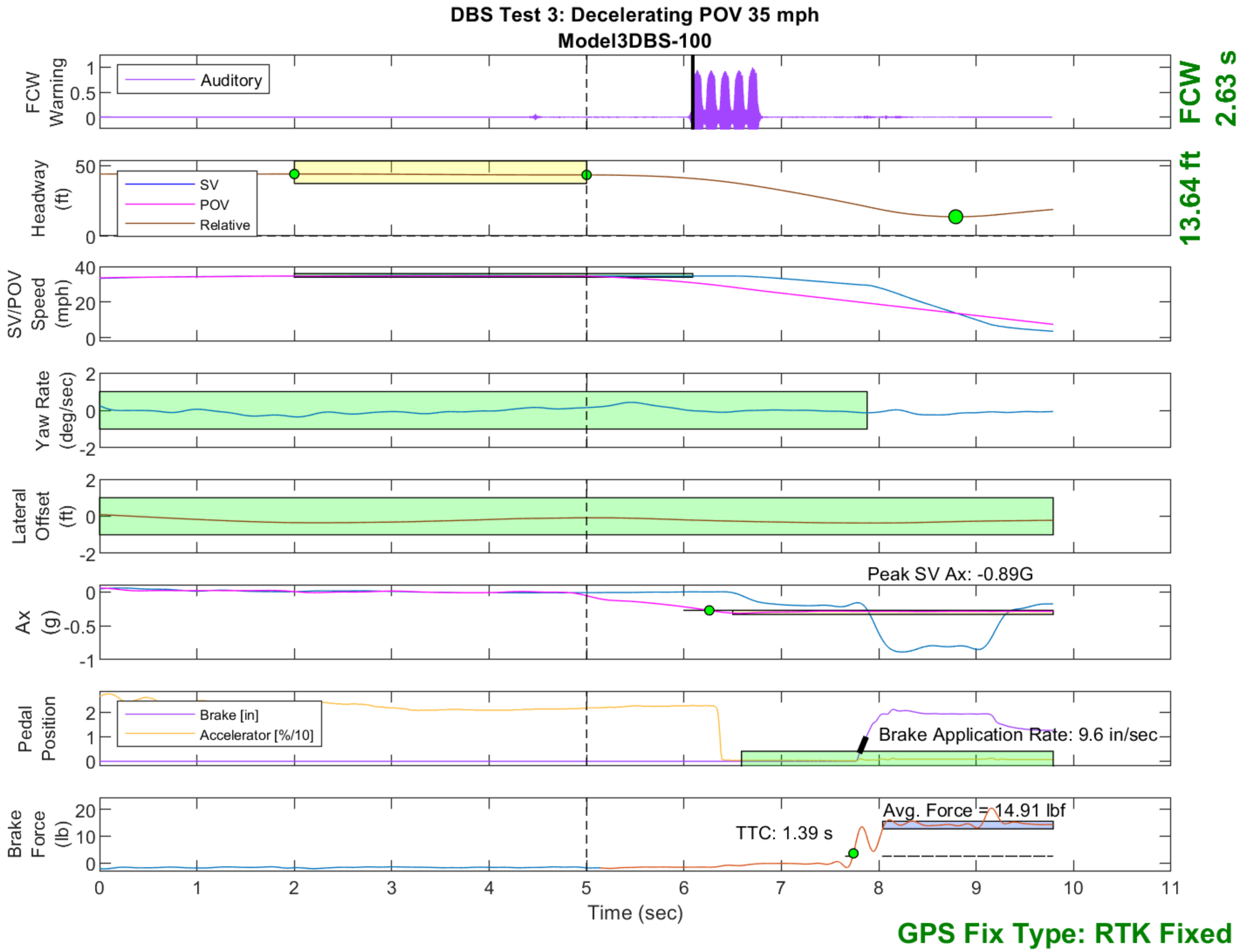


Figure E47. Time History for DBS Run 100, Test 3 - Decelerating POV 35 mph, Creep Mode, Battery SOC = ~70%

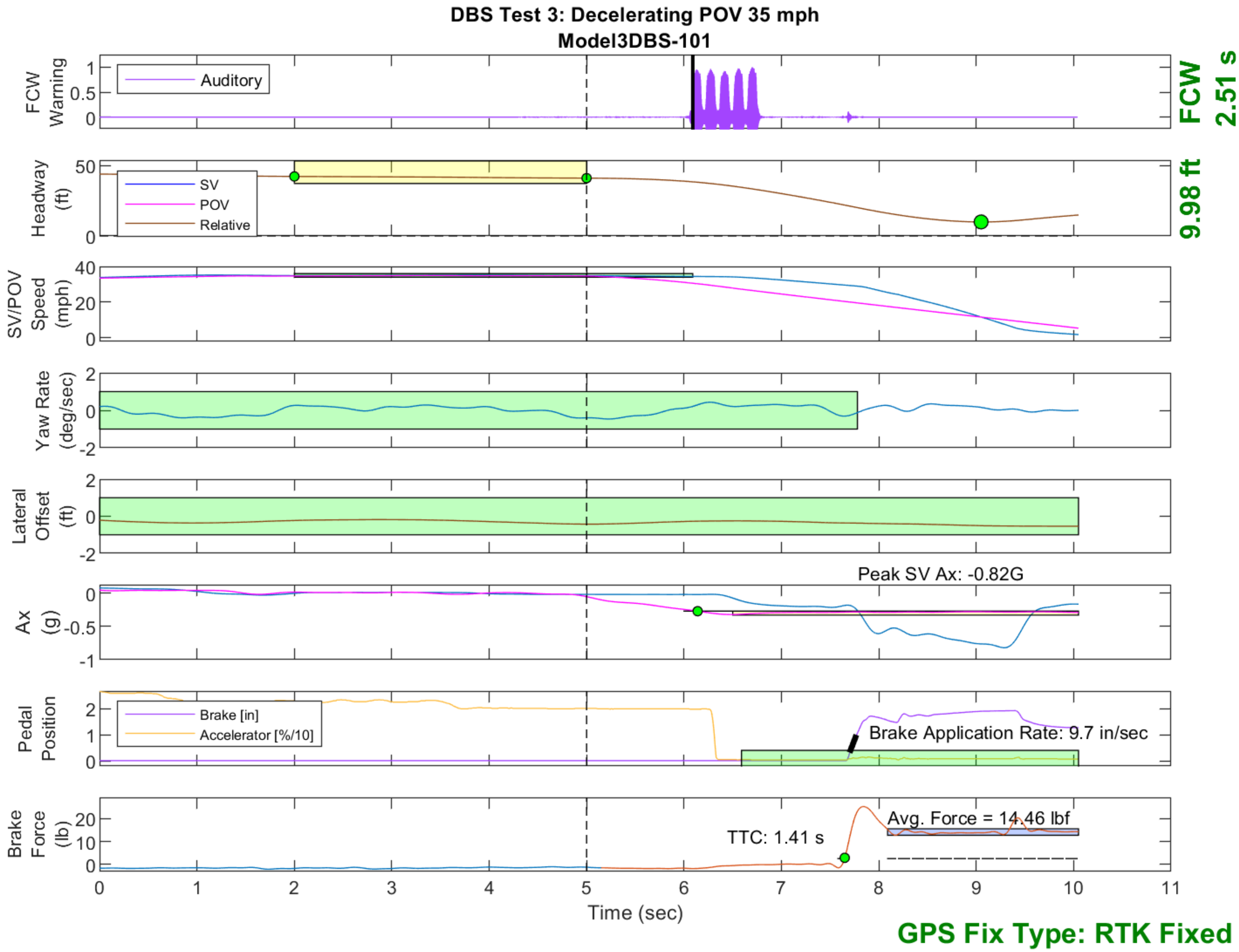


Figure E48. Time History for DBS Run 101, Test 3 - Decelerating POV 35 mph, Creep Mode, Battery SOC = ~70%

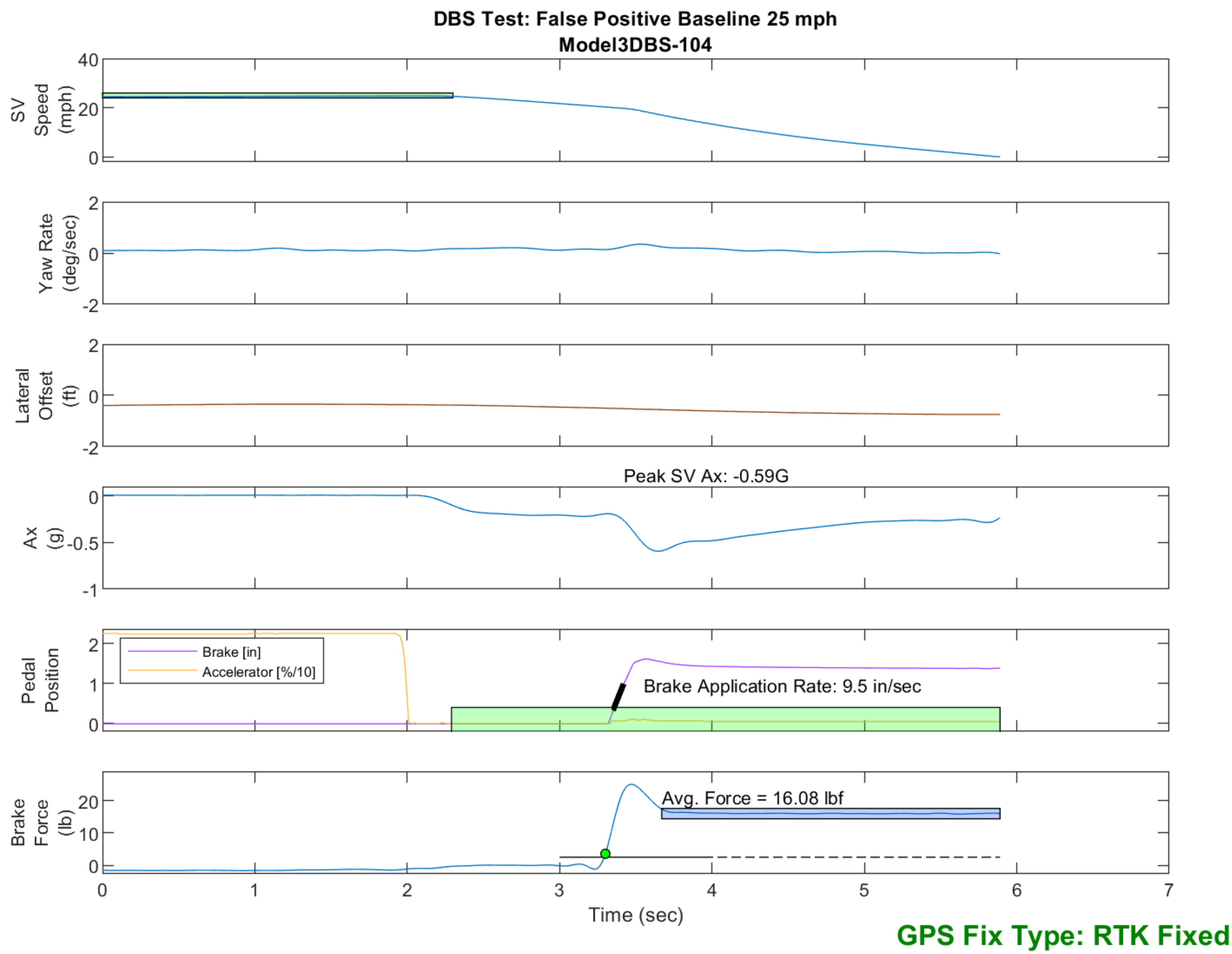


Figure E49. Time History for DBS Run 104, False Positive Baseline, SV 25 mph, Creep Mode, Battery SOC = ~68%

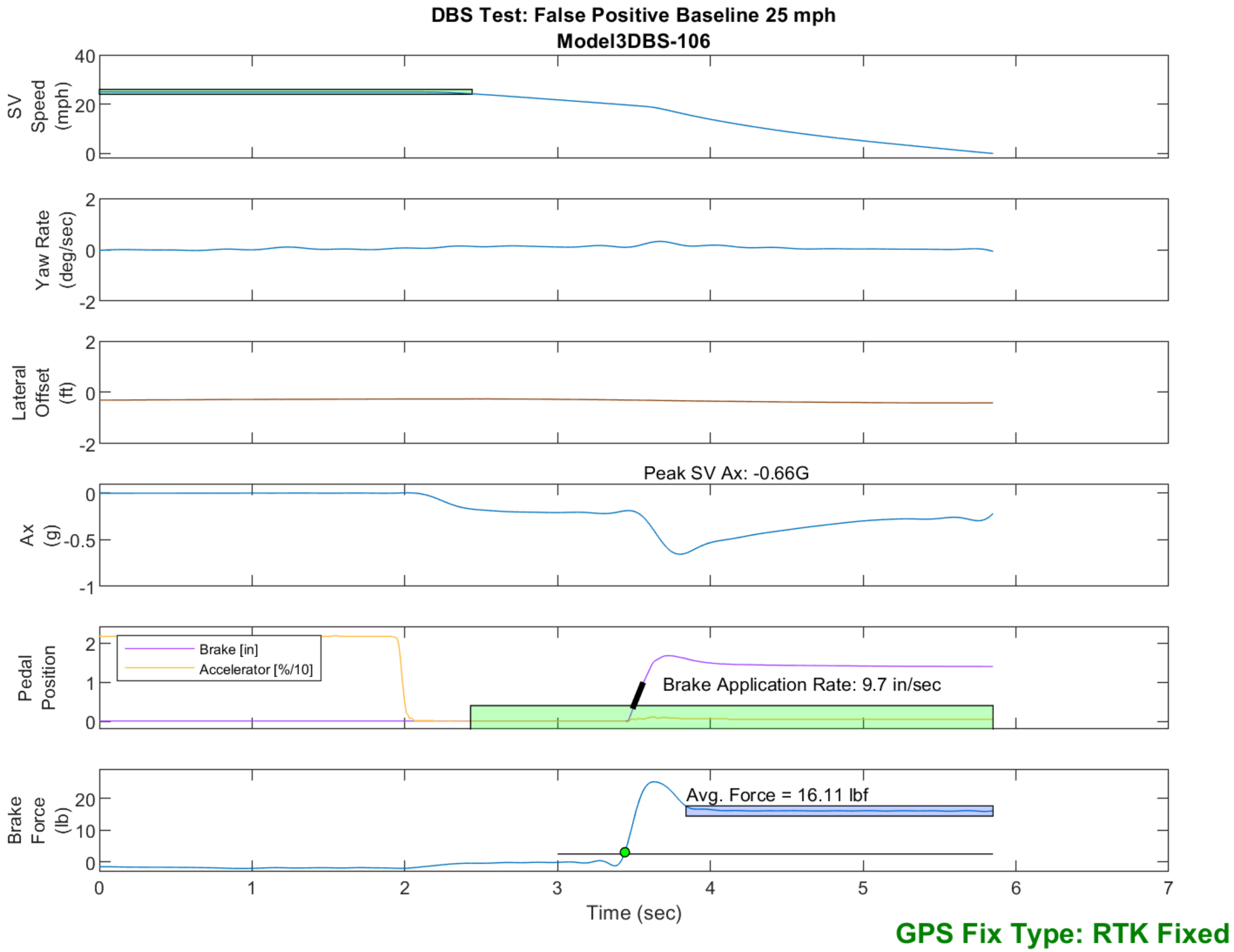


Figure E50. Time History for DBS Run 106, False Positive Baseline, SV 25 mph, Creep Mode, Battery SOC = ~68%

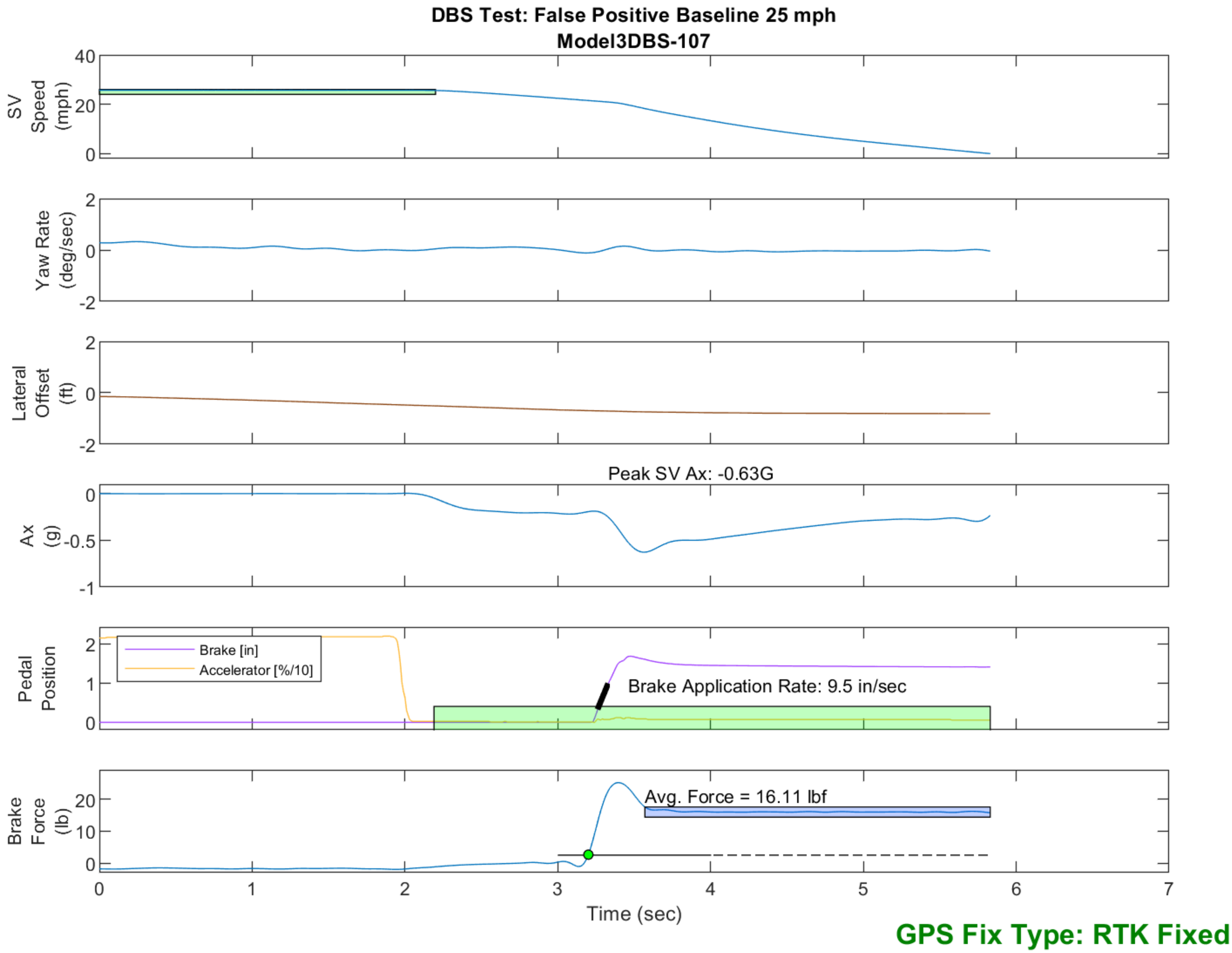


Figure E51. Time History for DBS Run 107, False Positive Baseline, SV 25 mph, Creep Mode, Battery SOC = ~68%

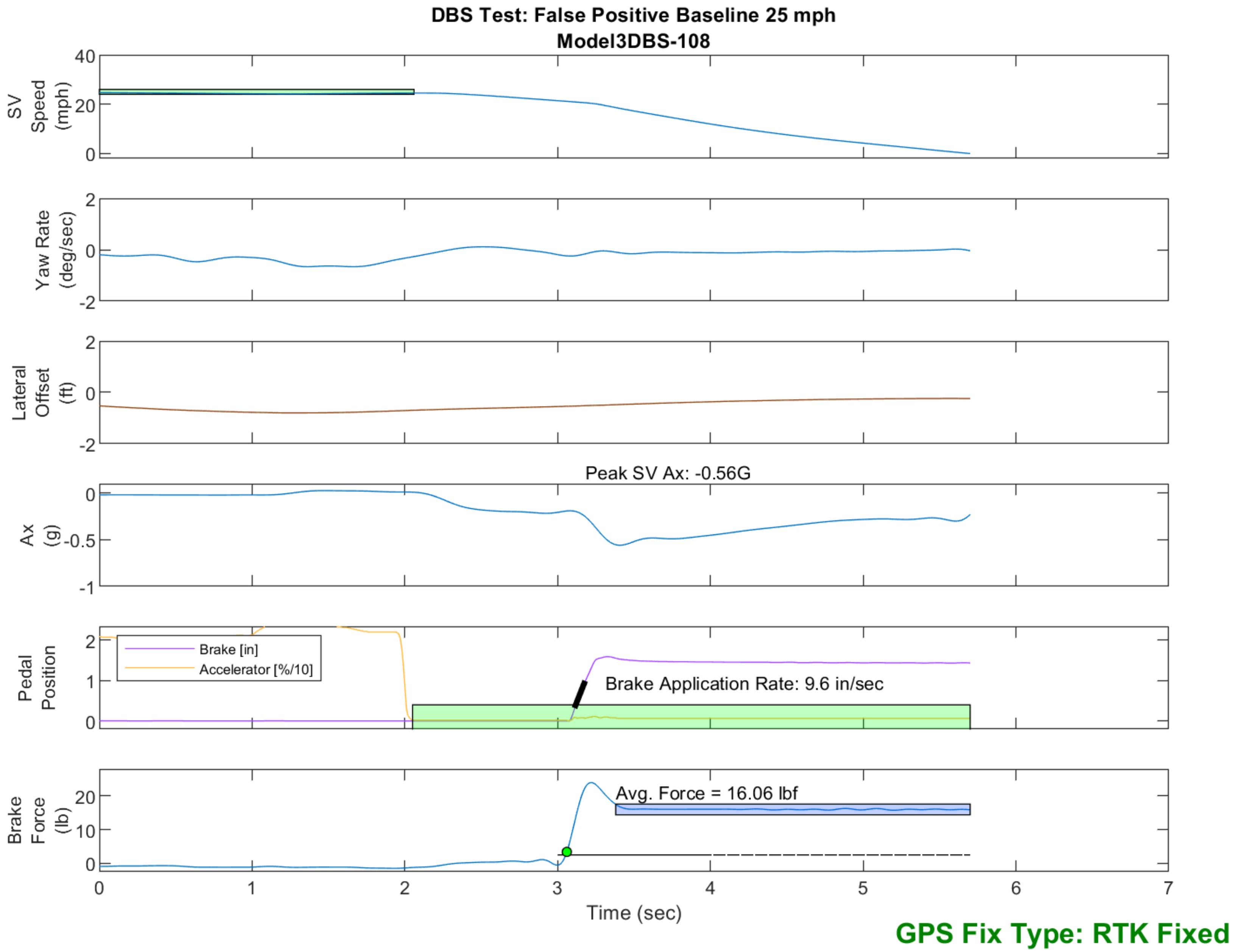


Figure E52. Time History for DBS Run 108, False Positive Baseline, SV 25 mph, Creep Mode, Battery SOC = ~68%

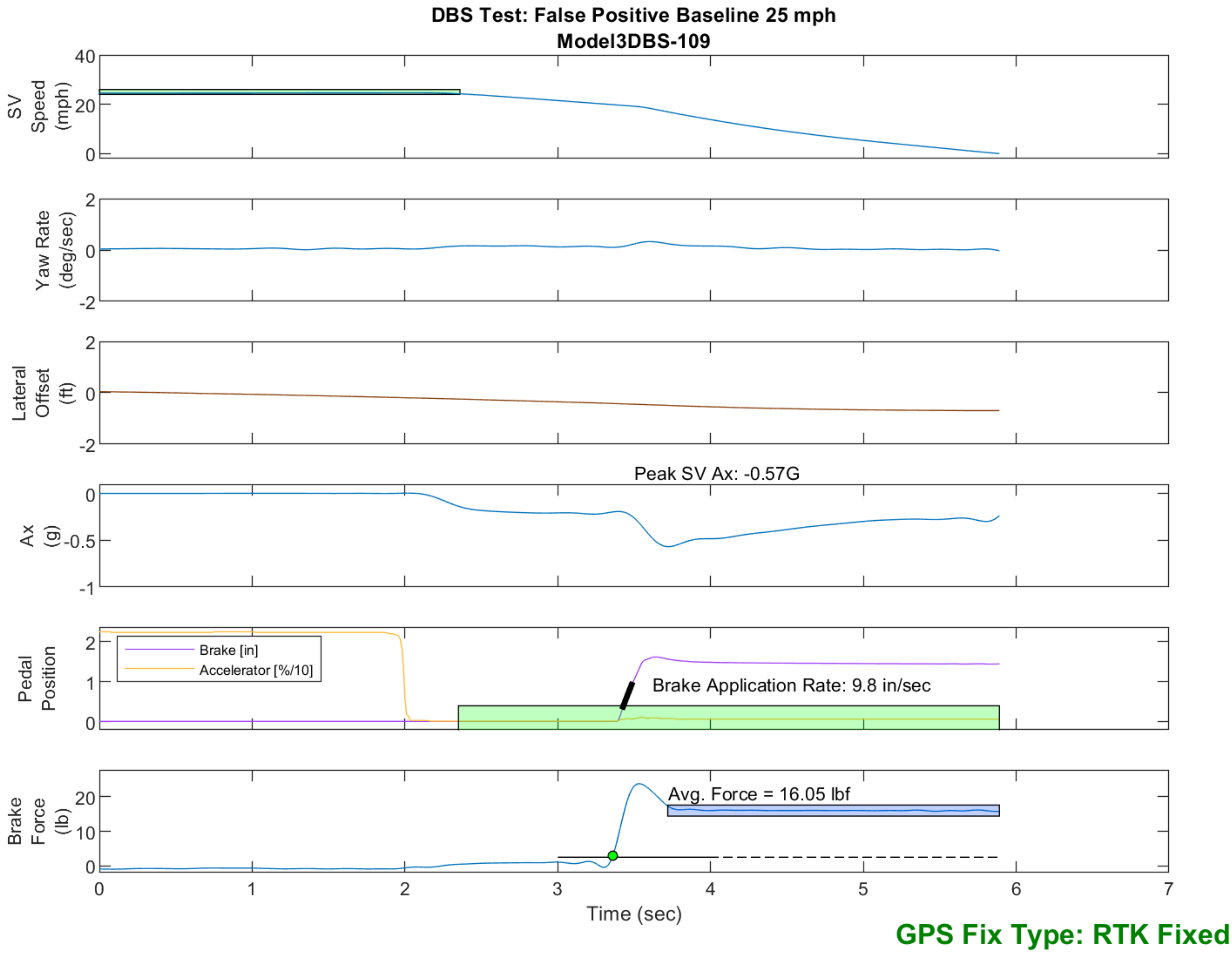


Figure E53. Time History for DBS Run 109, False Positive Baseline, SV 25 mph, Creep Mode, Battery SOC = ~68%

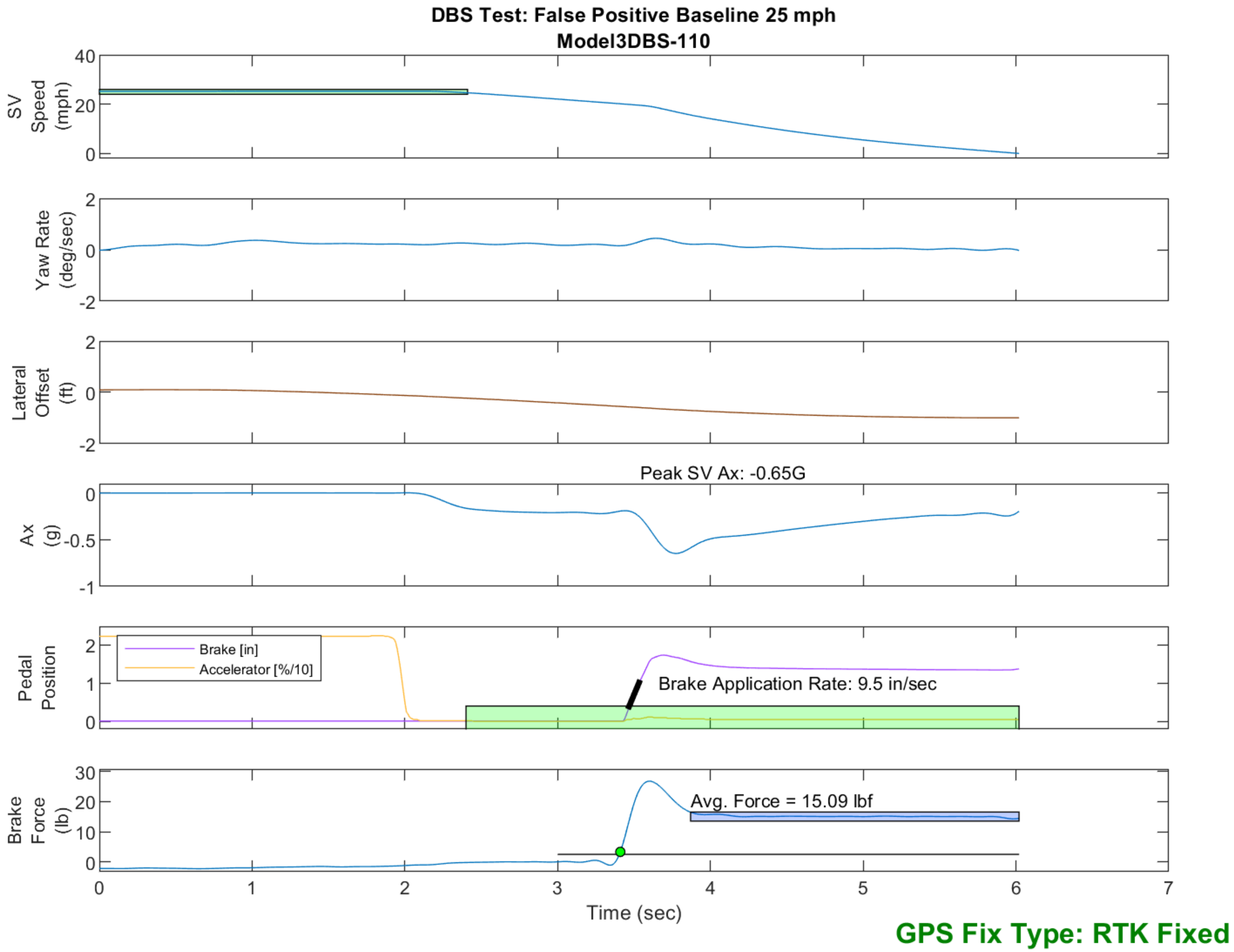


Figure E54. Time History for DBS Run 110, False Positive Baseline, SV 25 mph, Roll Mode, Battery SOC = ~68%

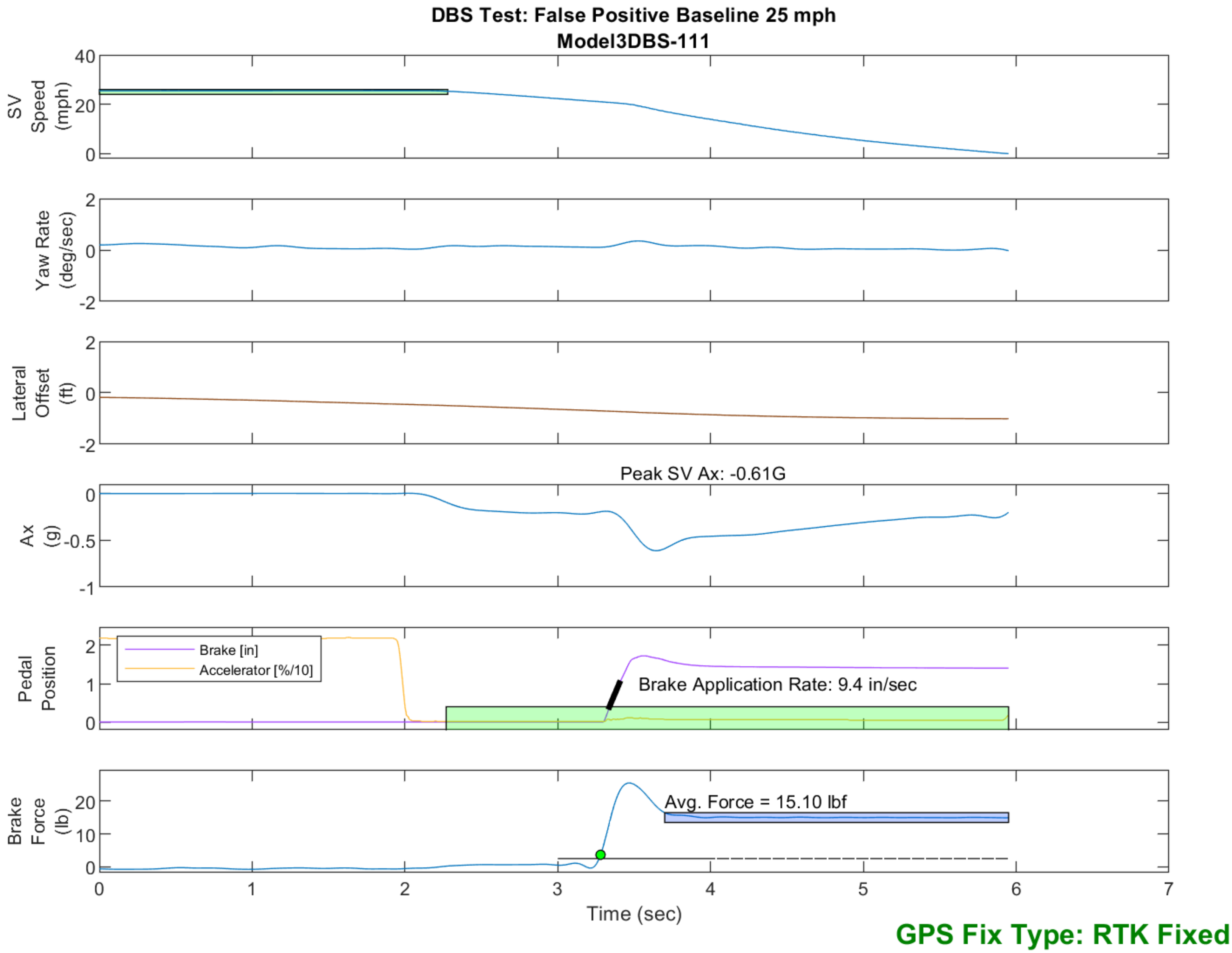


Figure E55. Time History for DBS Run 111, False Positive Baseline, SV 25 mph, Roll Mode, Battery SOC = ~68%

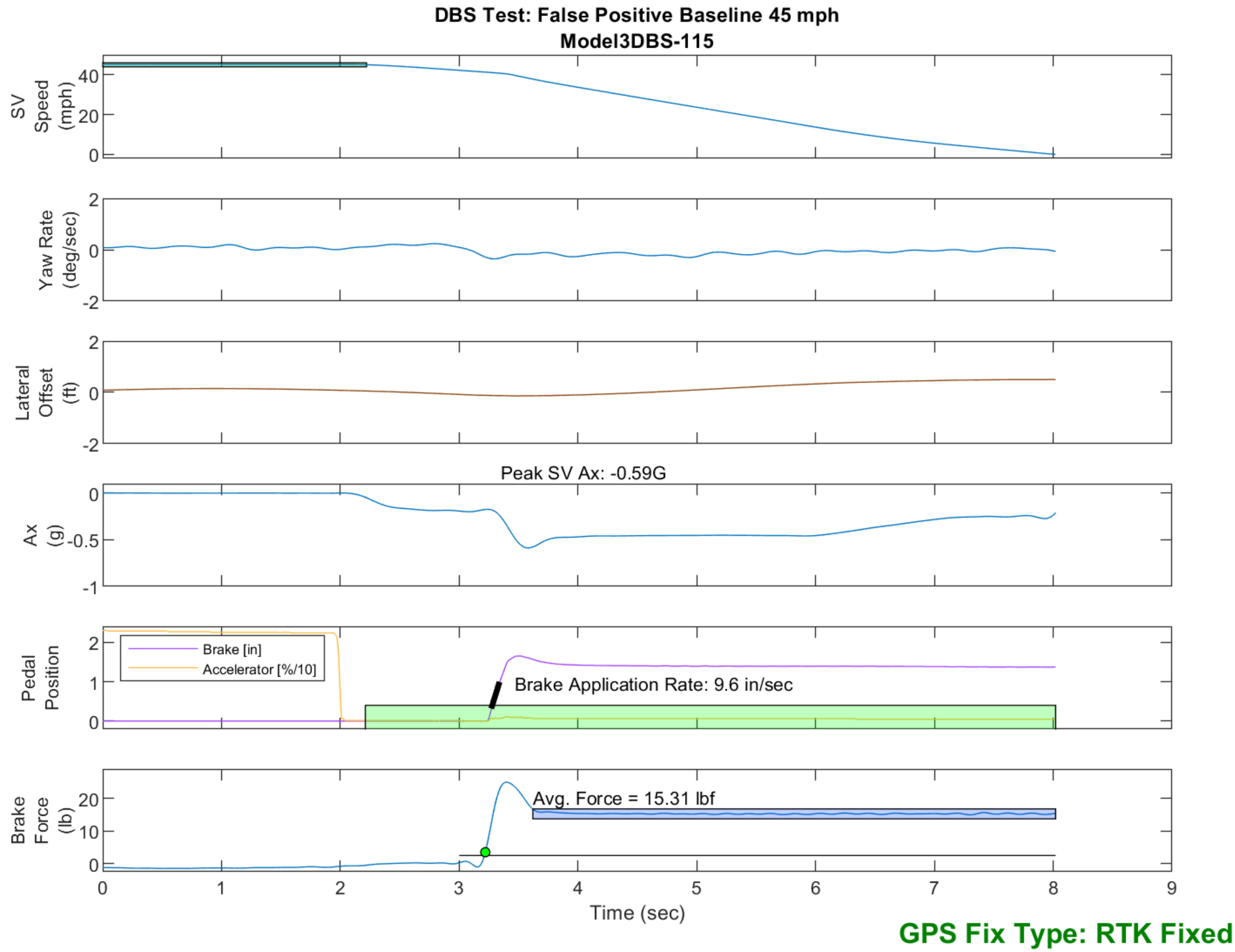


Figure E56. Time History for DBS Run 115, False Positive Baseline, SV 45 mph, Creep Mode, Battery SOC = ~65%

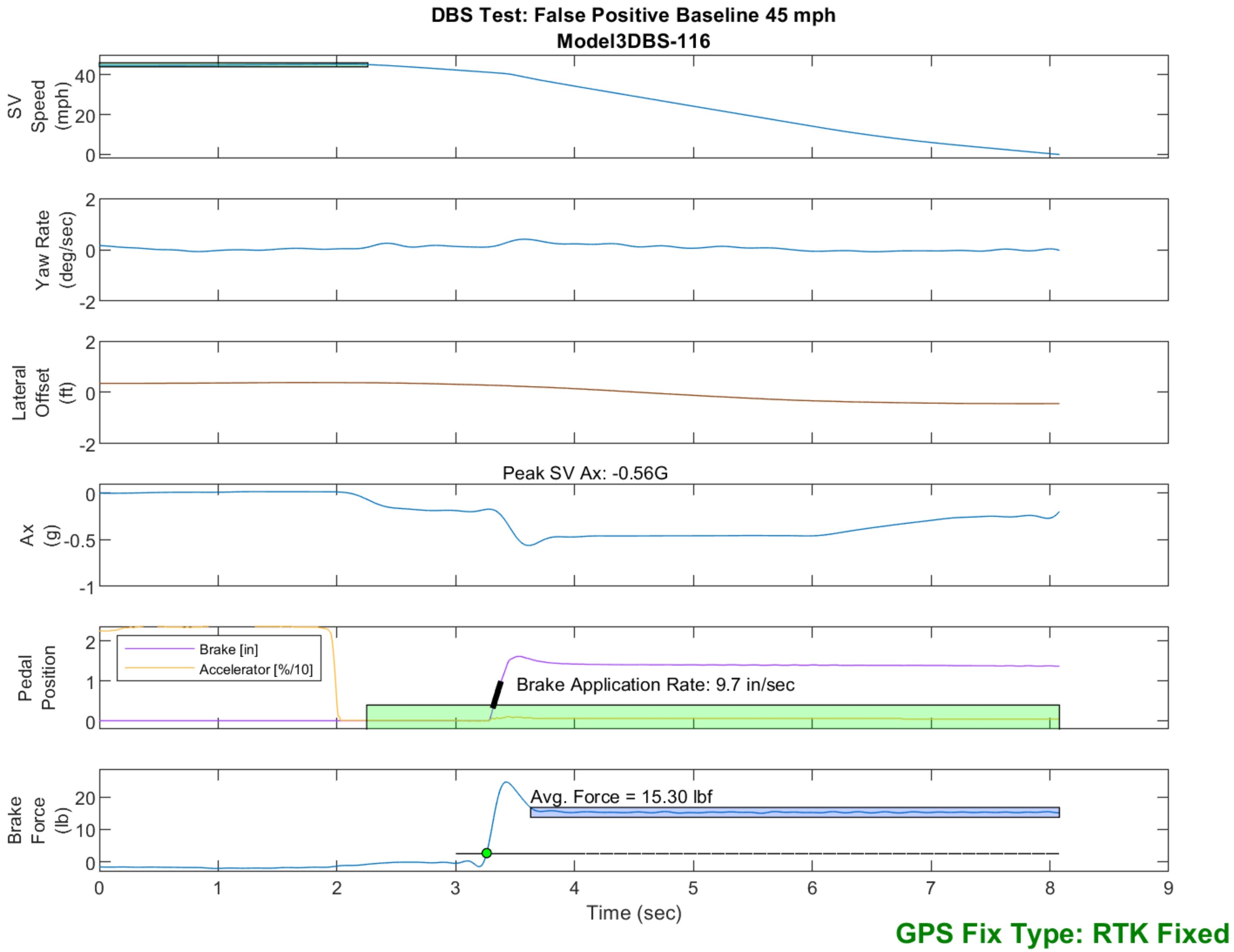


Figure E57. Time History for DBS Run 116, False Positive Baseline, SV 45 mph, Creep Mode, Battery SOC = ~65%

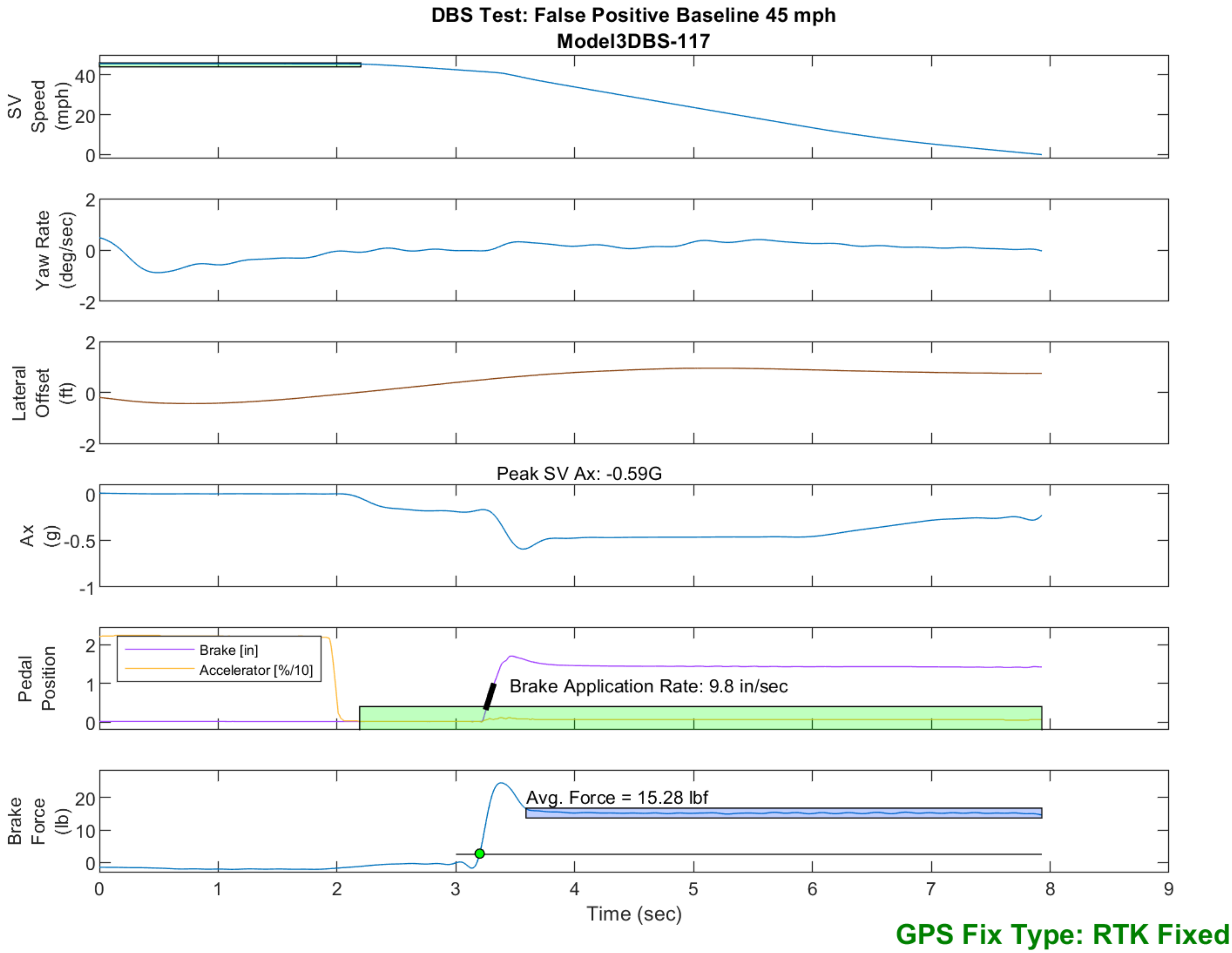


Figure E58. Time History for DBS Run 117, False Positive Baseline, SV 45 mph, Creep Mode, Battery SOC = ~65%

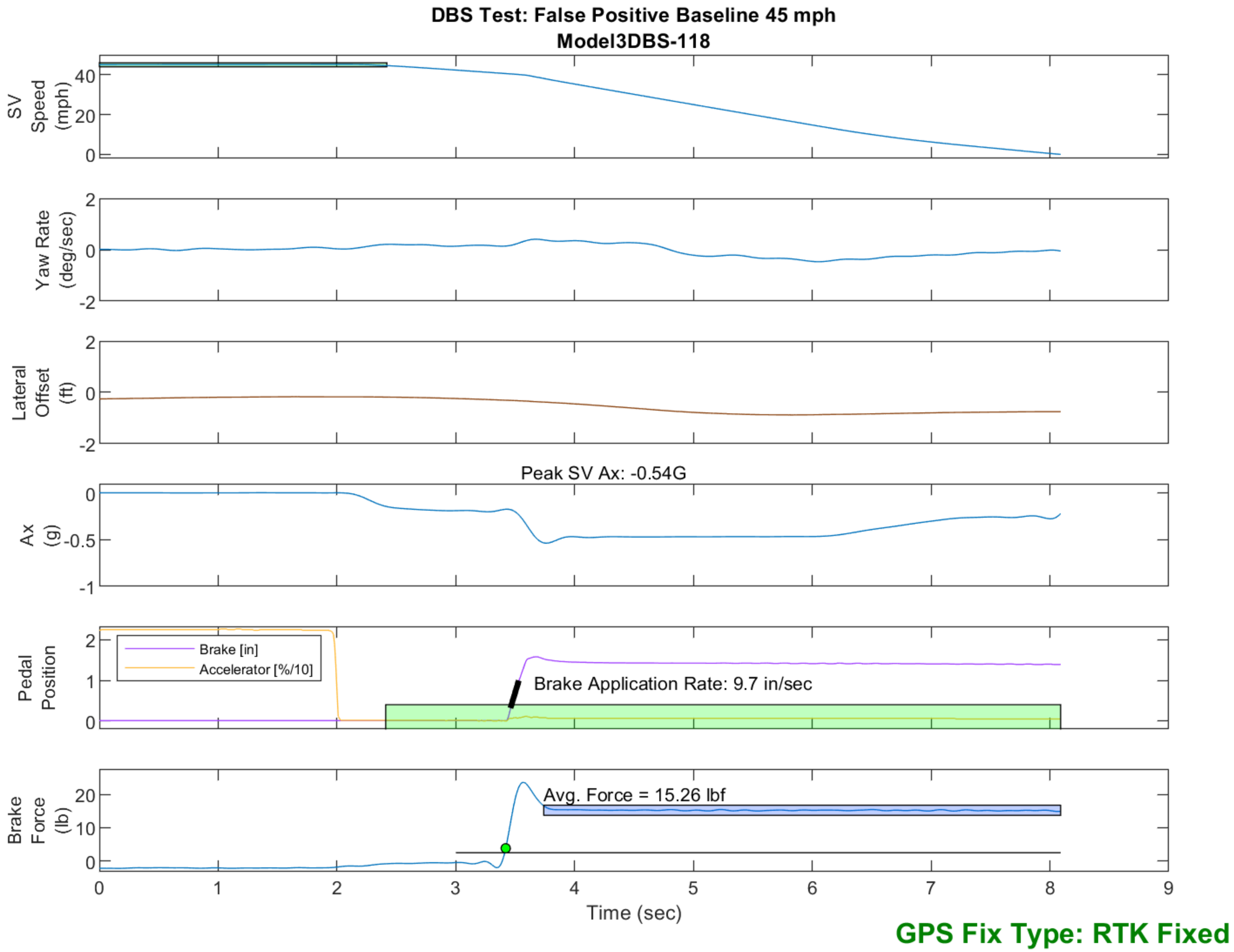


Figure E59. Time History for DBS Run 118, False Positive Baseline, SV 45 mph, Creep Mode, Battery SOC = ~65%

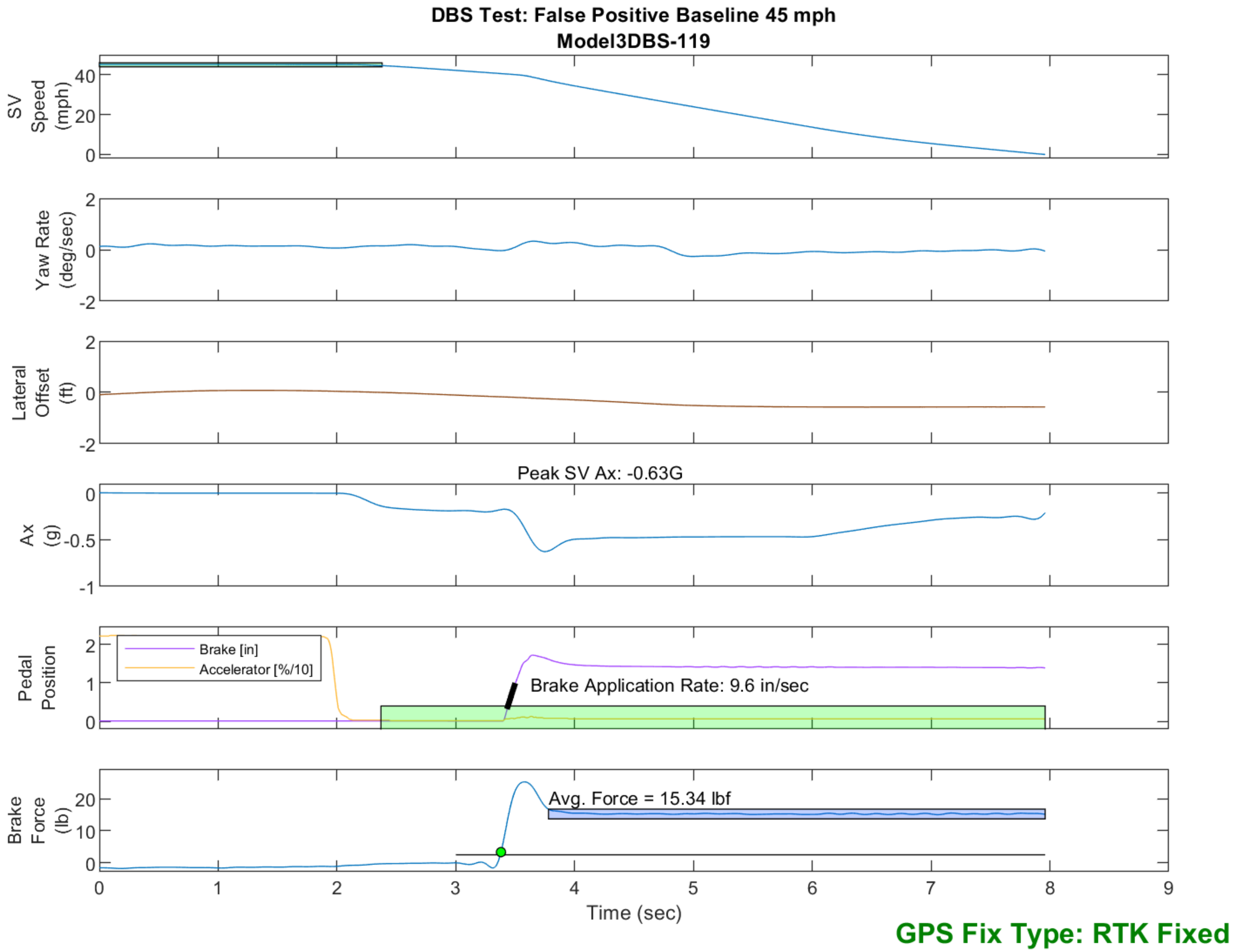


Figure E60. Time History for DBS Run 119, False Positive Baseline, SV 45 mph, Creep Mode, Battery SOC = ~65%

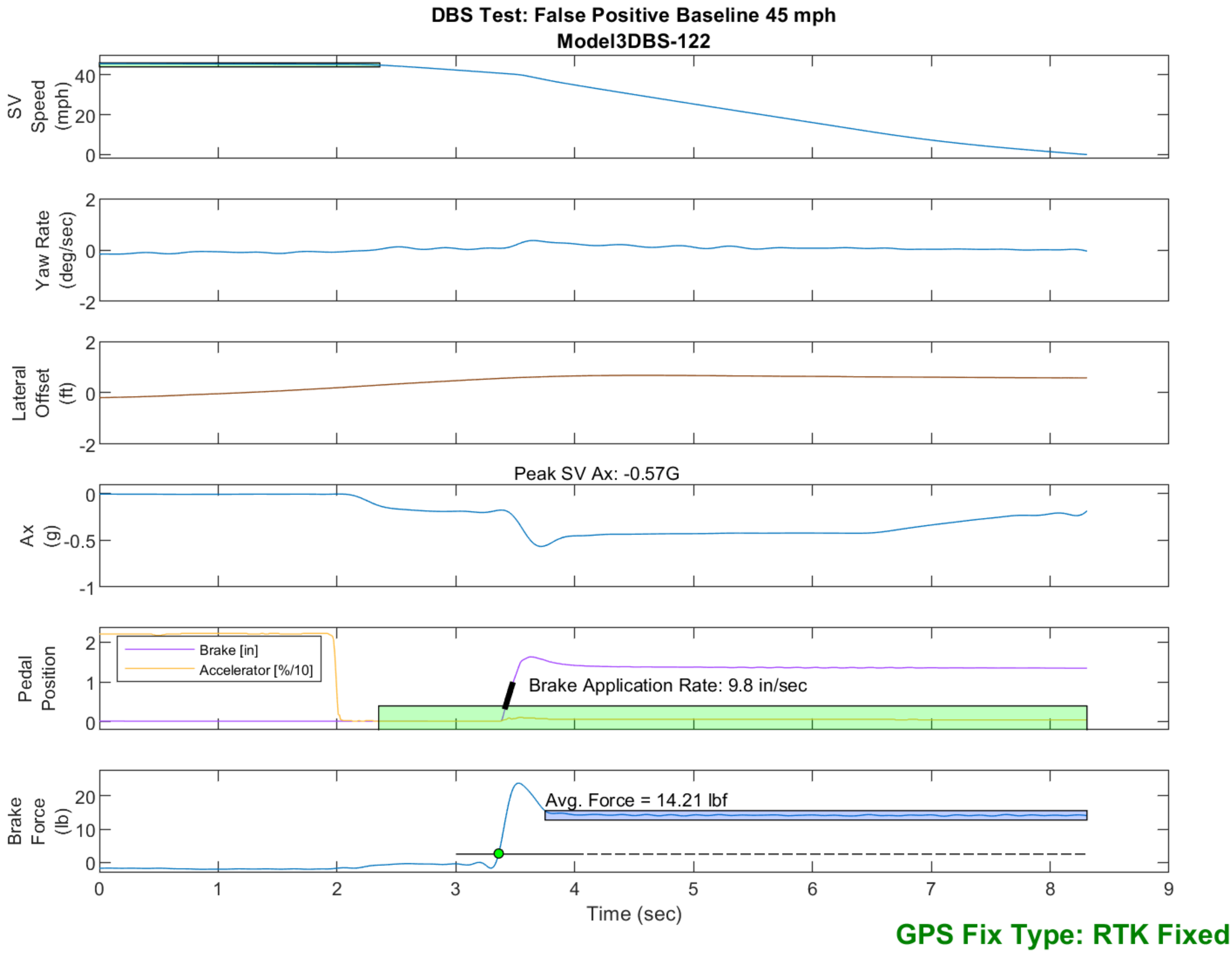


Figure E61. Time History for DBS Run 122, False Positive Baseline, SV 45 mph, Roll Mode, Battery SOC = ~65%

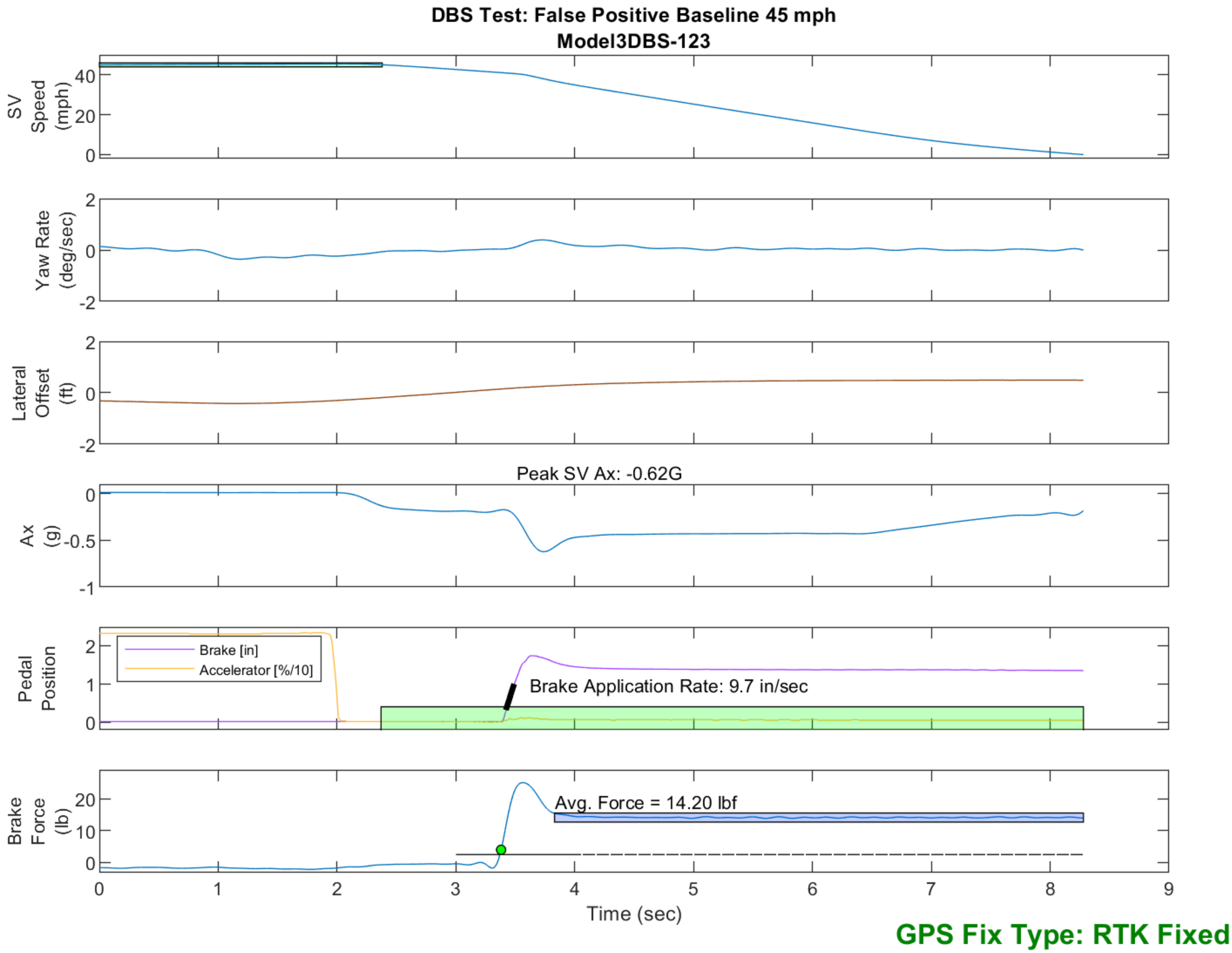


Figure E62. Time History for DBS Run 123, False Positive Baseline, SV 45 mph, Roll Mode, Battery SOC = ~65%

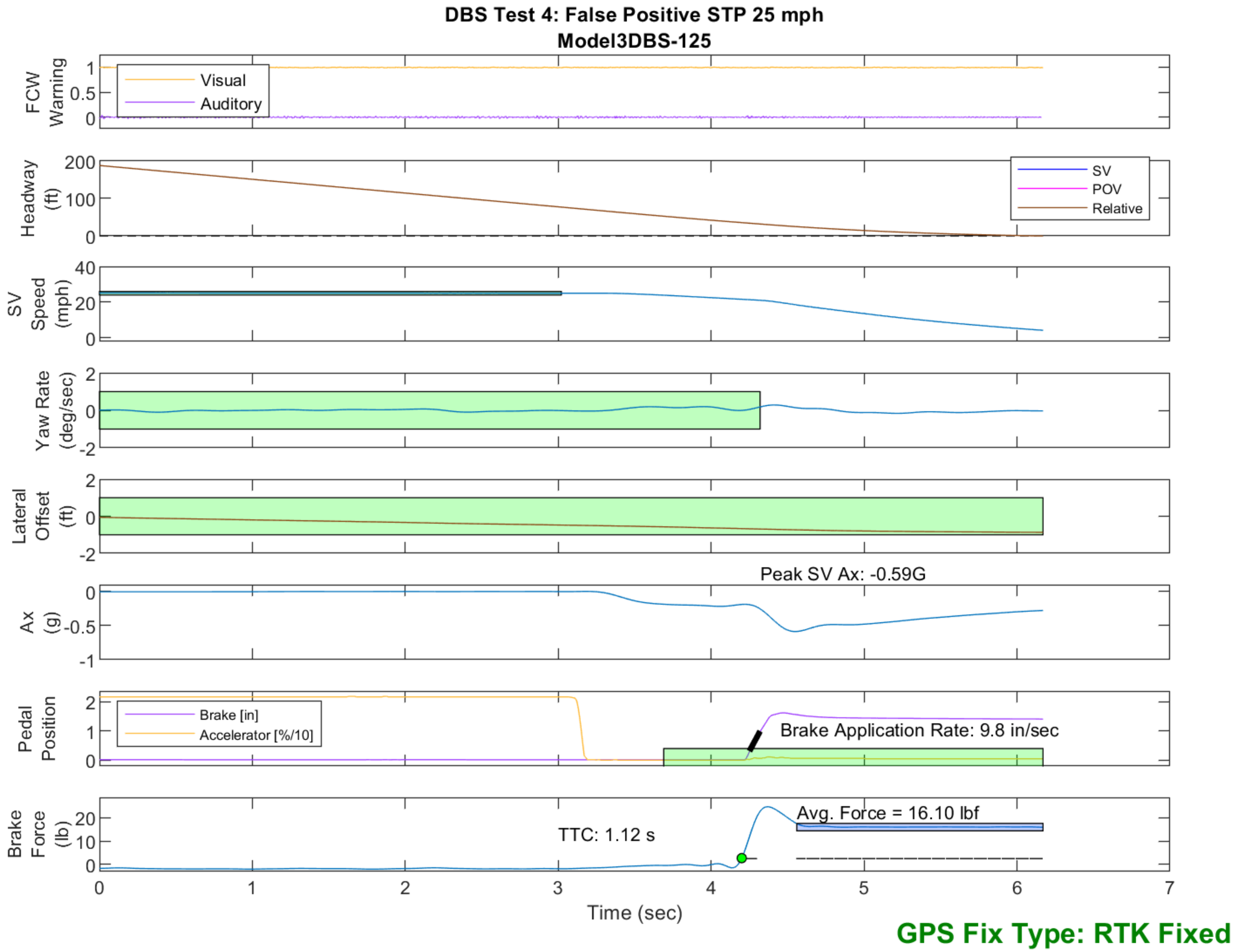


Figure E63. Time History for DBS Run 125, Test 4 - False Positive STP 25 mph, Creep Mode, Battery SOC = ~64%

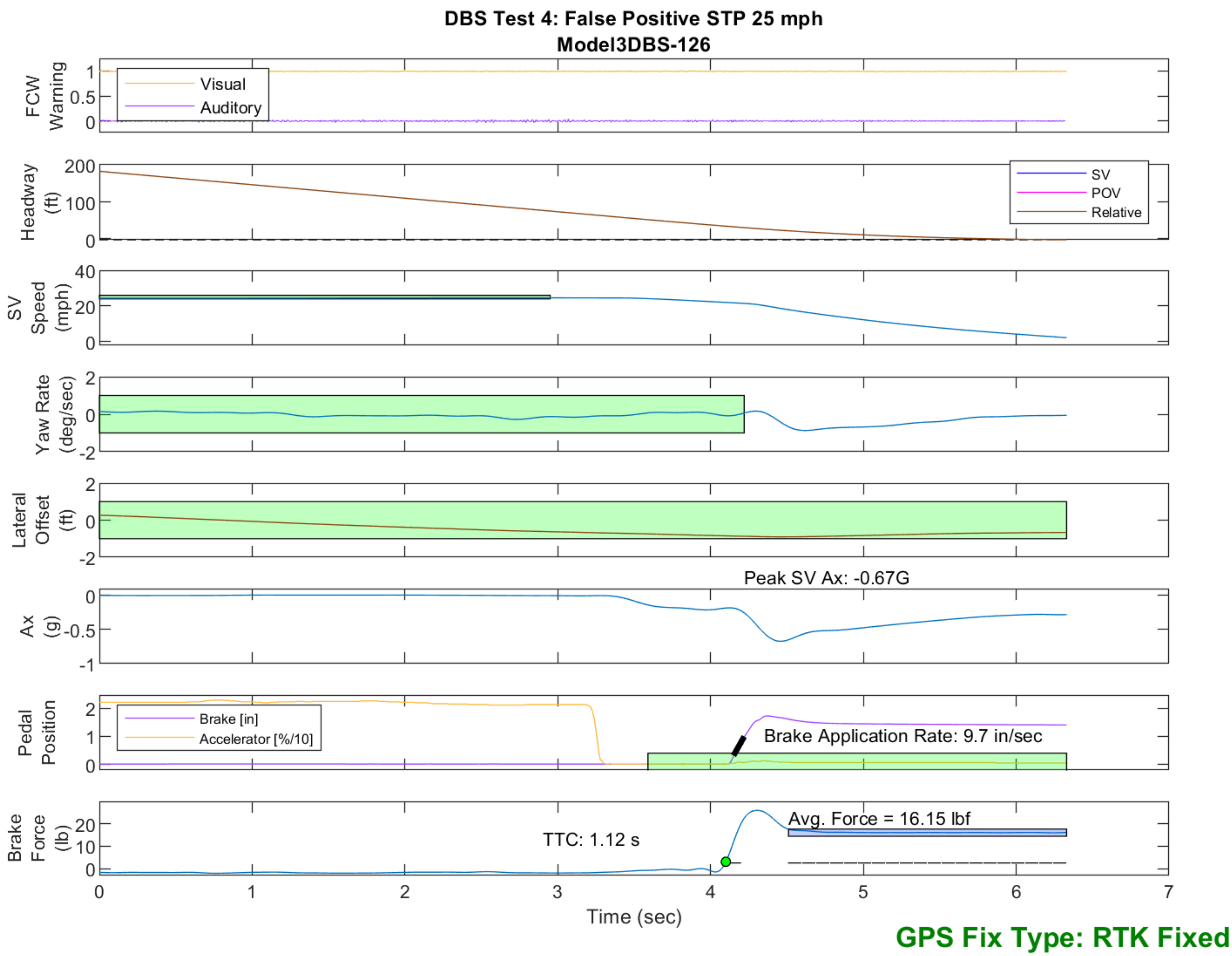


Figure E64. Time History for DBS Run 126, Test 4 - False Positive STP 25 mph, Creep Mode, Battery SOC = ~64%

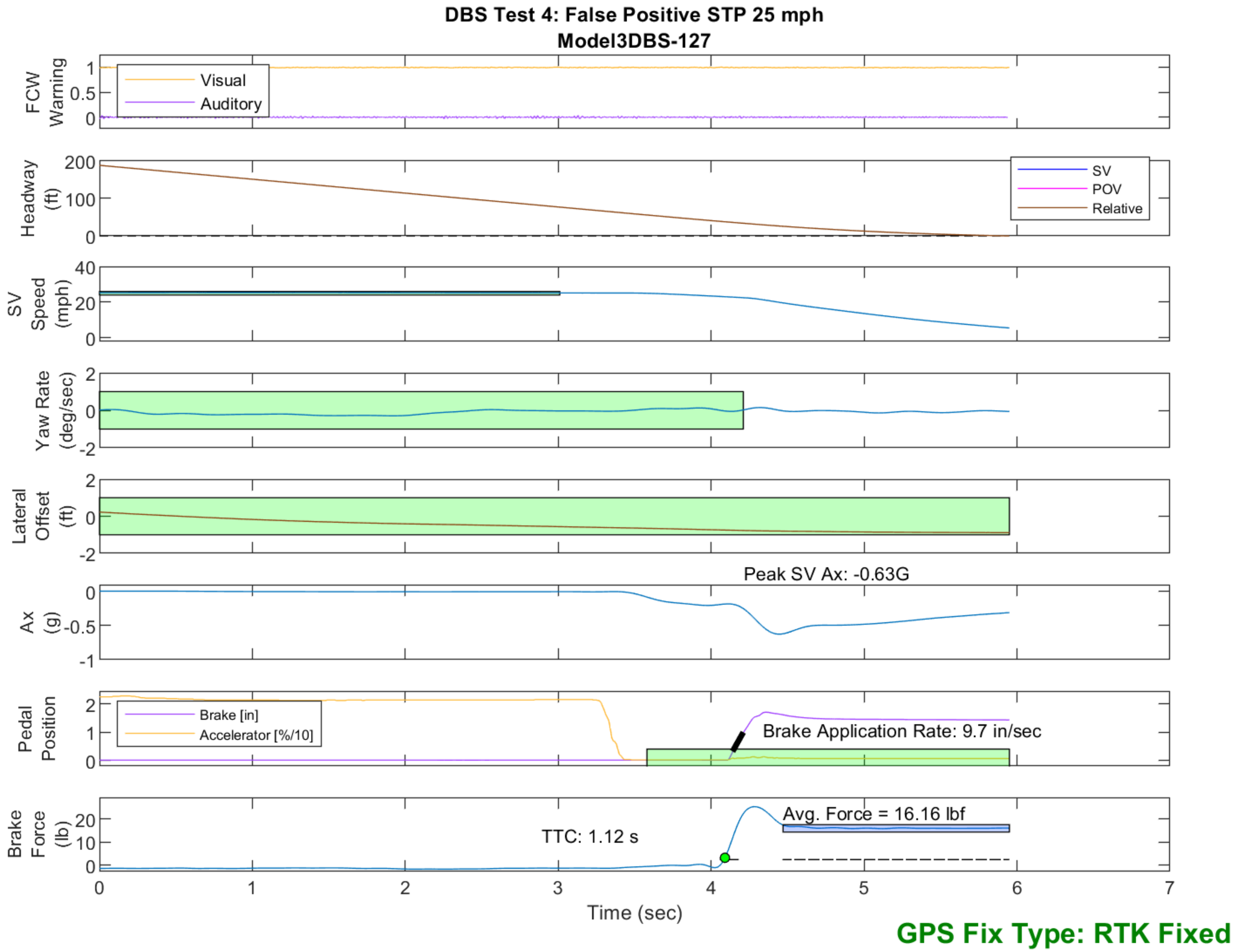


Figure E65. Time History for DBS Run 127, Test 4 - False Positive STP 25 mph, Creep Mode, Battery SOC = ~64%

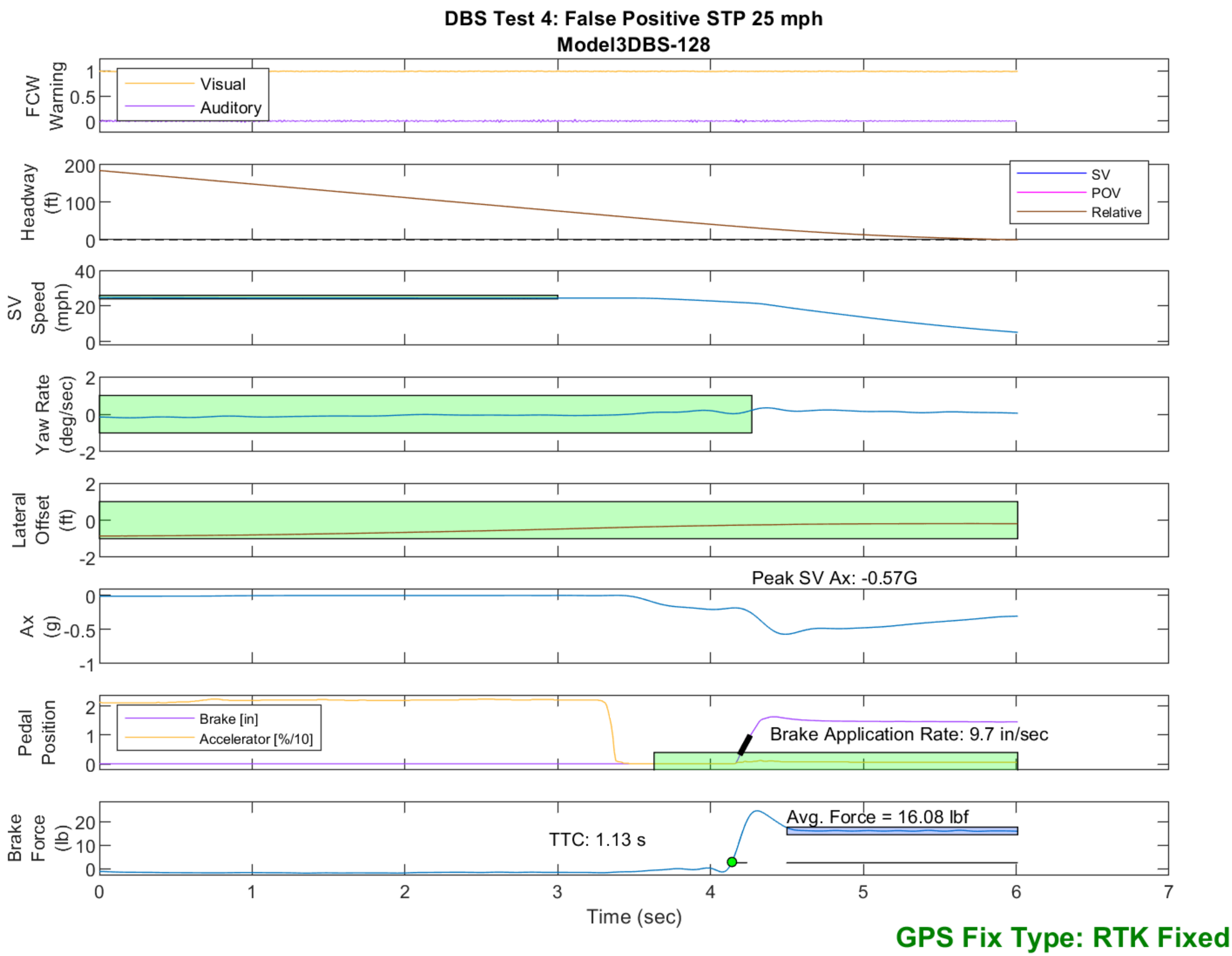


Figure E66. Time History for DBS Run 128, Test 4 - False Positive STP 25 mph, Creep Mode, Battery SOC = ~64%

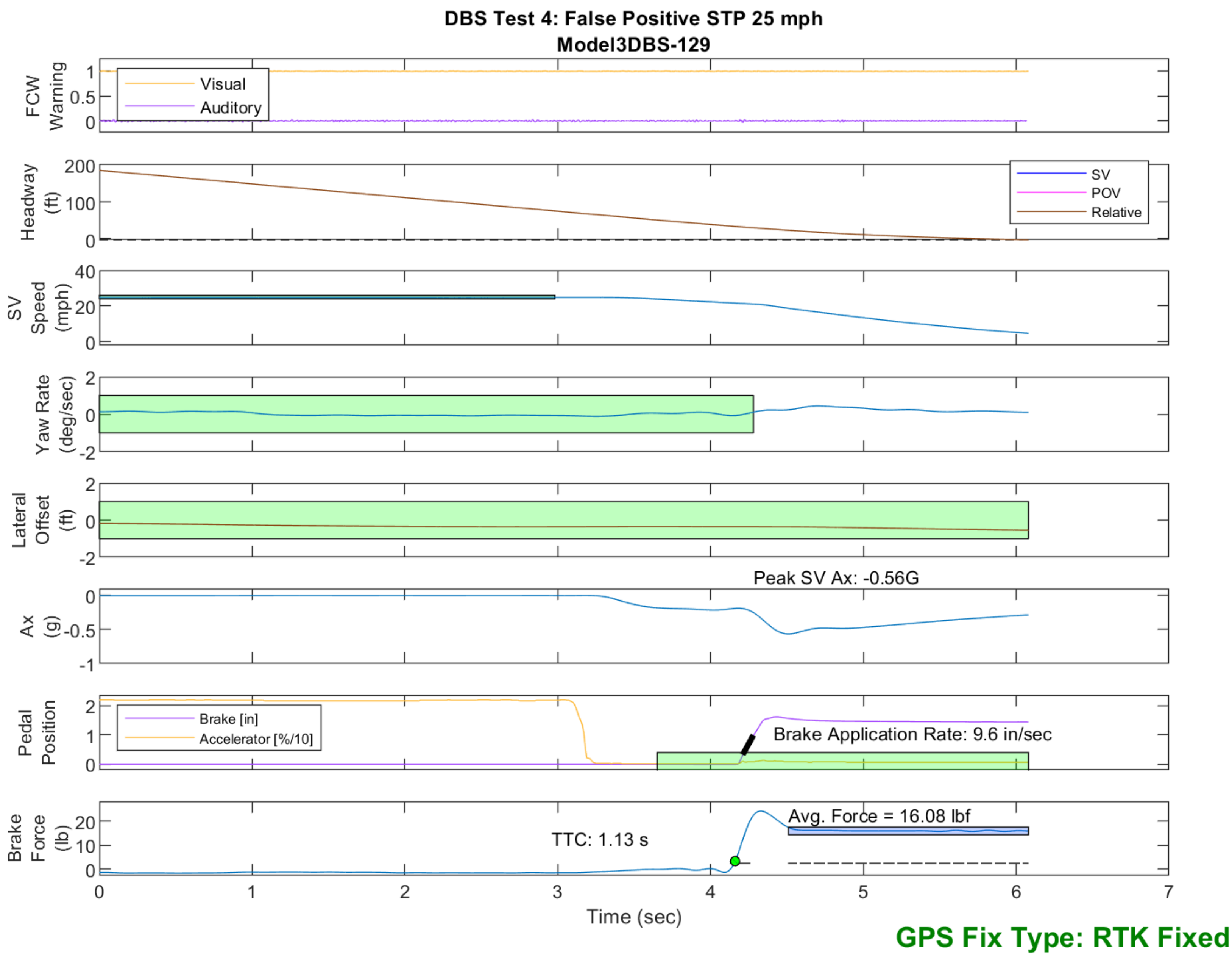


Figure E67. Time History for DBS Run 129, Test 4 - False Positive STP 25 mph, Creep Mode, Battery SOC = ~64%

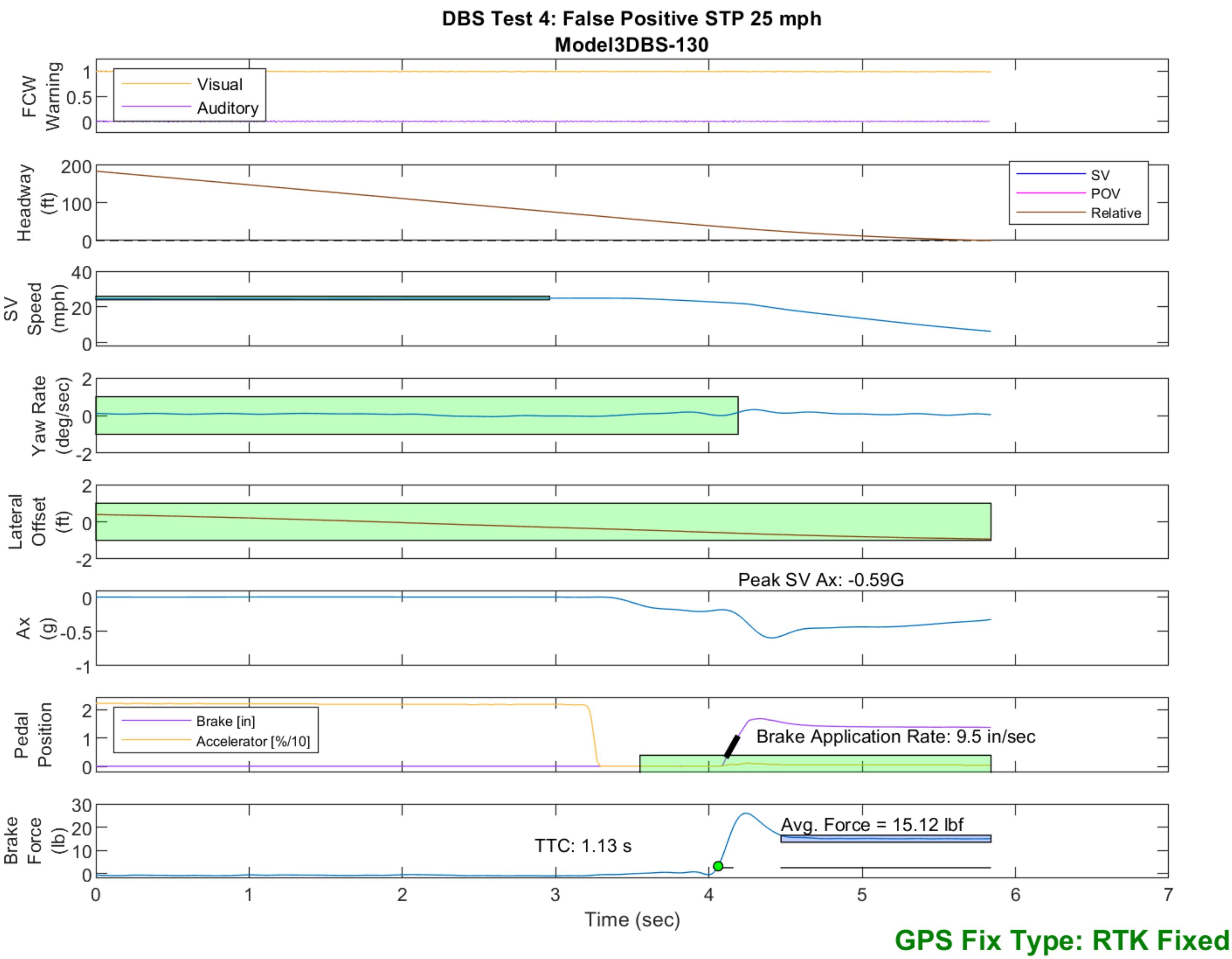


Figure E68. Time History for DBS Run 130, Test 4 - False Positive STP 25 mph, Roll Mode, Battery SOC = ~64%

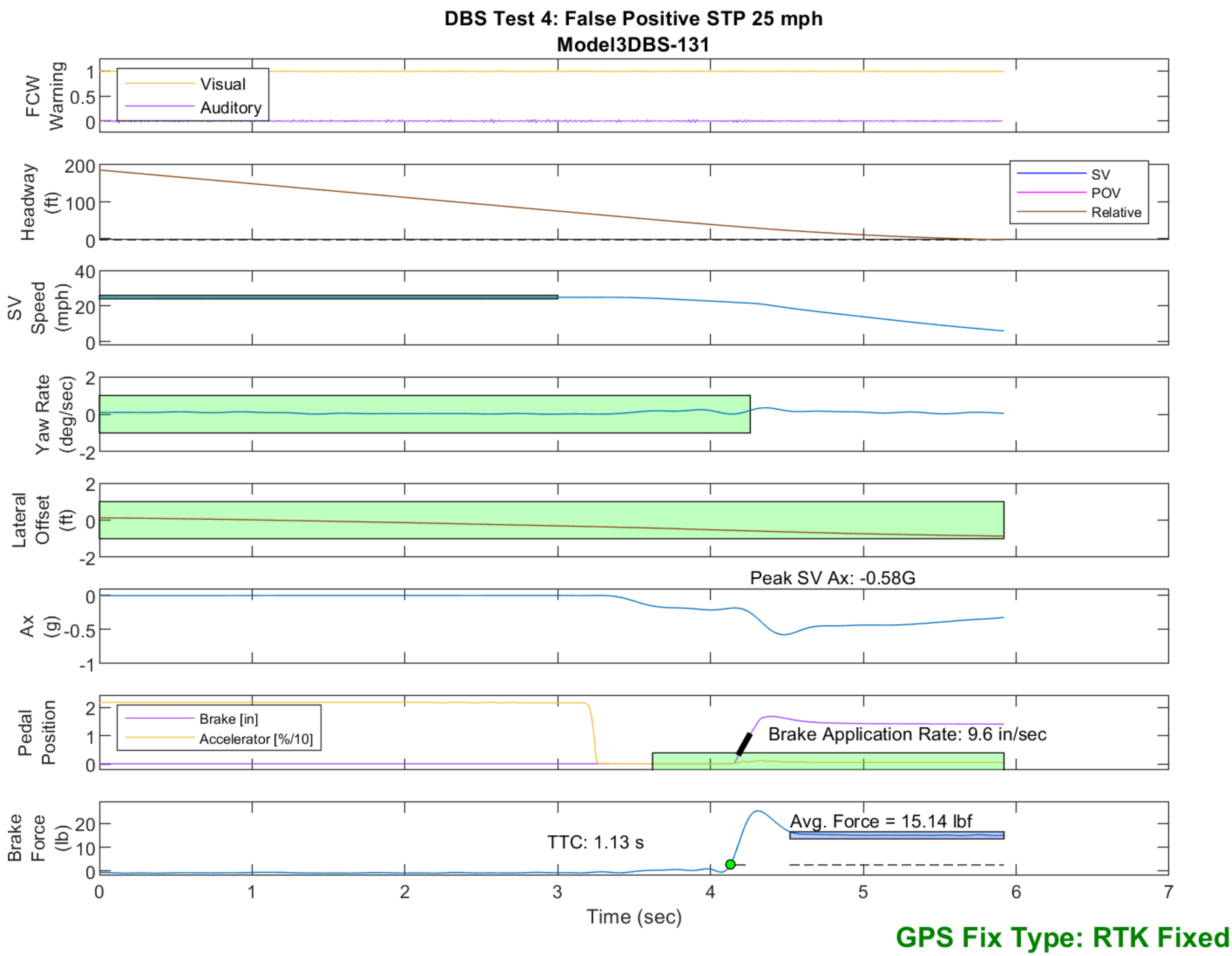


Figure E69. Time History for DBS Run 131, Test 4 - False Positive STP 25 mph, Roll Mode, Battery SOC = ~64%

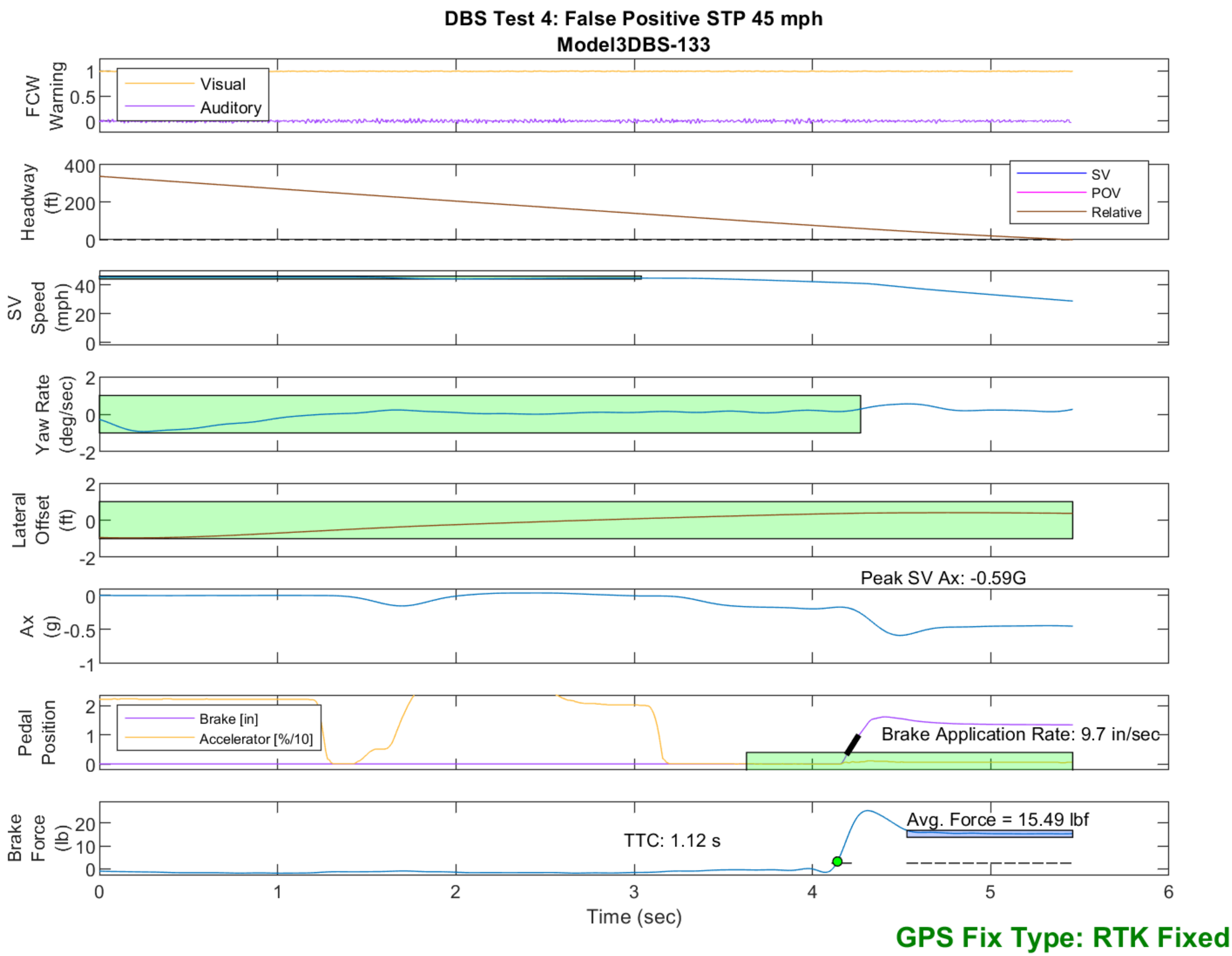


Figure E70. Time History for DBS Run 133, Test 4 - False Positive STP 45 mph, Creep Mode, Battery SOC = ~62%

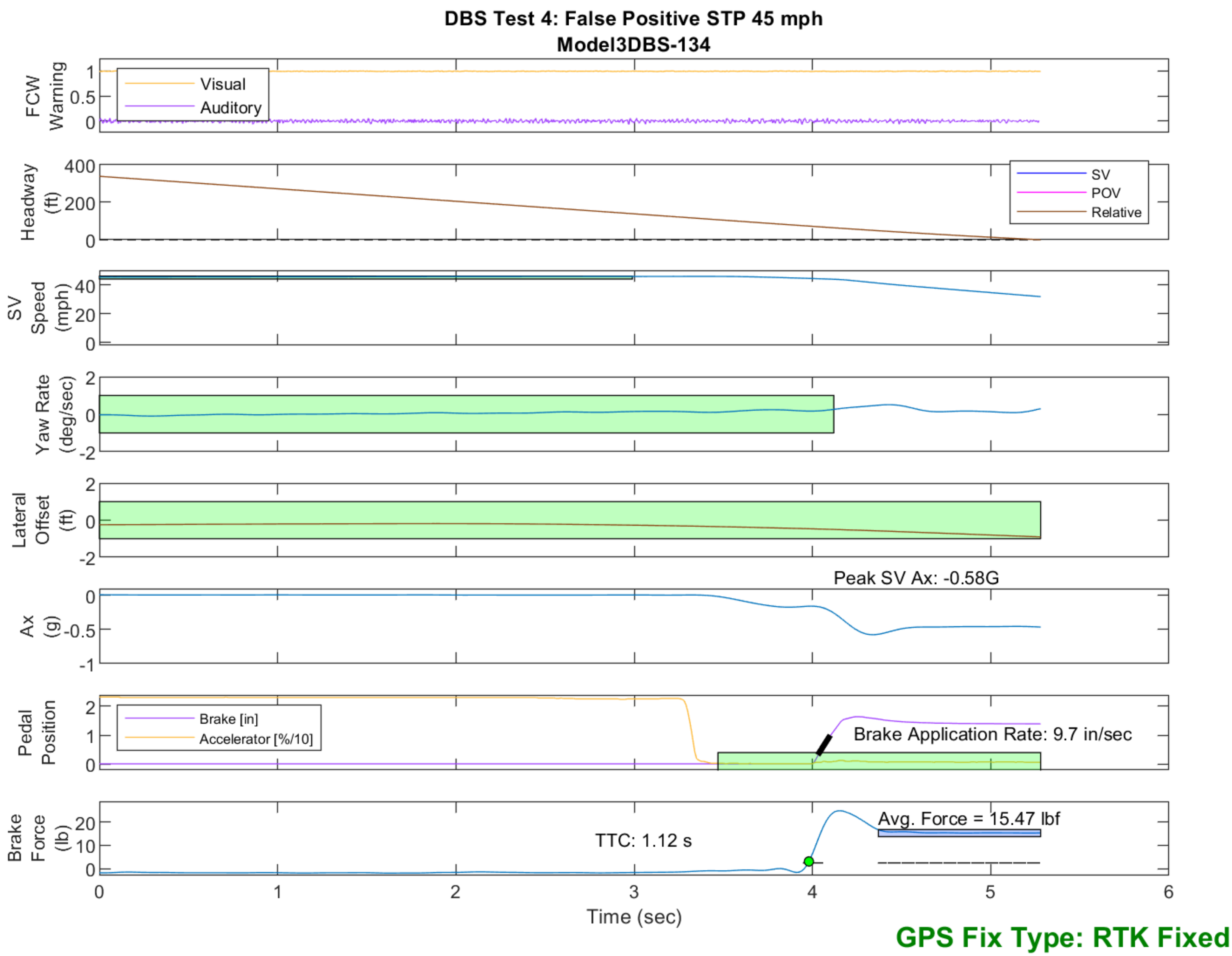


Figure E71. Time History for DBS Run 134, Test 4 - False Positive STP 45 mph, Creep Mode, Battery SOC = ~62%

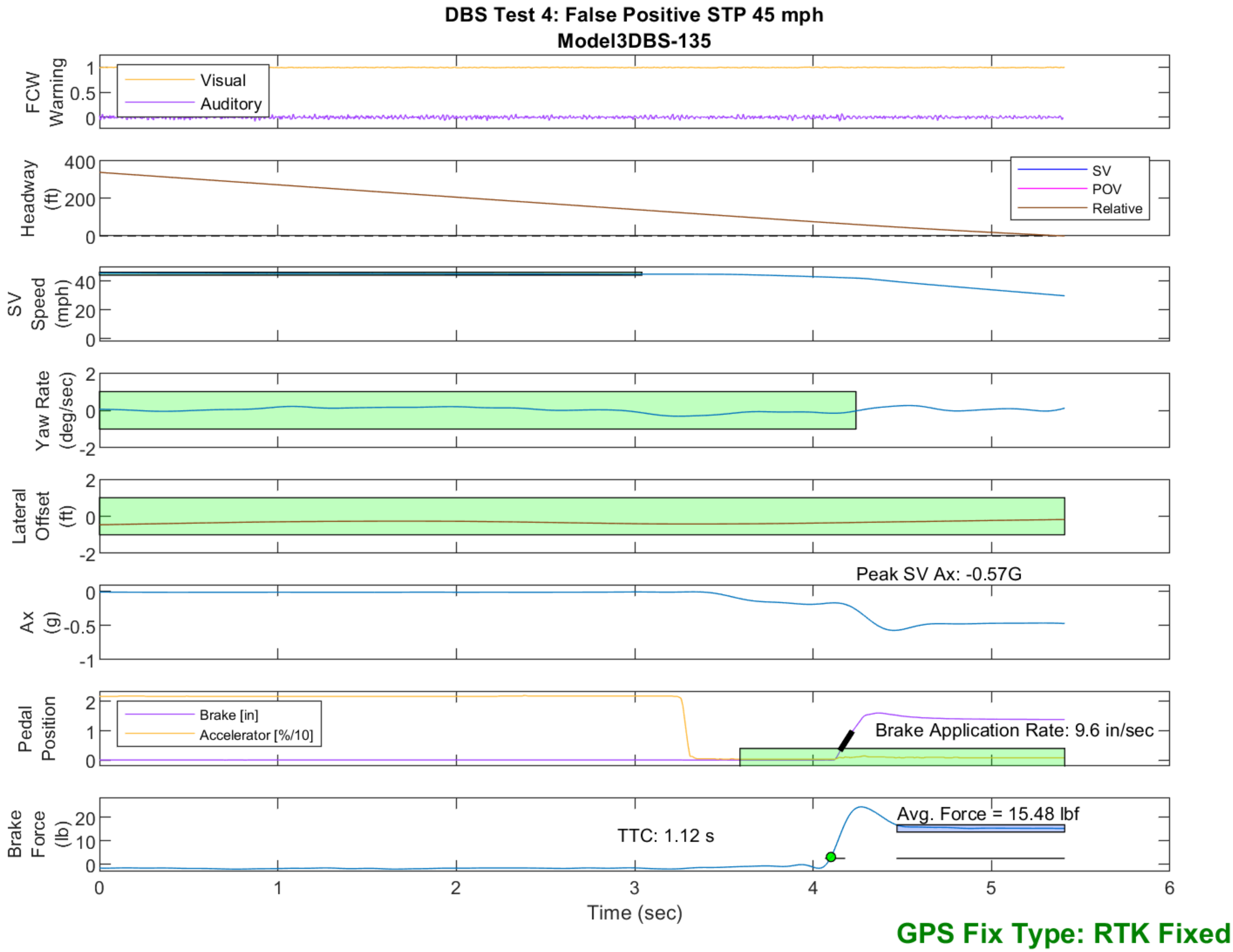


Figure E72. Time History for DBS Run 135, Test 4 - False Positive STP 45 mph, Creep Mode, Battery SOC = ~62%

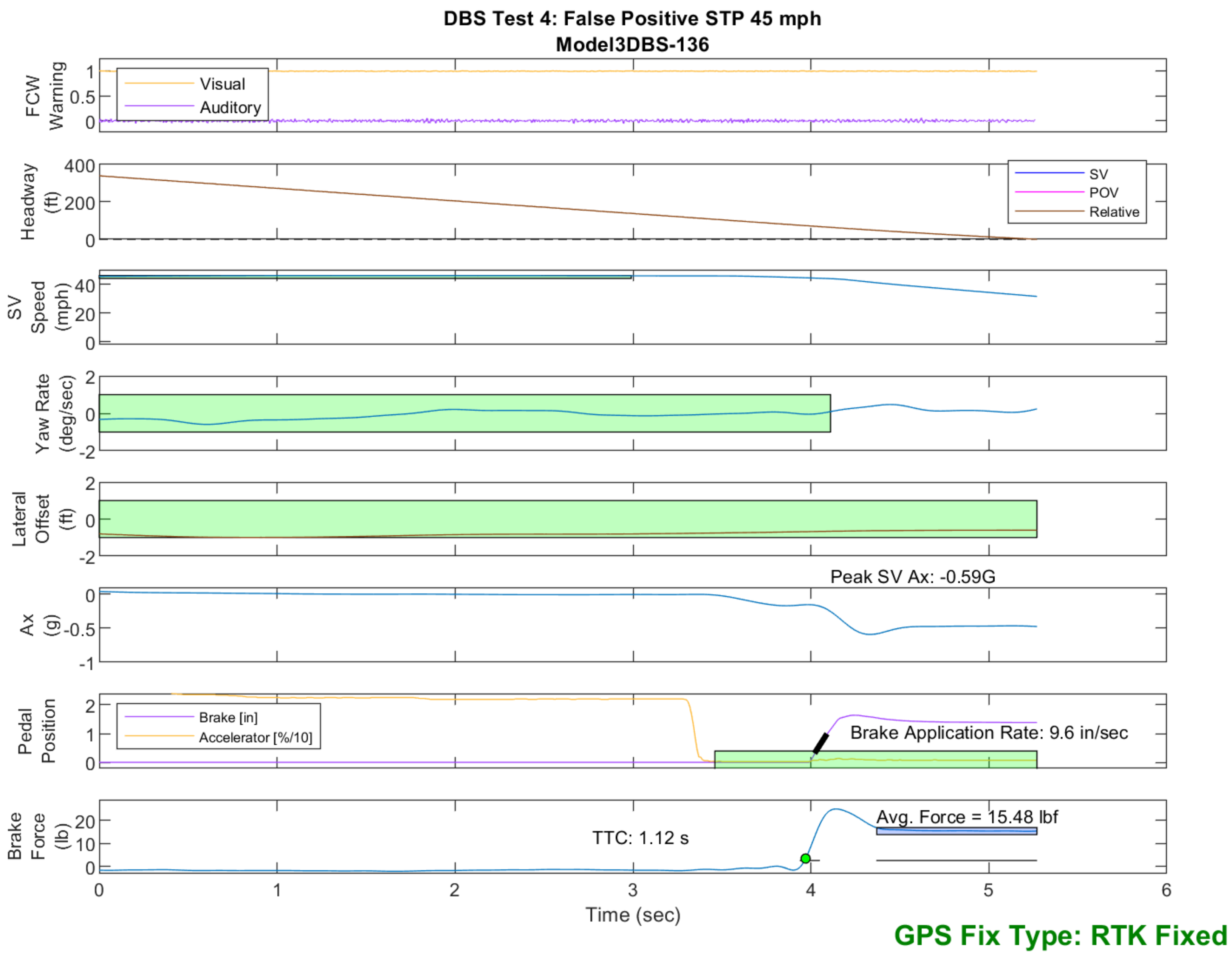


Figure E73. Time History for DBS Run 136, Test 4 - False Positive STP 45 mph, Creep Mode, Battery SOC = ~62%

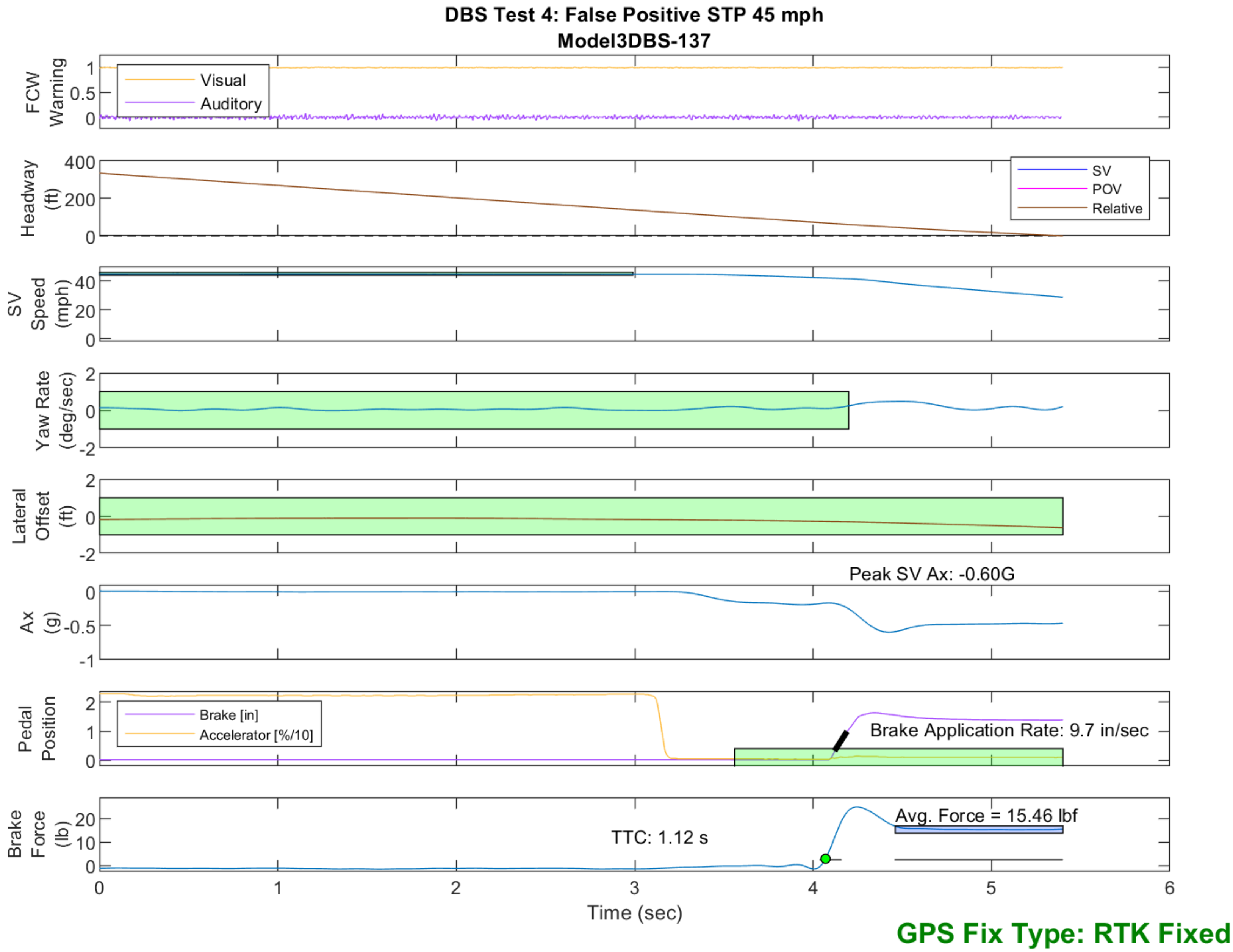


Figure E74. Time History for DBS Run 137, Test 4 - False Positive STP 45 mph, Creep Mode, Battery SOC = ~62%

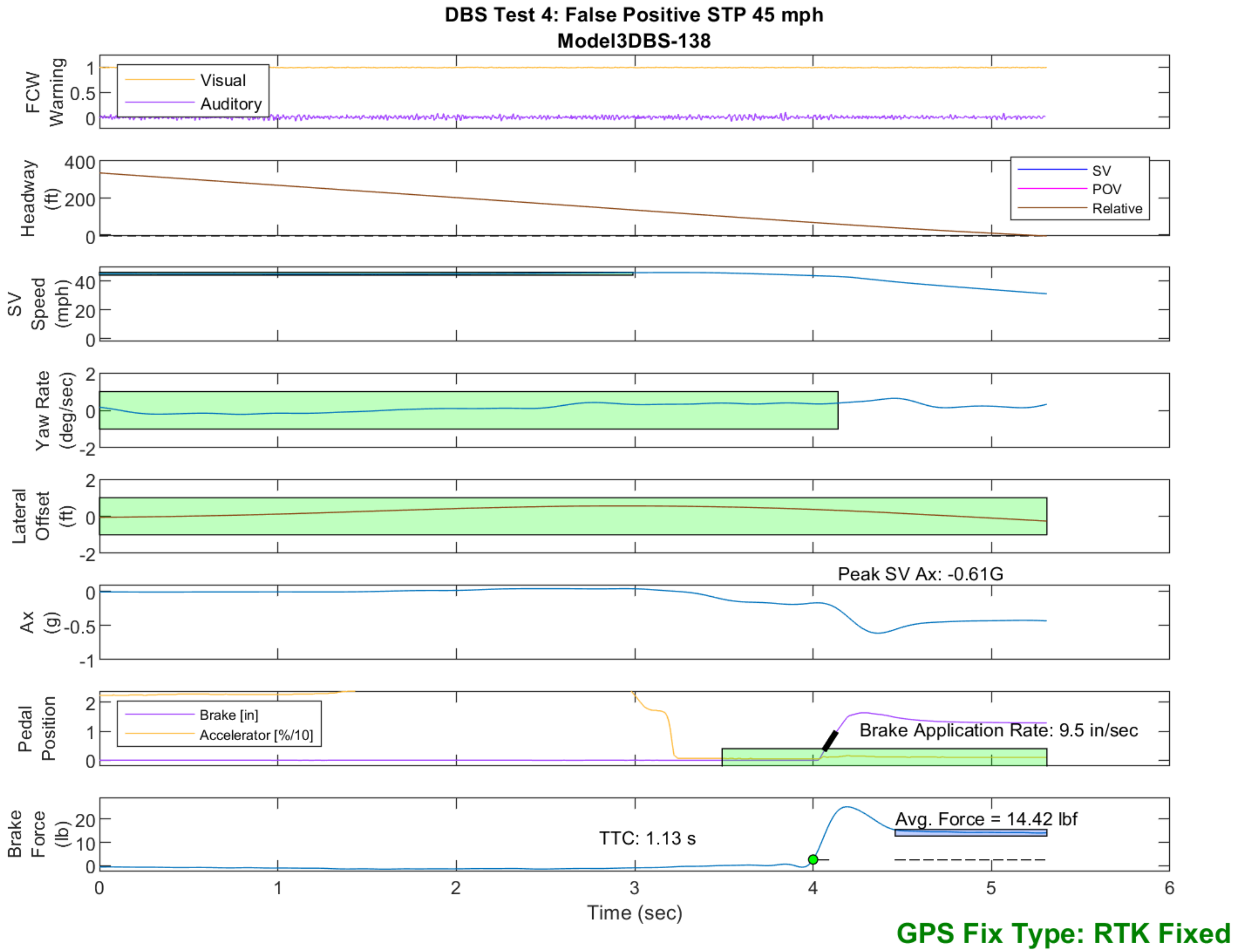


Figure E75. Time History for DBS Run 138, Test 4 - False Positive STP 45 mph, Roll Mode, Battery SOC = ~62%

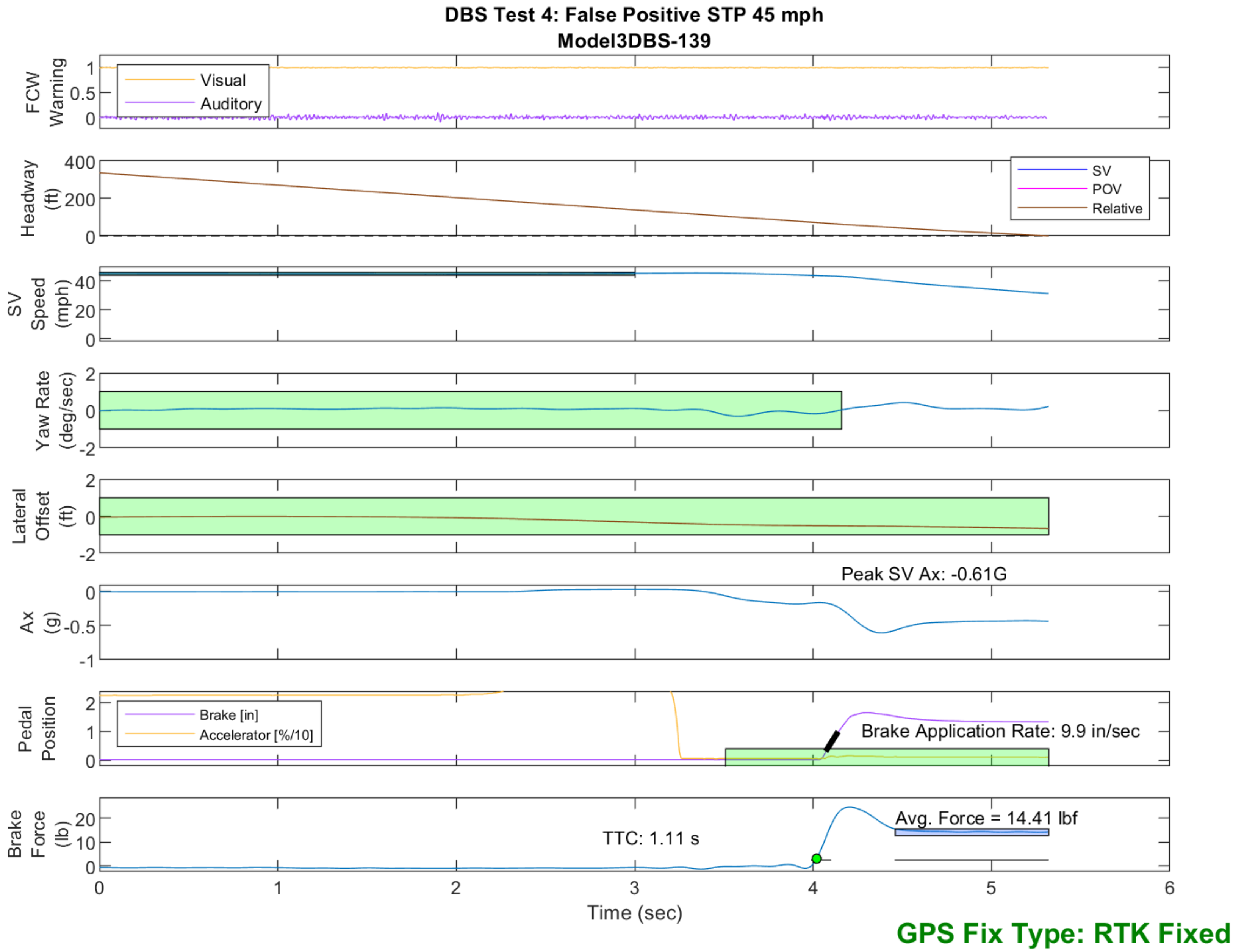


Figure E76. Time History for DBS Run 139, Test 4 - False Positive STP 45 mph, Roll Mode, Battery SOC = ~62%

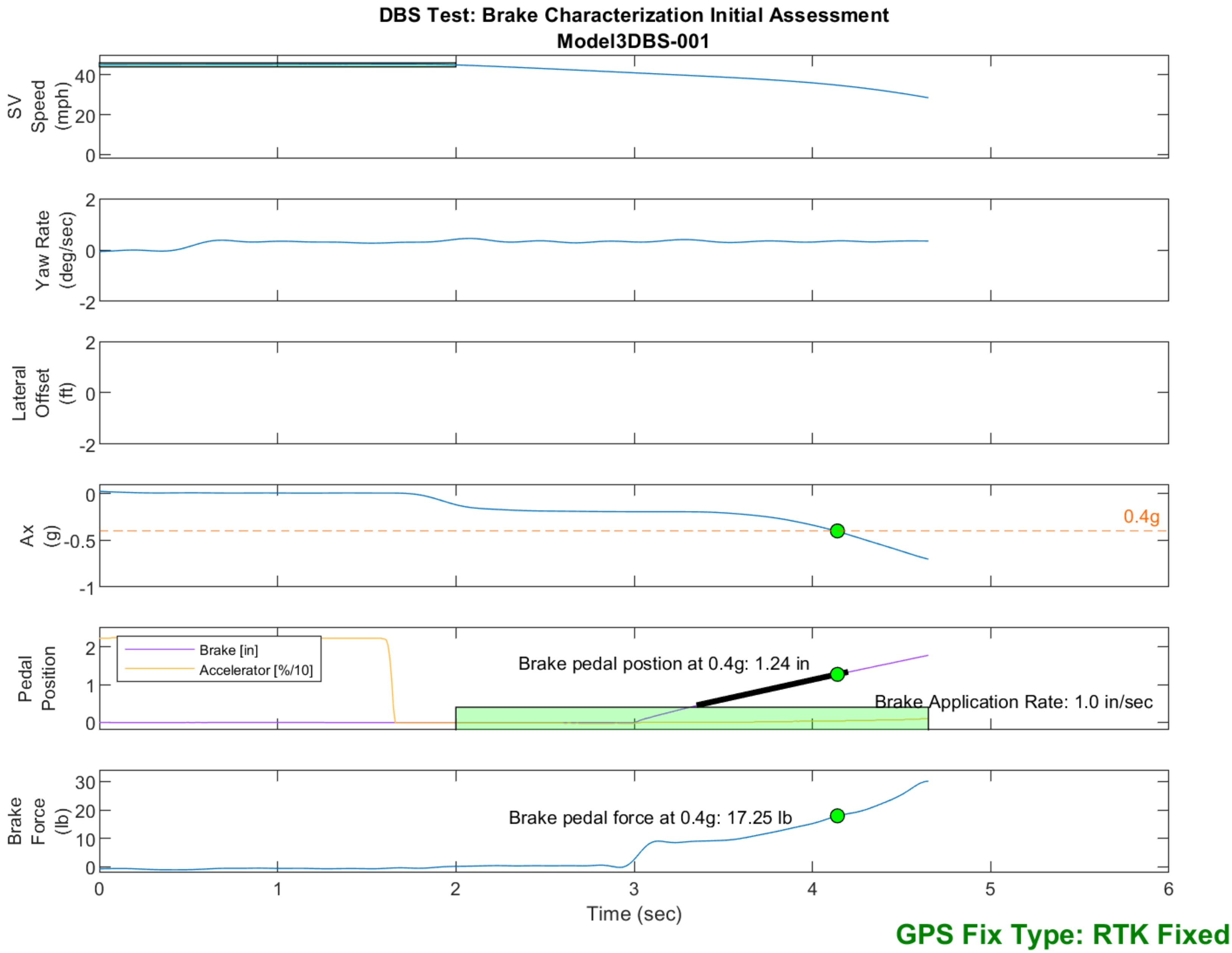


Figure E77. Time History for DBS Run 1, Brake Characterization Initial, Creep Mode

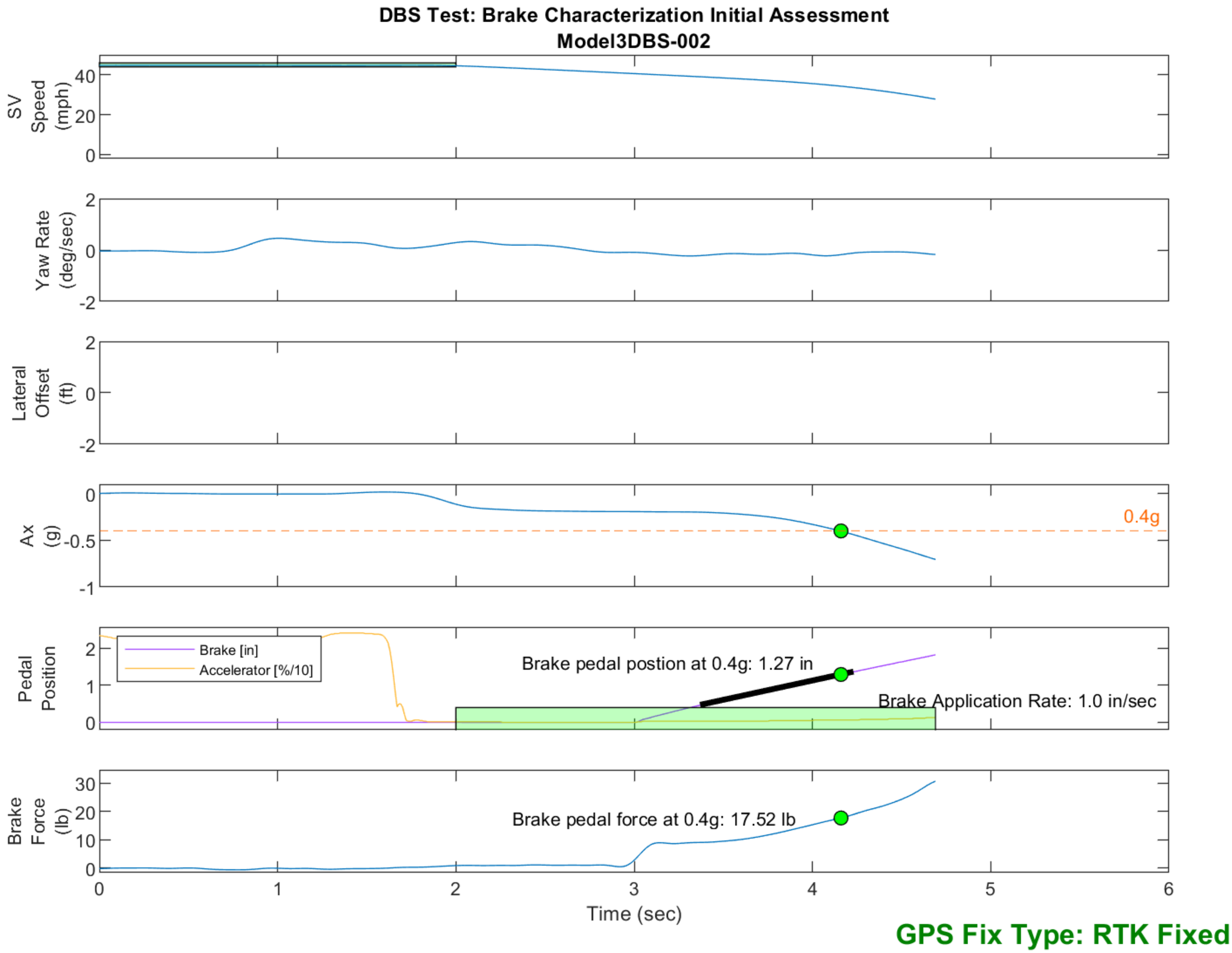


Figure E78. Time History for DBS Run 2, Brake Characterization Initial, Creep Mode

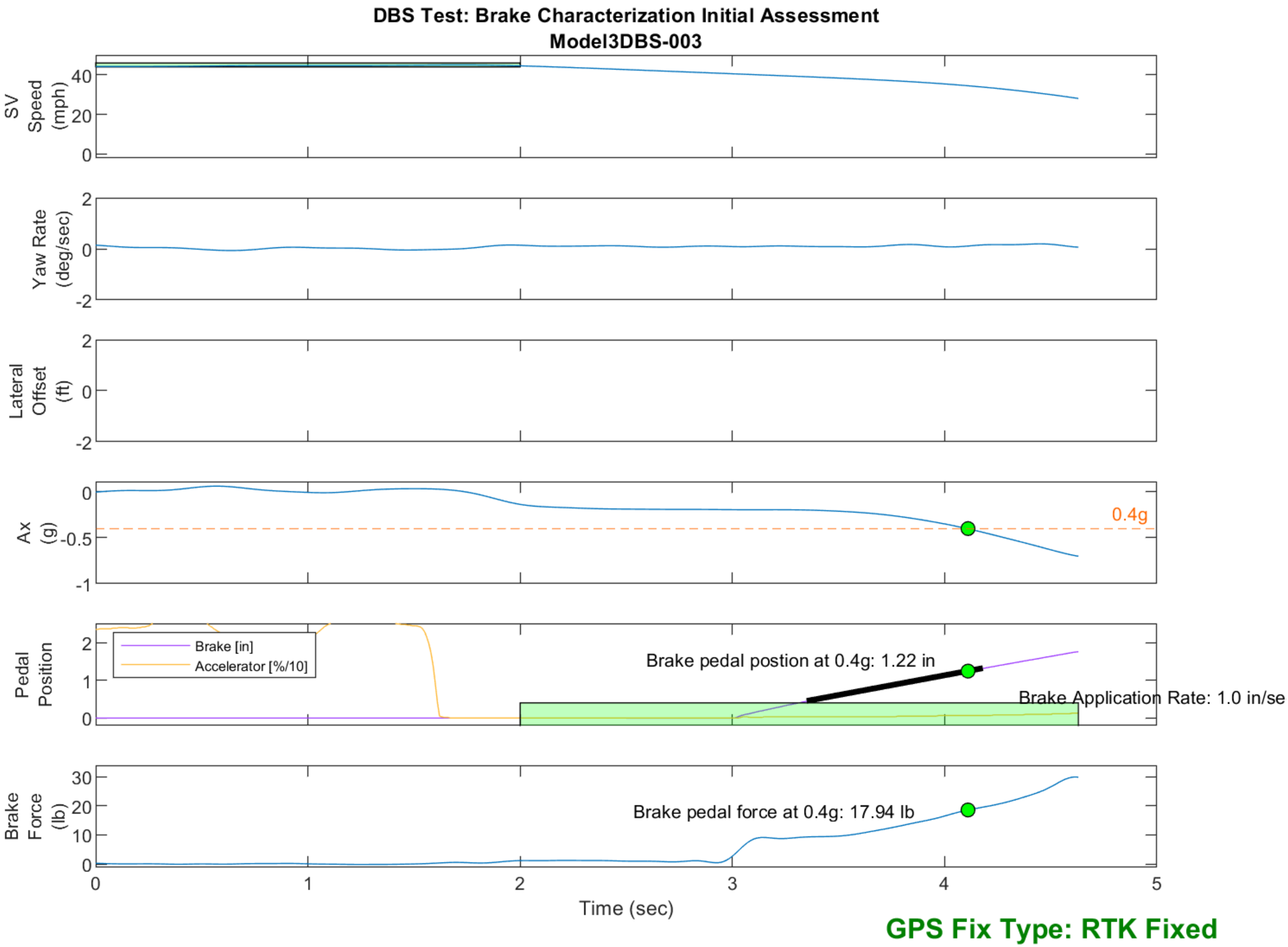


Figure E79. Time History for DBS Run 3, Brake Characterization Initial, Creep Mode

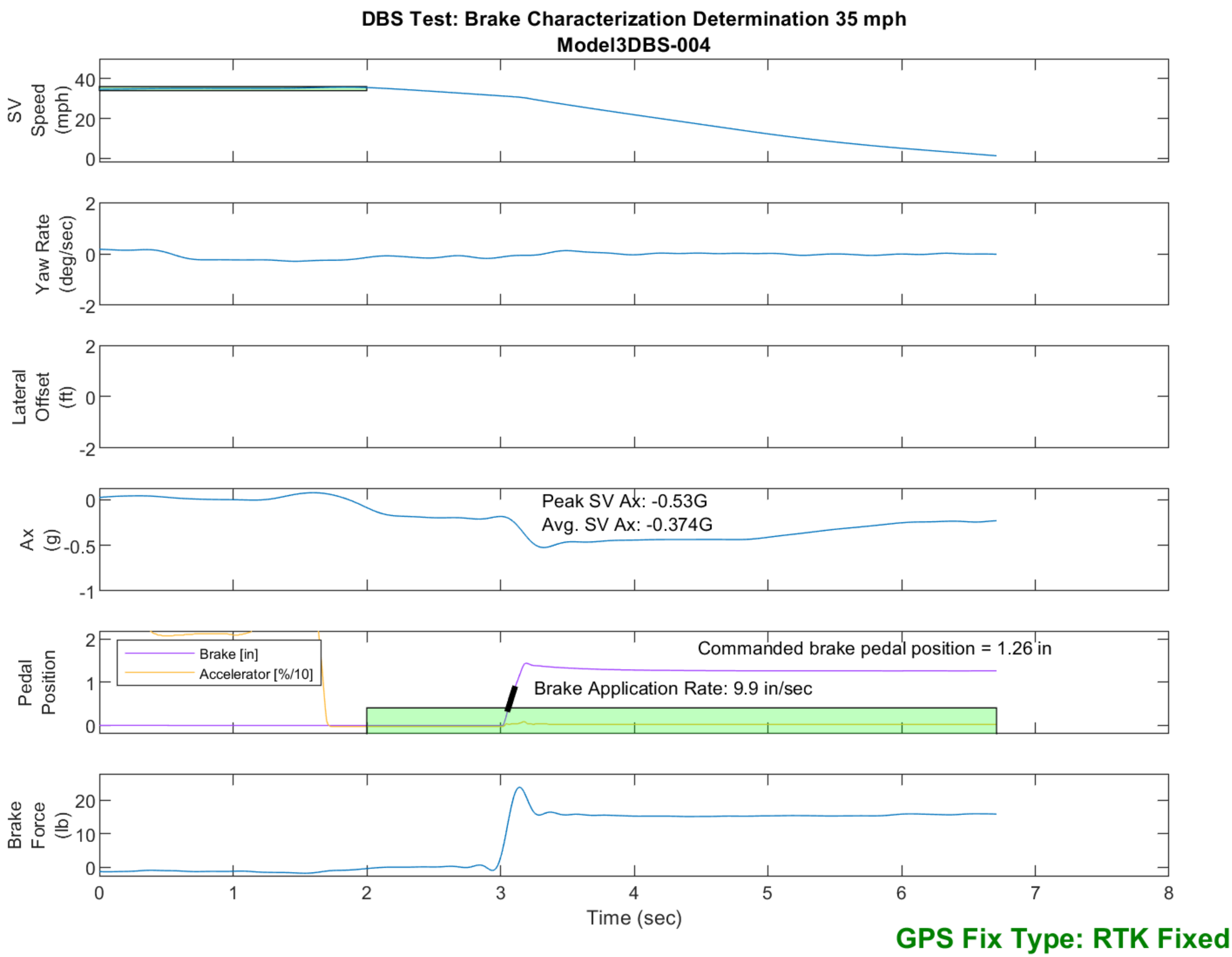


Figure E80. Time History for DBS Run 4, Brake Characterization Determination, Displacement Mode, 35 mph, Creep Mode

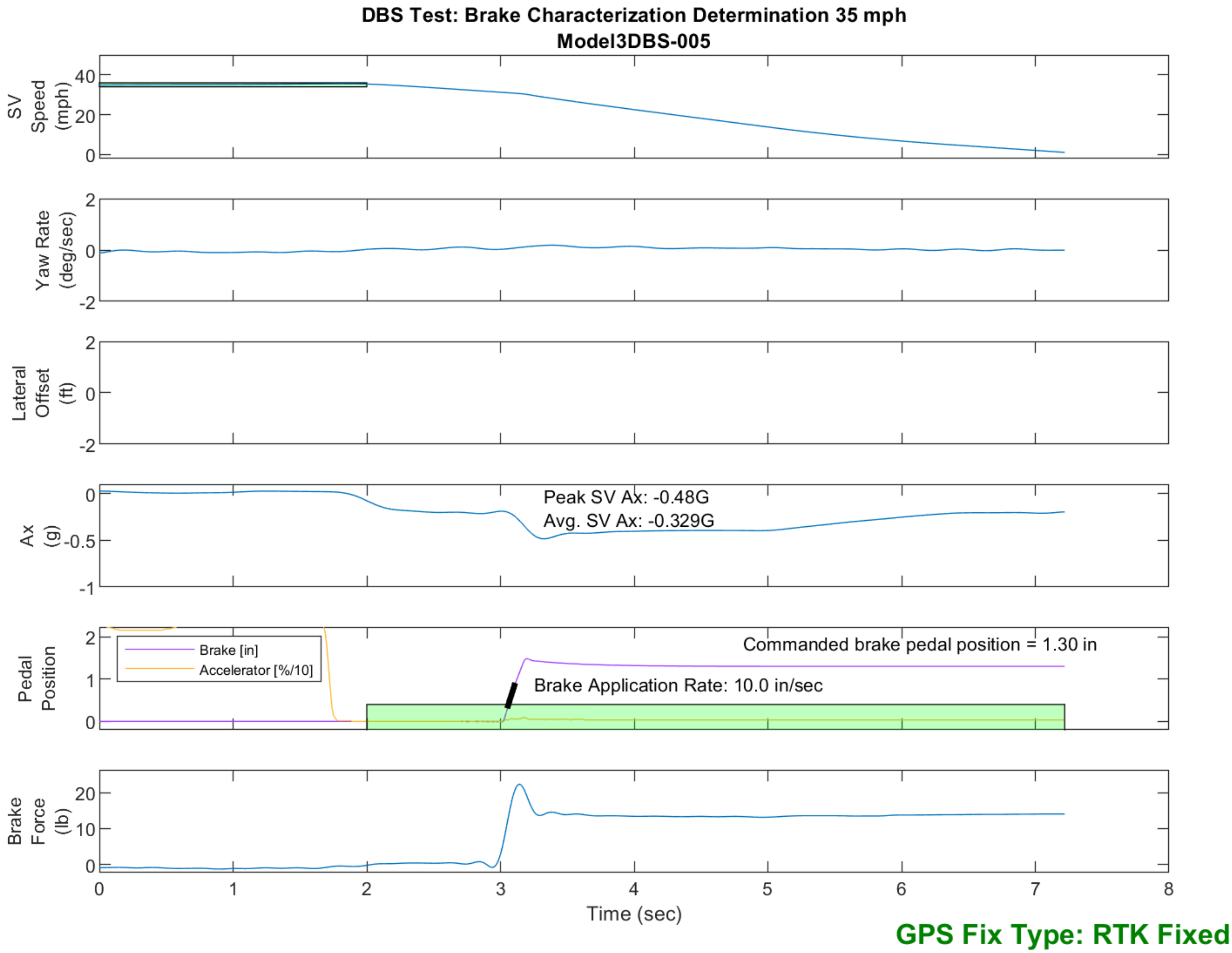


Figure E81. Time History for DBS Run 5, Brake Characterization Determination, Displacement Mode, 35 mph, Creep Mode

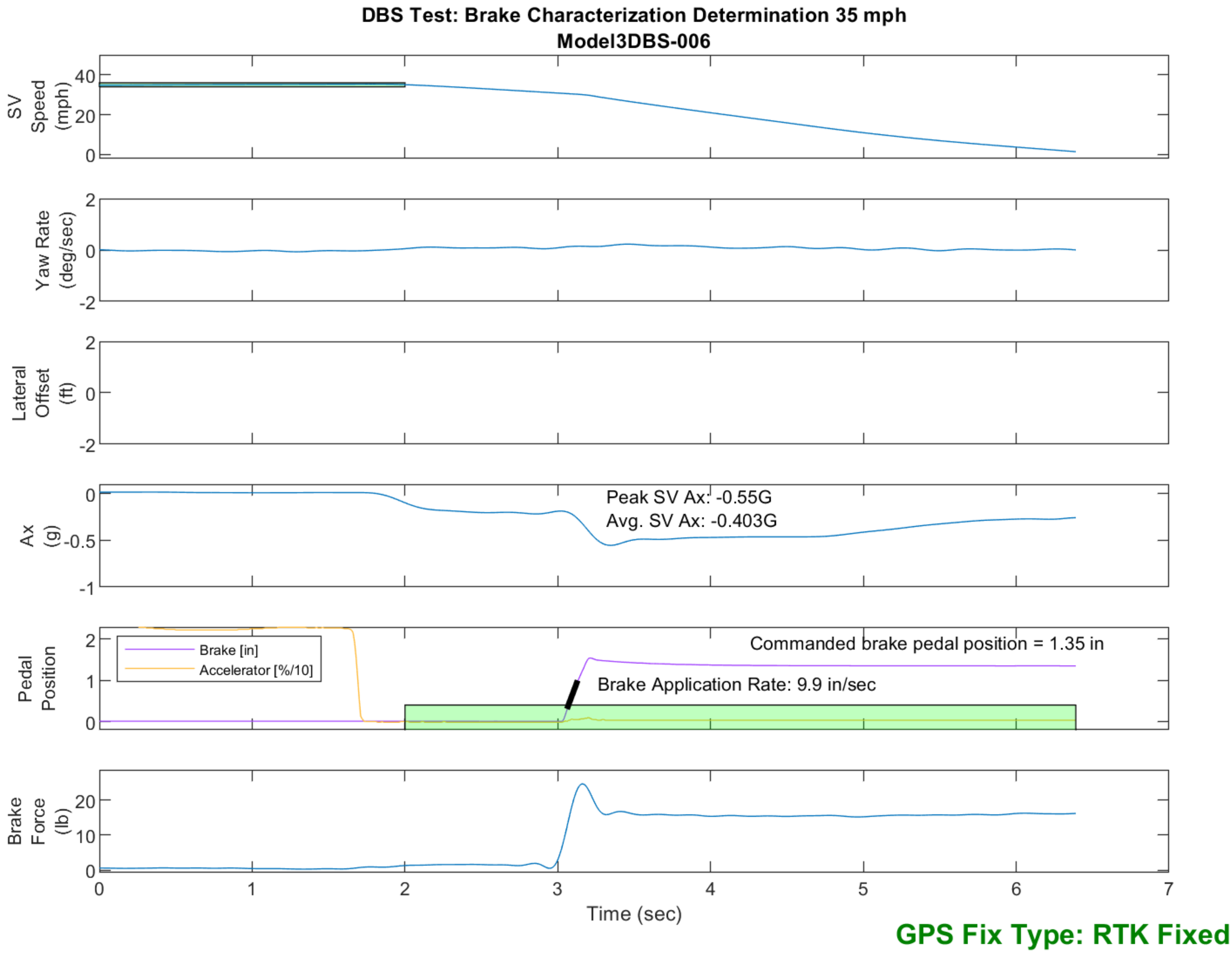


Figure E82. Time History for DBS Run 6, Brake Characterization Determination, Displacement Mode, 35 mph, Creep Mode

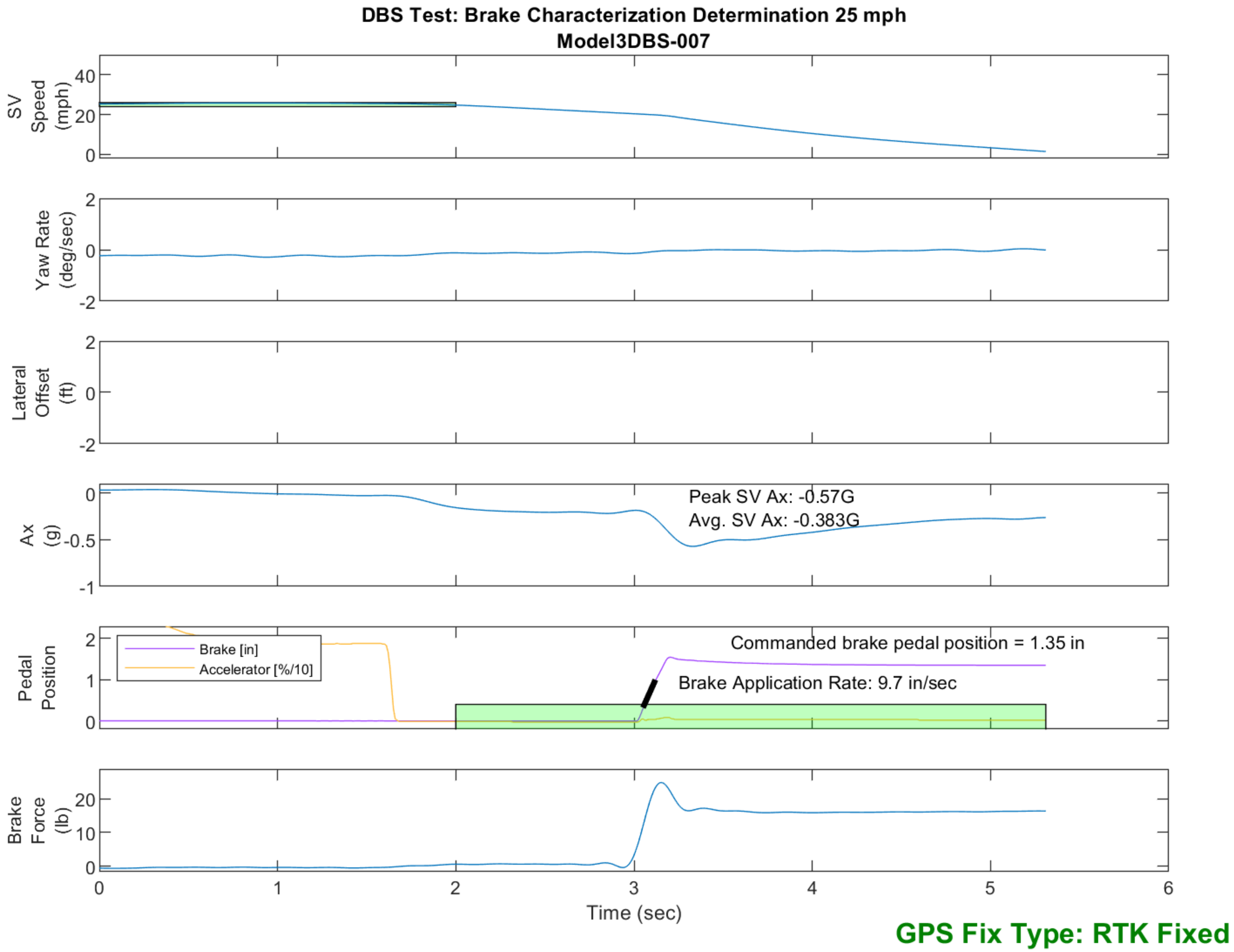


Figure E83. Time History for DBS Run 7, Brake Characterization Determination, Displacement Mode, 25 mph, Creep Mode

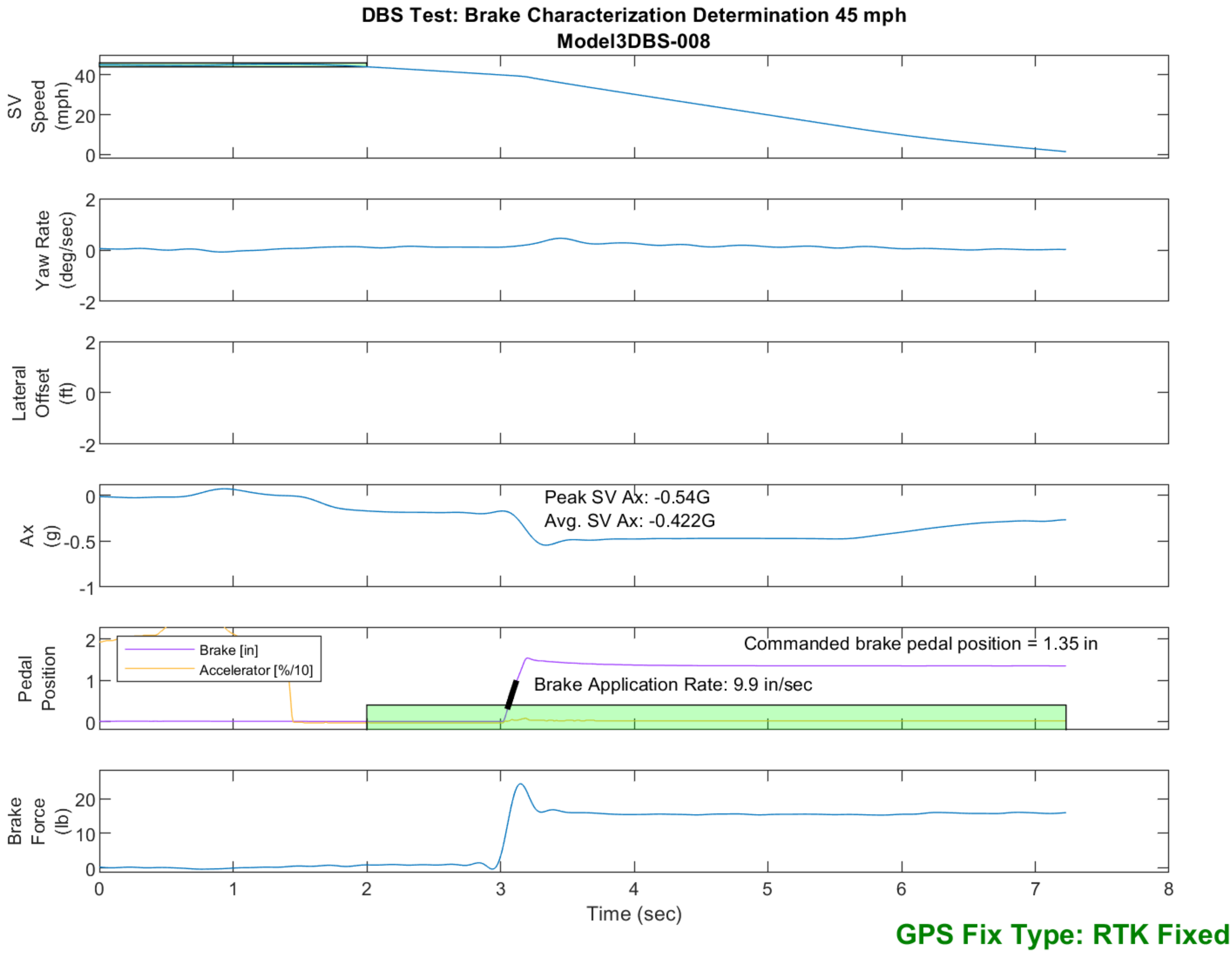


Figure E84. Time History for DBS Run 8, Brake Characterization Determination, Displacement Mode, 45 mph, Creep Mode

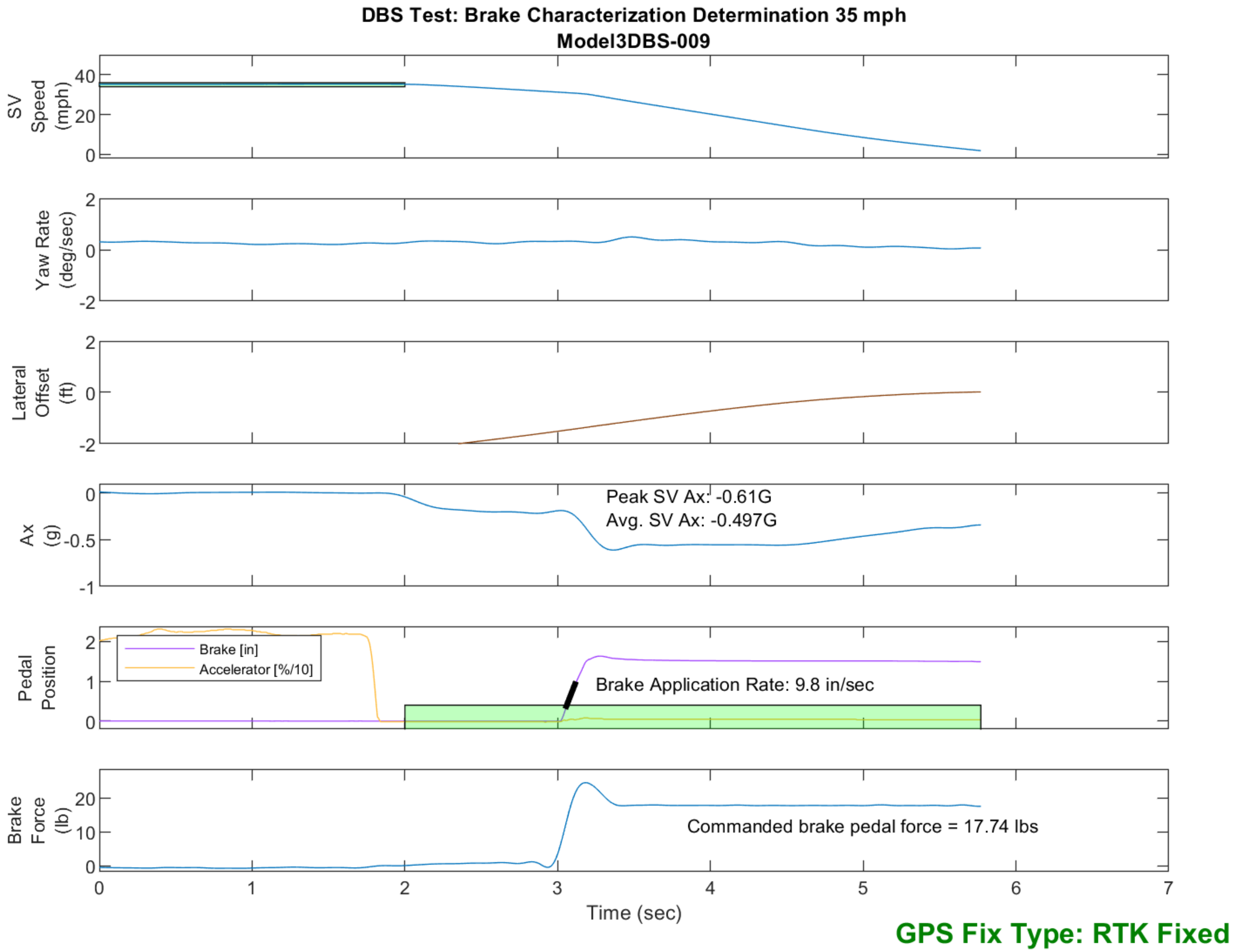


Figure E85. Time History for DBS Run 9, Brake Characterization Determination, Hybrid Mode, 35 mph, Creep Mode

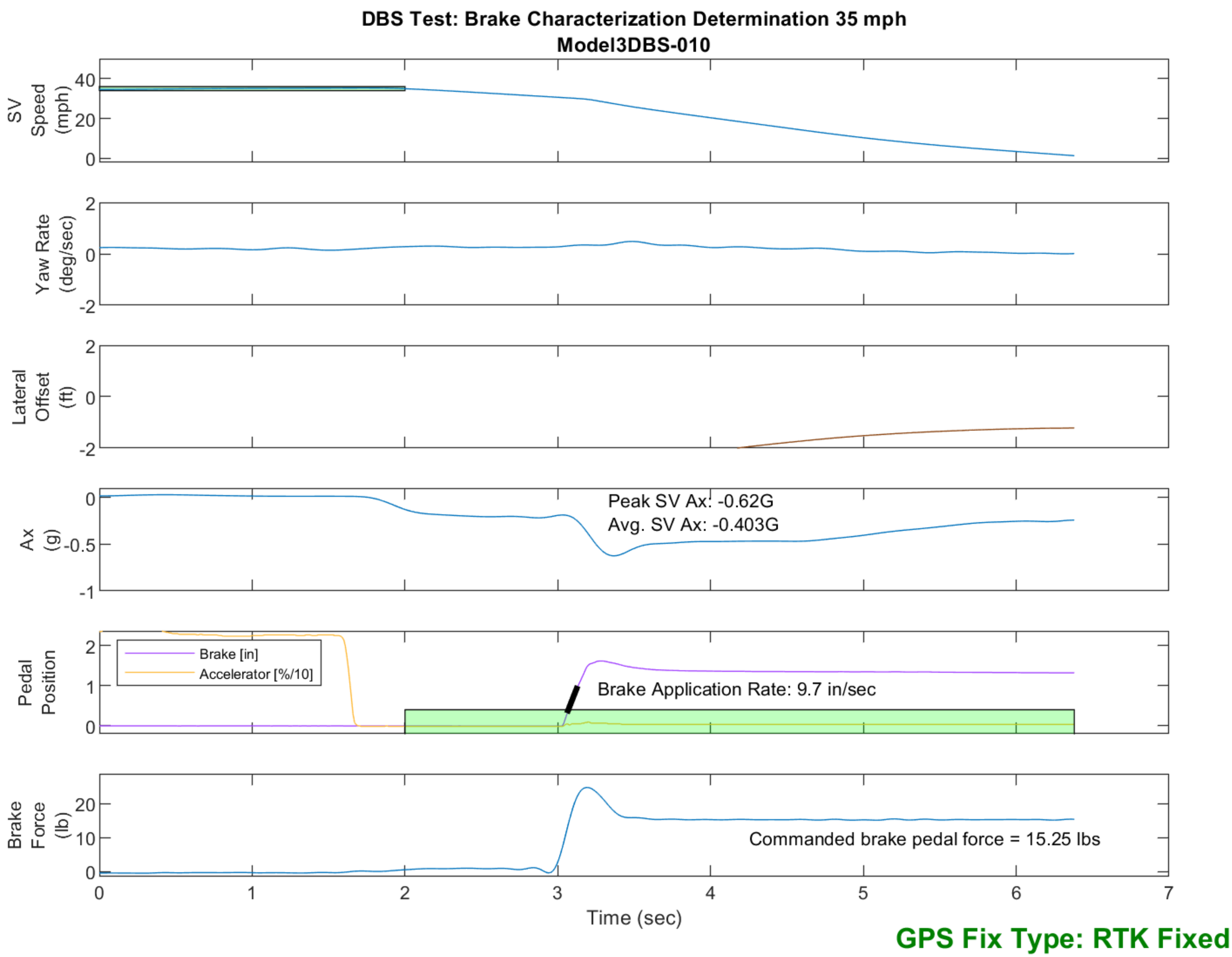


Figure E86. Time History for DBS Run 10, Brake Characterization Determination, Hybrid Mode, 35 mph, Creep Mode

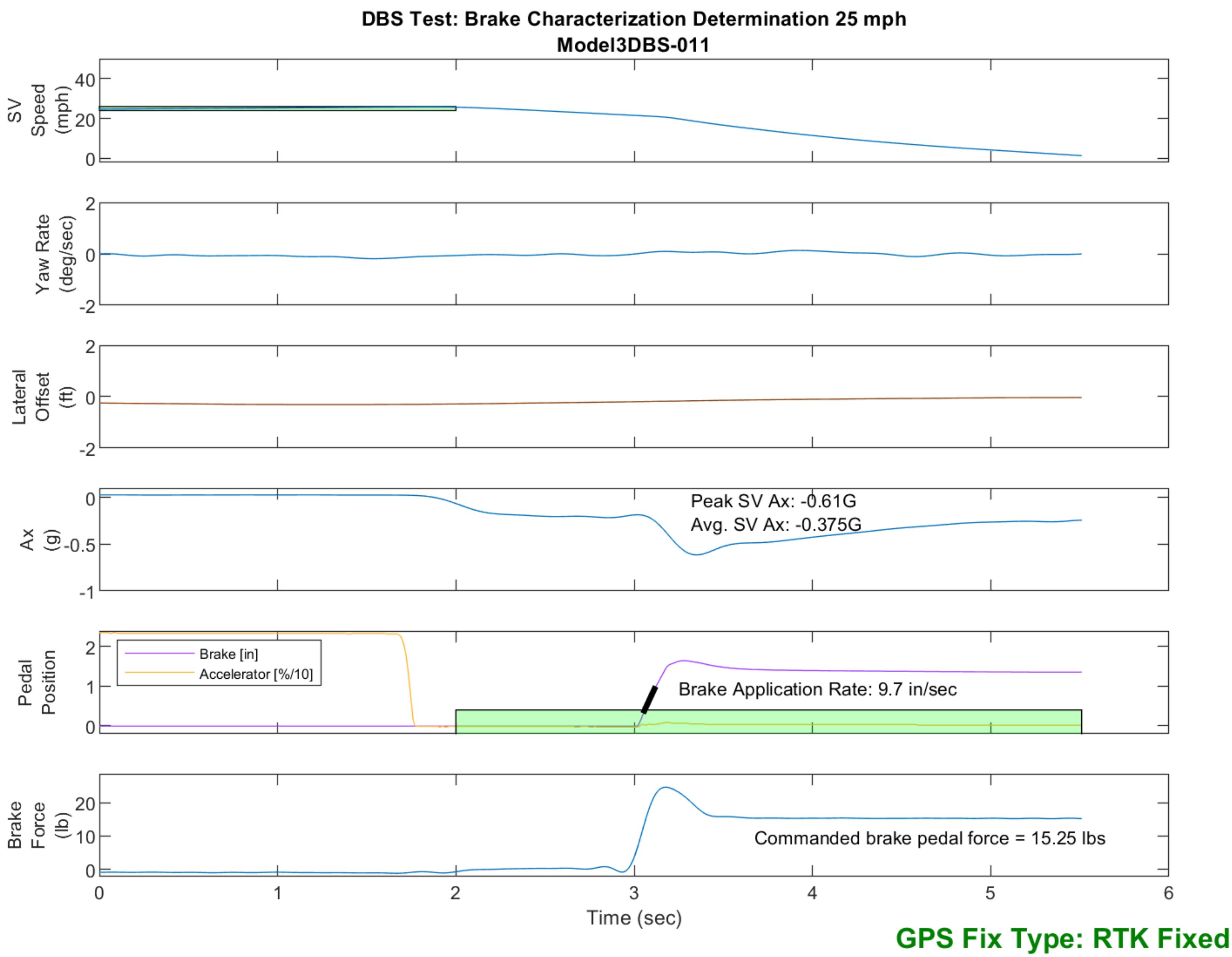


Figure E87. Time History for DBS Run 11, Brake Characterization Determination, Hybrid Mode, 25 mph, Creep Mode

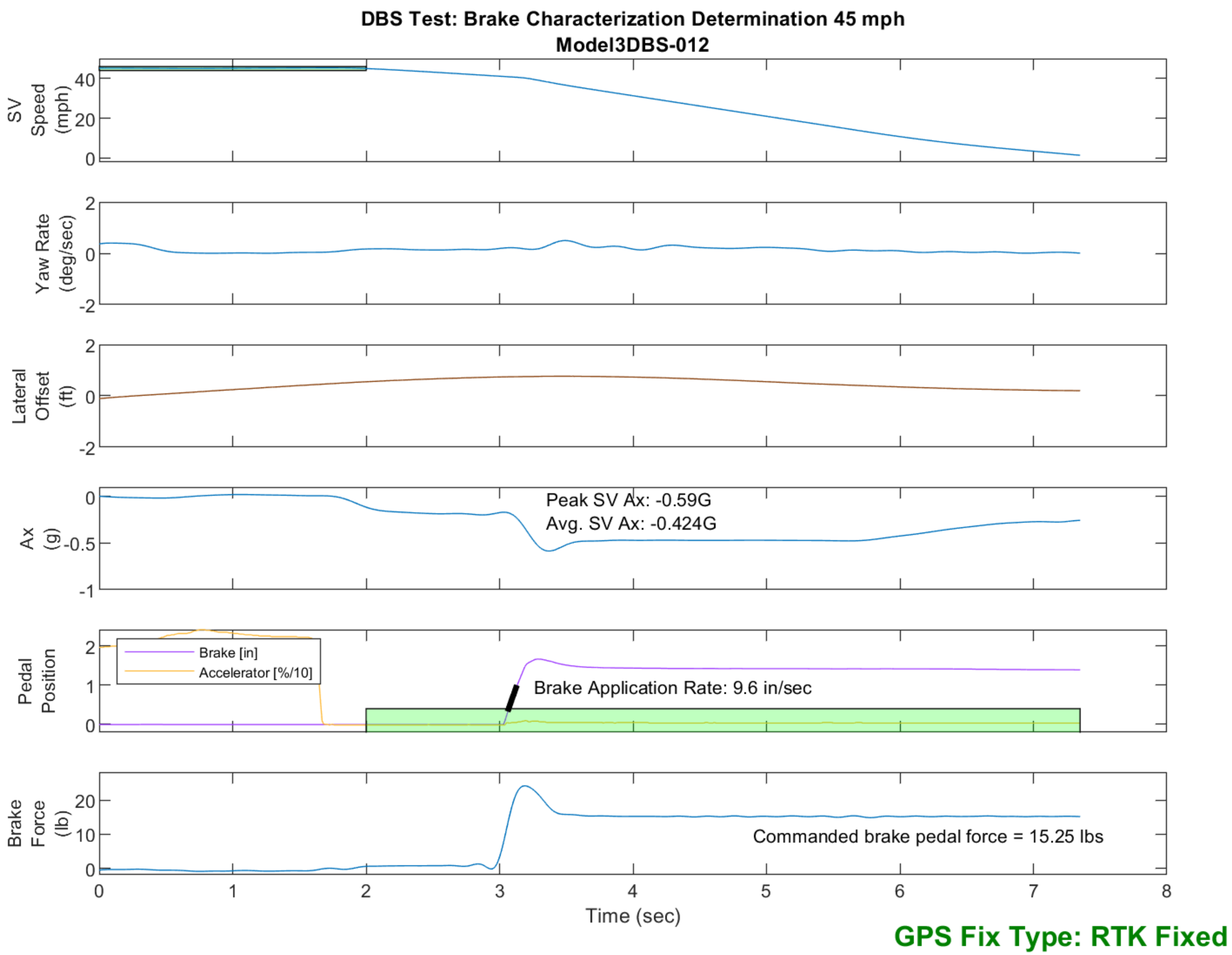


Figure E88. Time History for DBS Run 12, Brake Characterization Determination, Hybrid Mode, 45 mph, Creep Mode

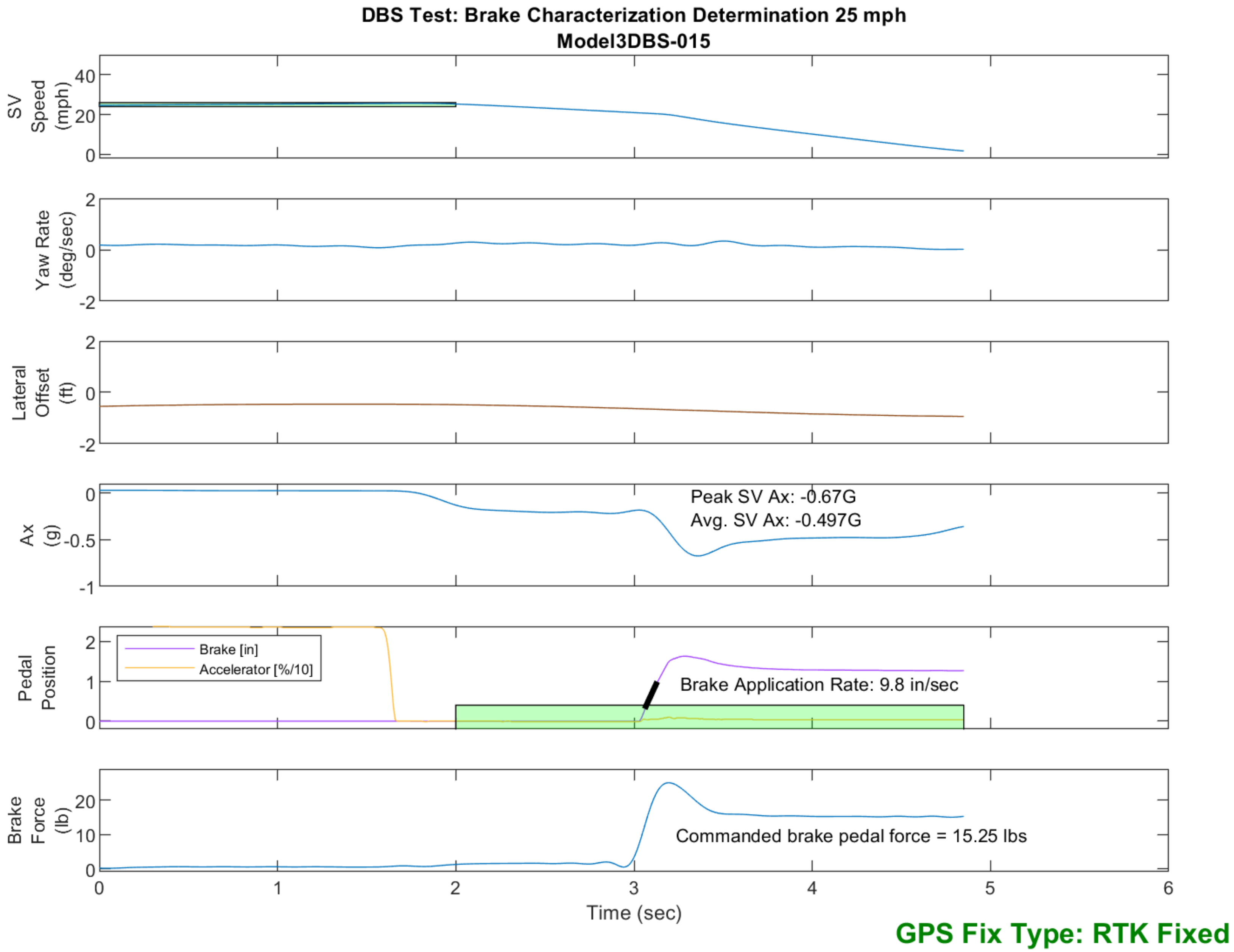


Figure E89. Time History for DBS Run 15, Brake Characterization Determination, Hybrid Mode, 25 mph, Hold Mode

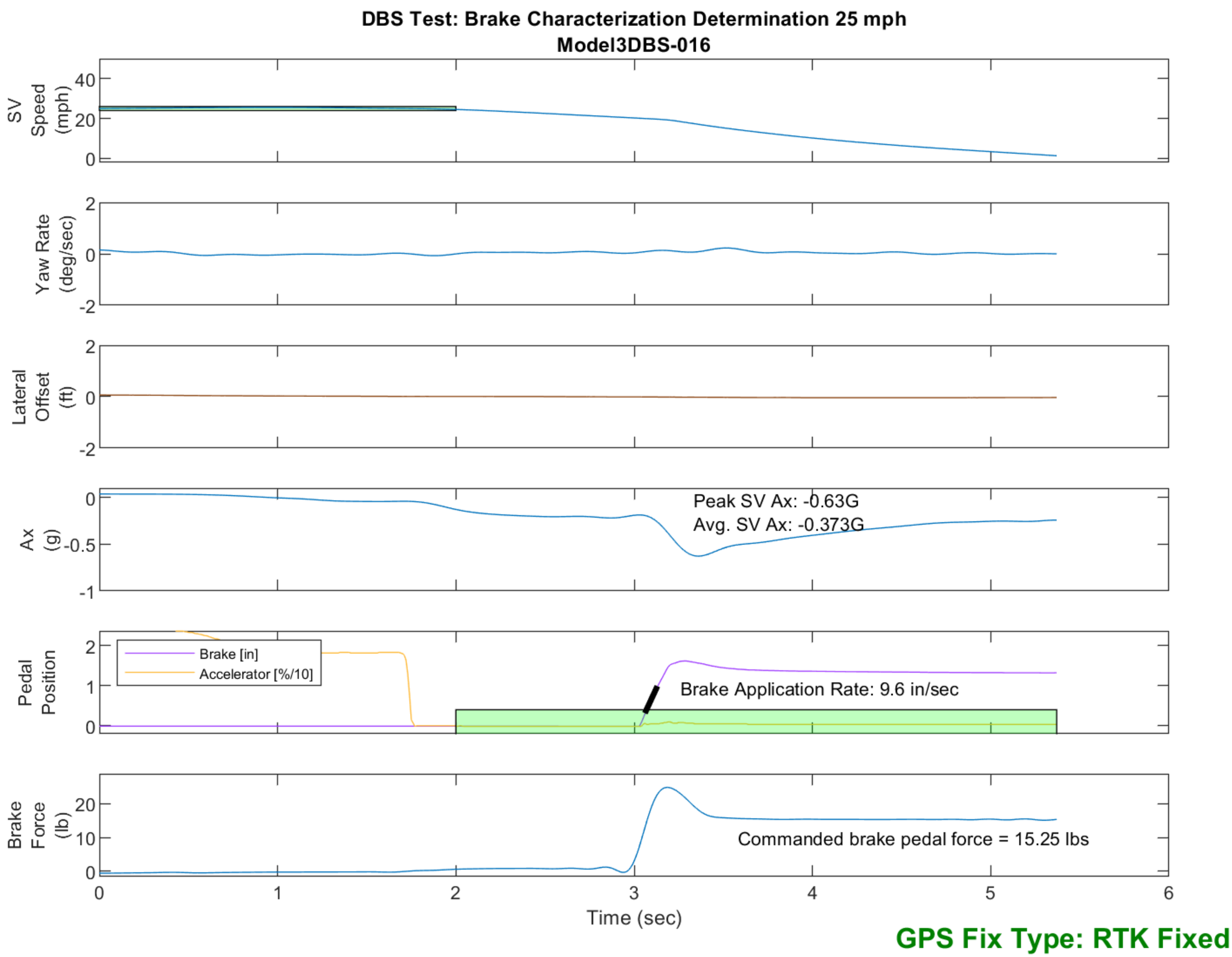


Figure E90. Time History for DBS Run 16, Brake Characterization Determination, Hybrid Mode, 25 mph, Creep Mode

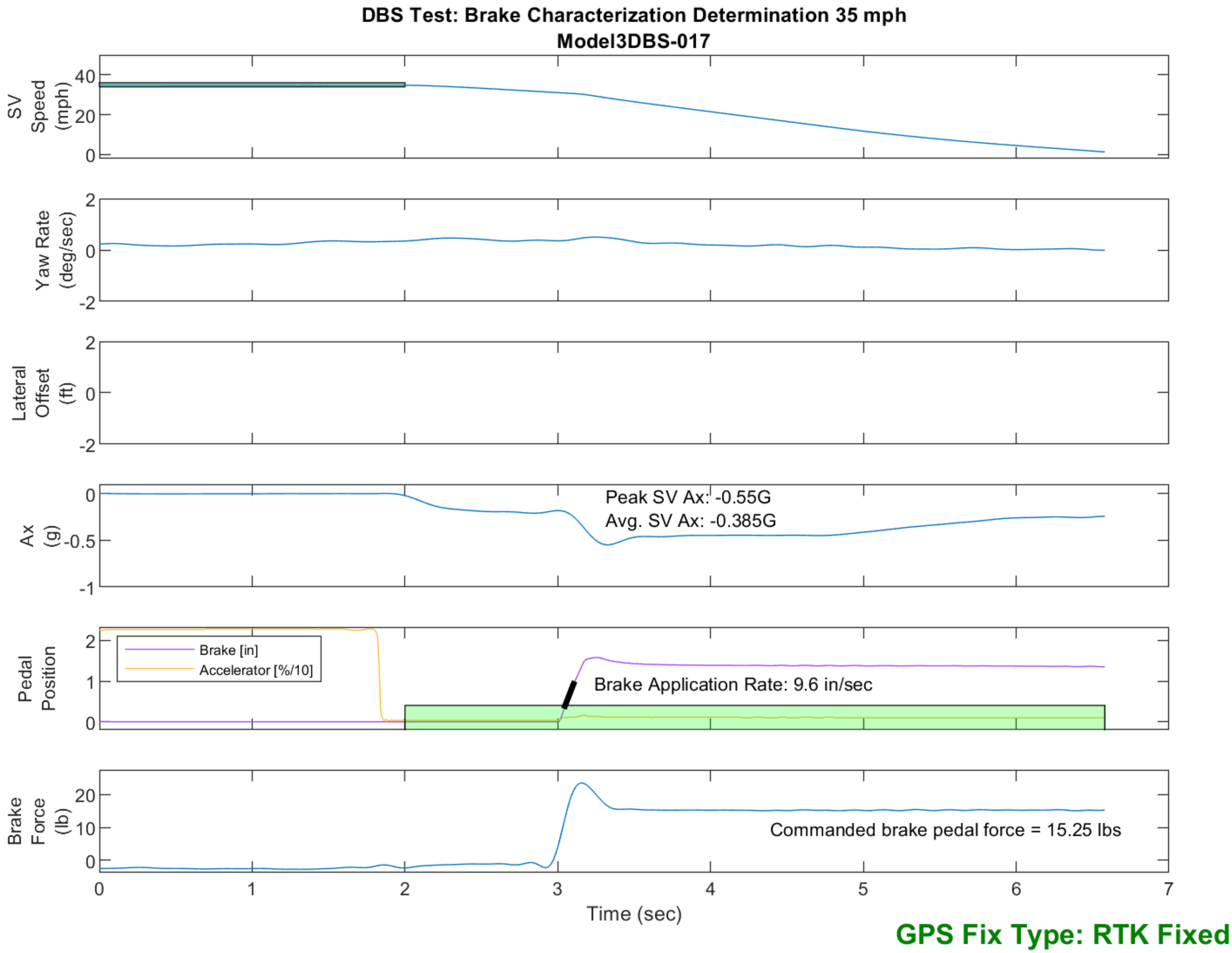


Figure E91. Time History for DBS Run 17, Brake Characterization Determination, Hybrid Mode, 35 mph, Creep Mode

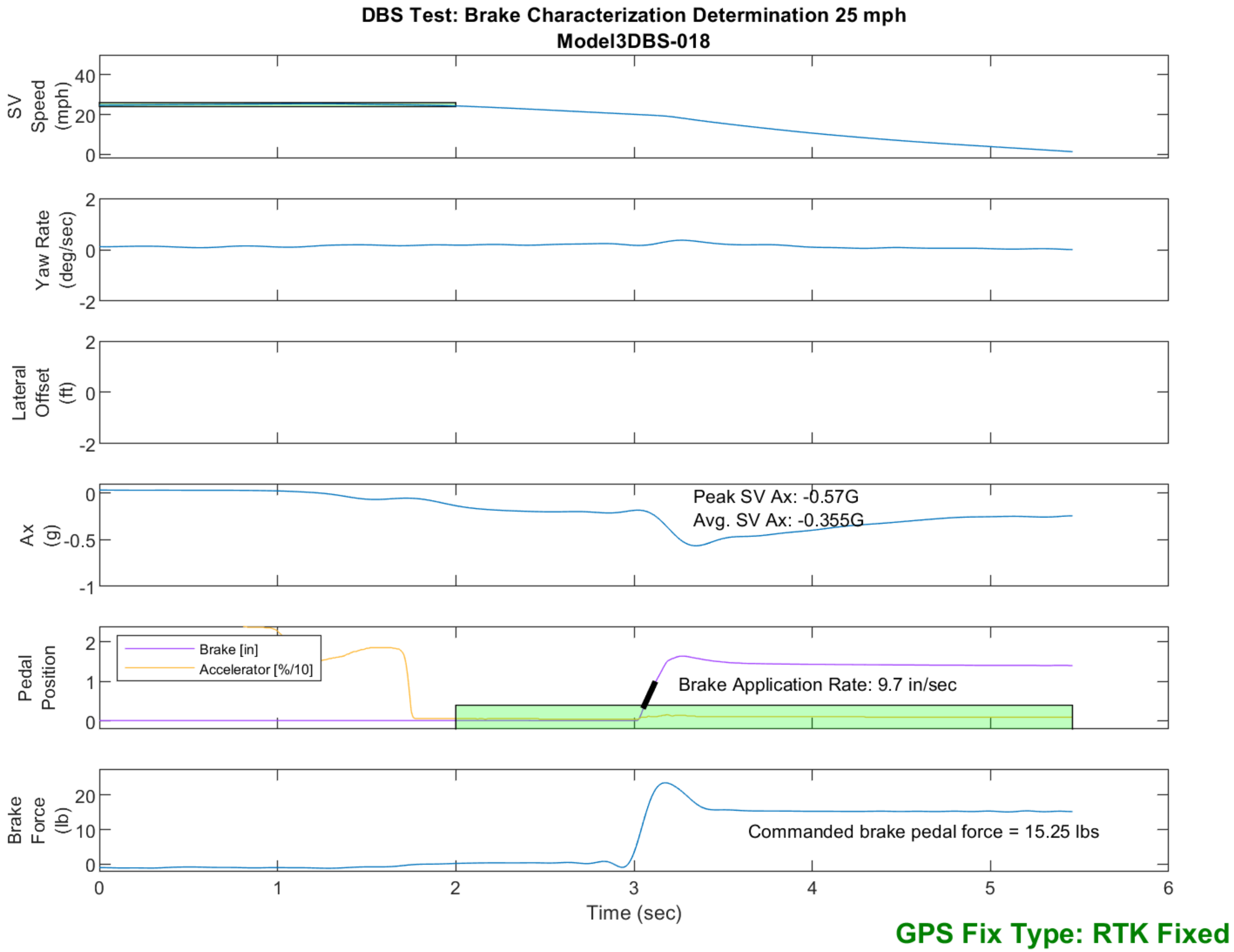


Figure E92. Time History for DBS Run 18, Brake Characterization Determination, Hybrid Mode, 25 mph, Creep Mode

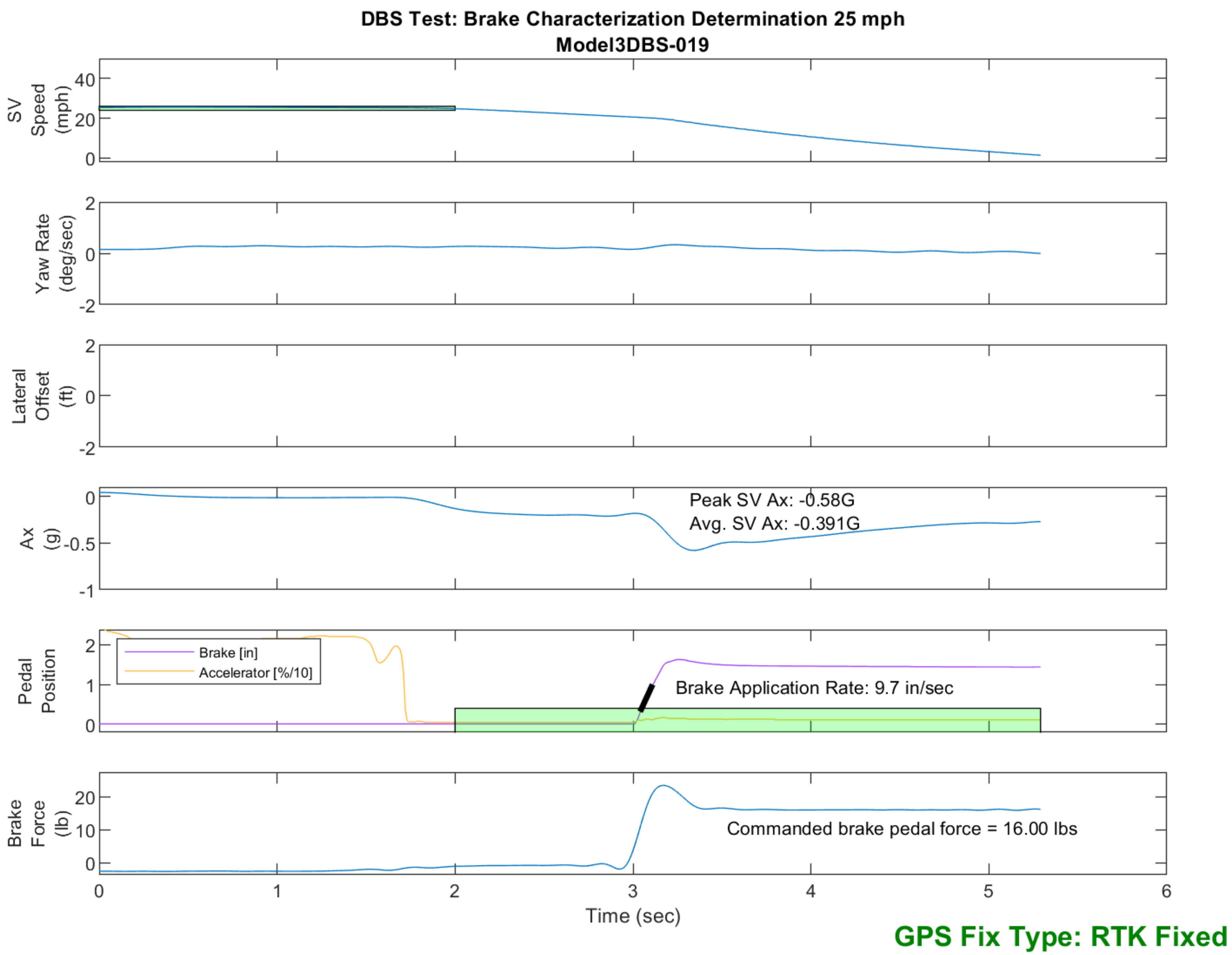


Figure E93. Time History for DBS Run 19, Brake Characterization Determination, Hybrid Mode, 25 mph, Creep Mode

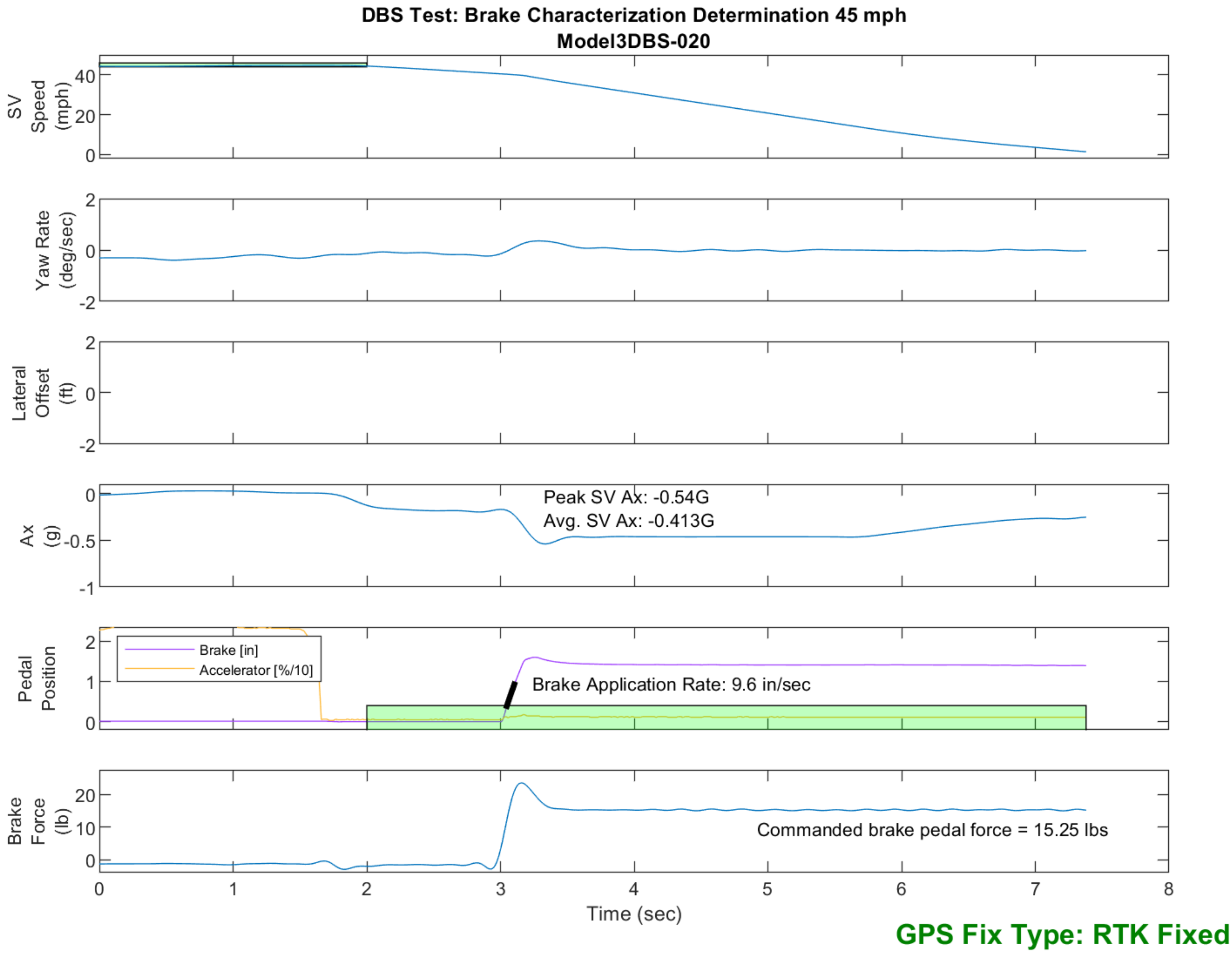


Figure E94. Time History for DBS Run 20, Brake Characterization Determination, Hybrid Mode, 45 mph, Creep Mode

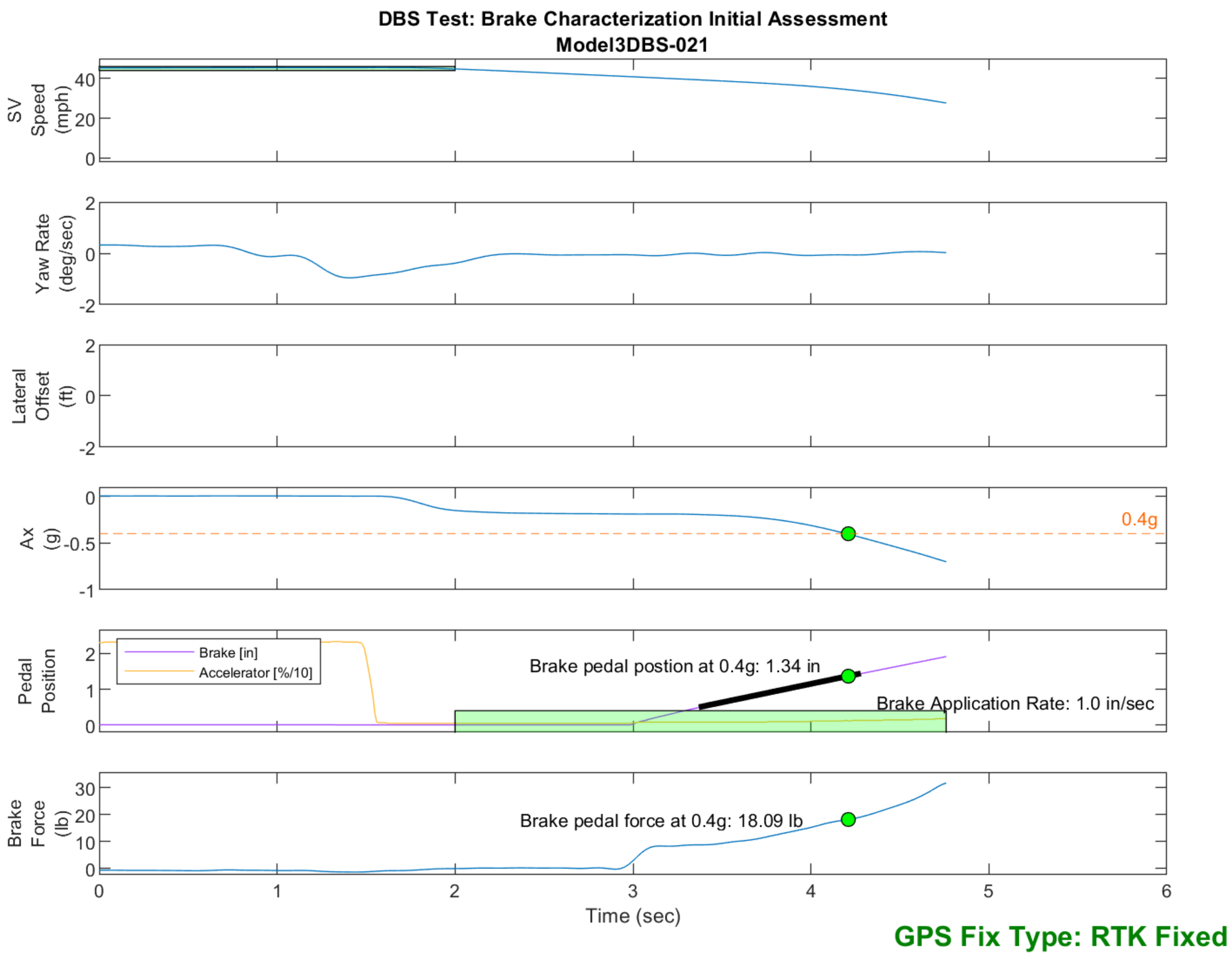


Figure E95. Time History for DBS Run 21, Brake Characterization Initial, Roll Mode

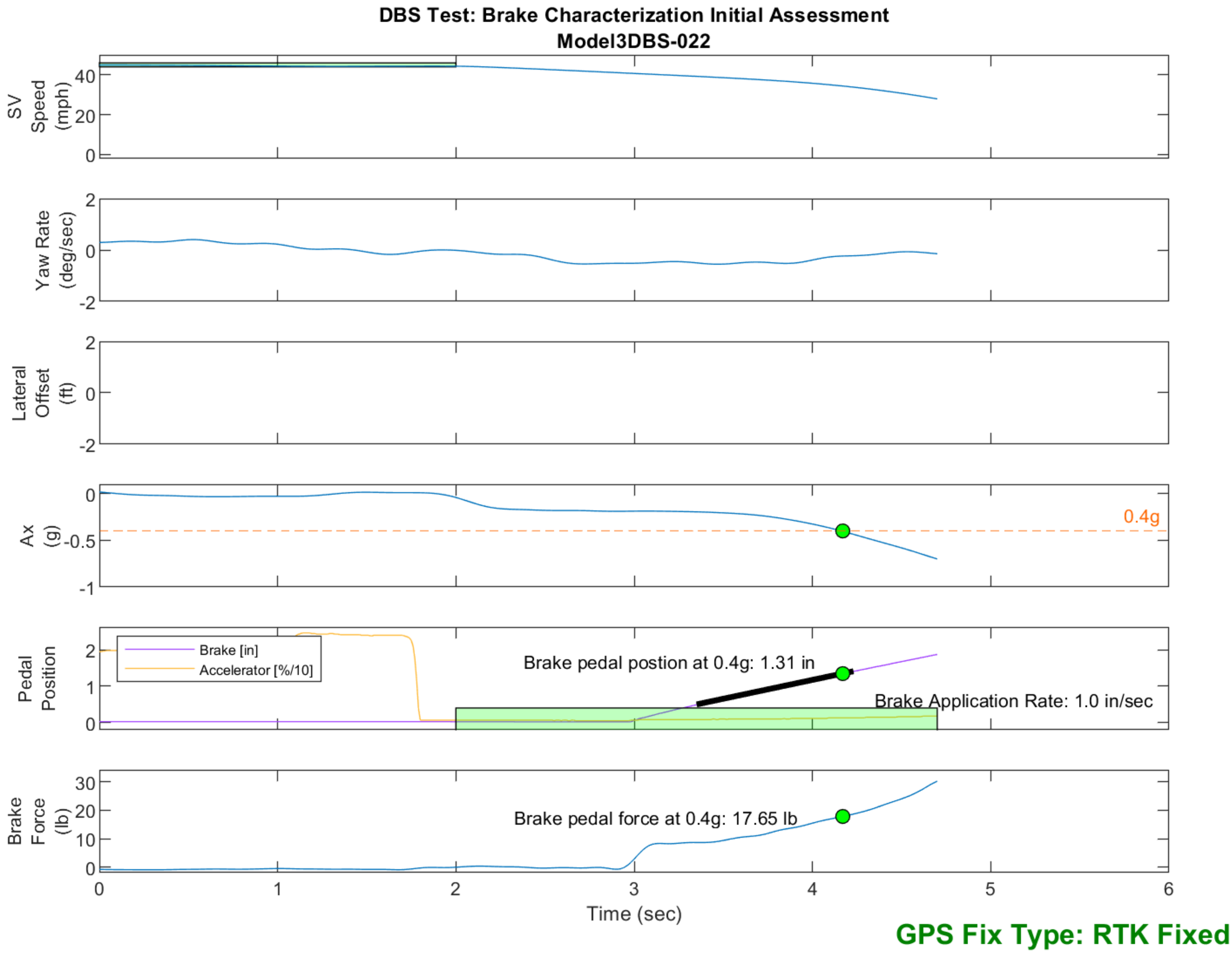


Figure E96. Time History for DBS Run 22, Brake Characterization Initial, Roll Mode

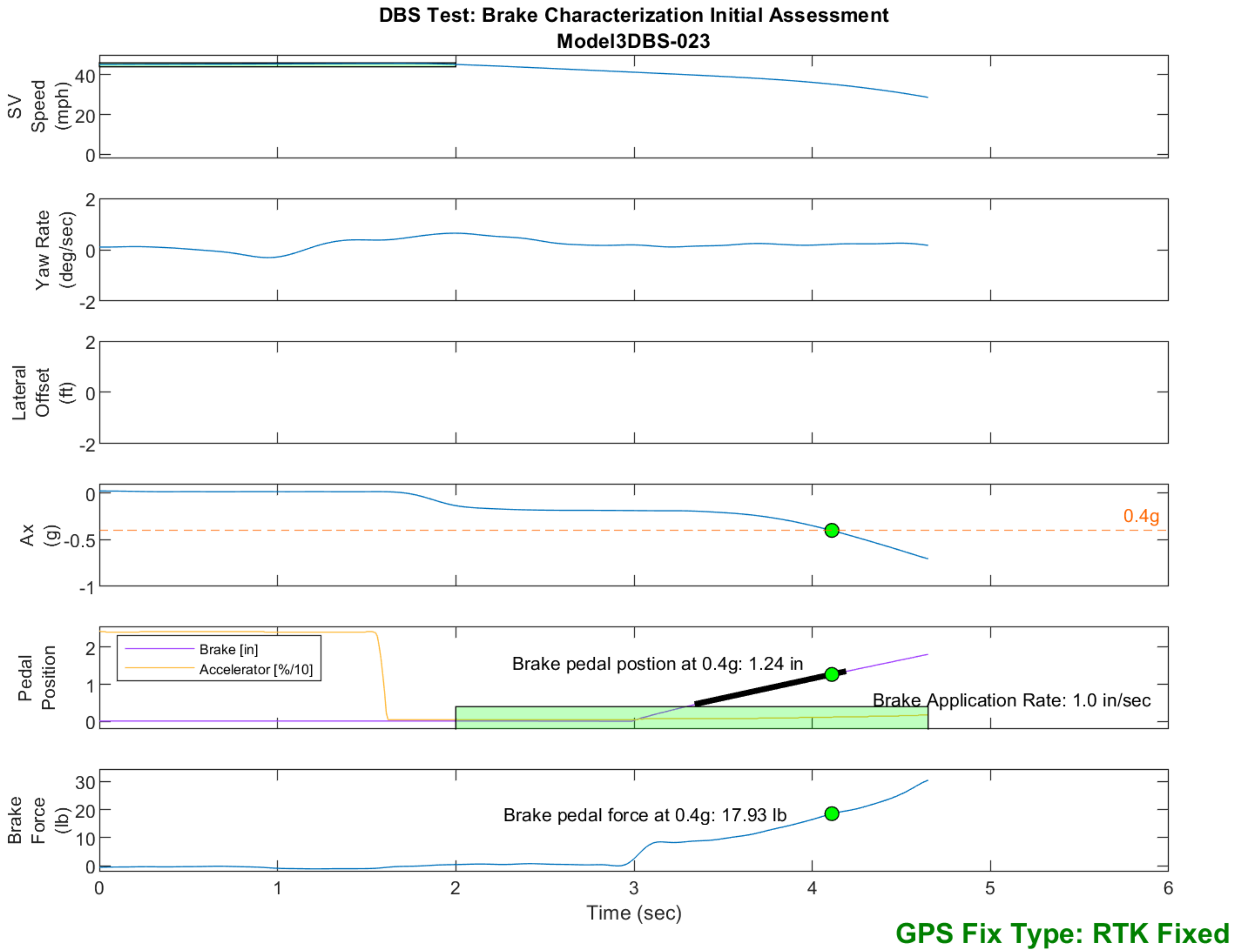


Figure E97. Time History for DBS Run 23, Brake Characterization Initial, Roll Mode

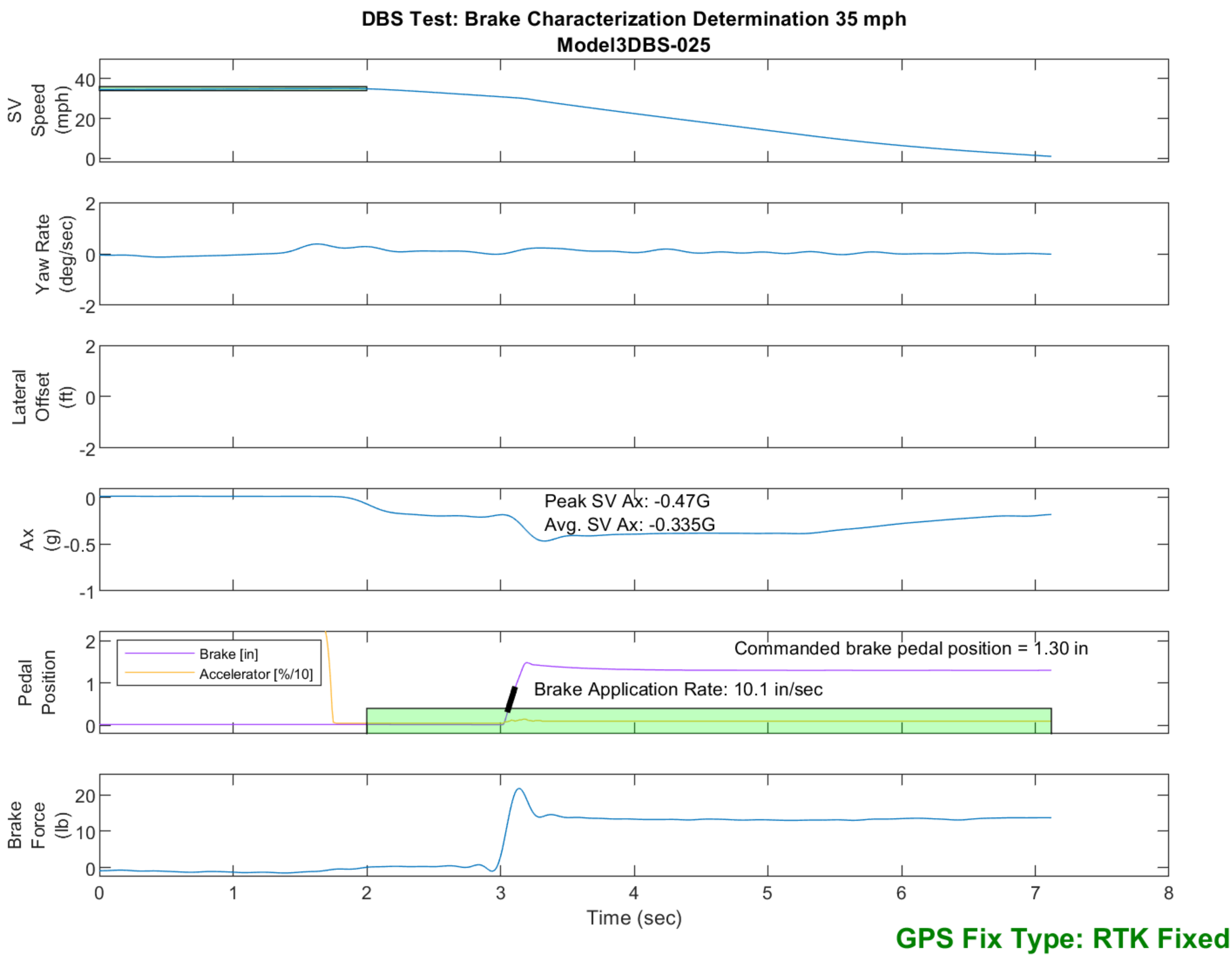


Figure E98. Time History for DBS Run 25, Brake Characterization Determination, Displacement Mode, 35 mph, Roll Mode

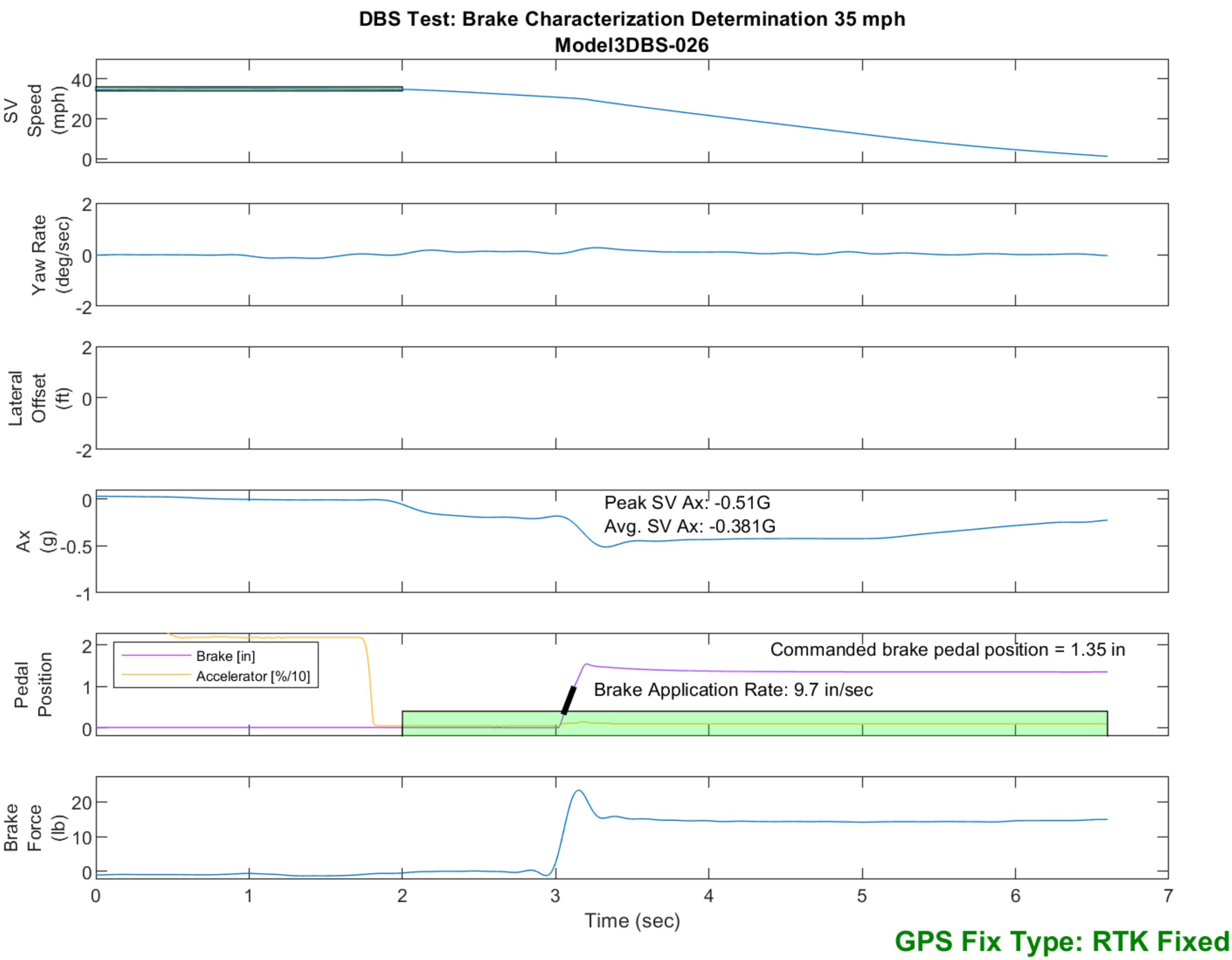


Figure E99. Time History for DBS Run 26, Brake Characterization Determination, Displacement Mode, 35 mph, Roll Mode

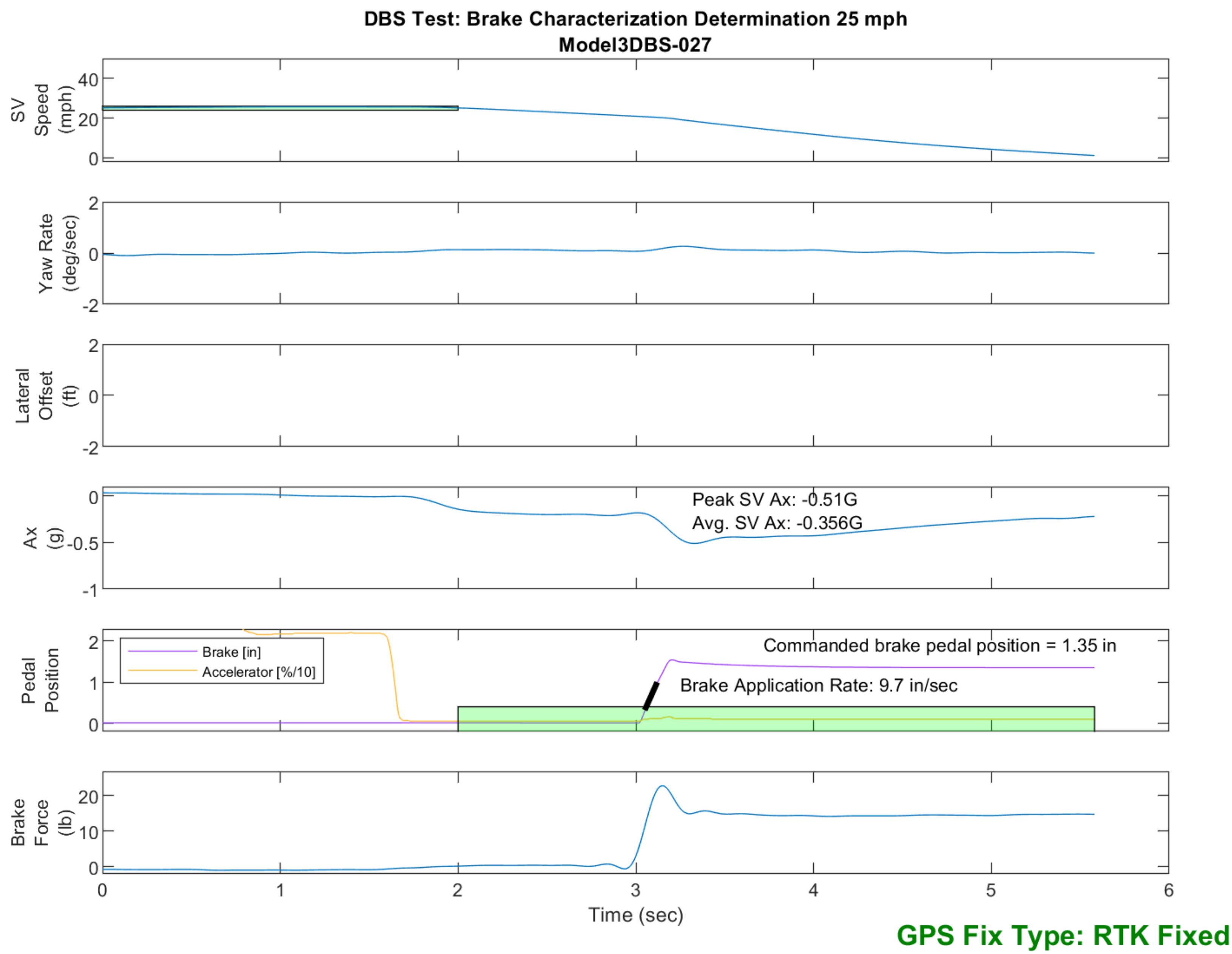


Figure E100. Time History for DBS Run 27, Brake Characterization Determination, Displacement Mode, 25 mph, Roll Mode

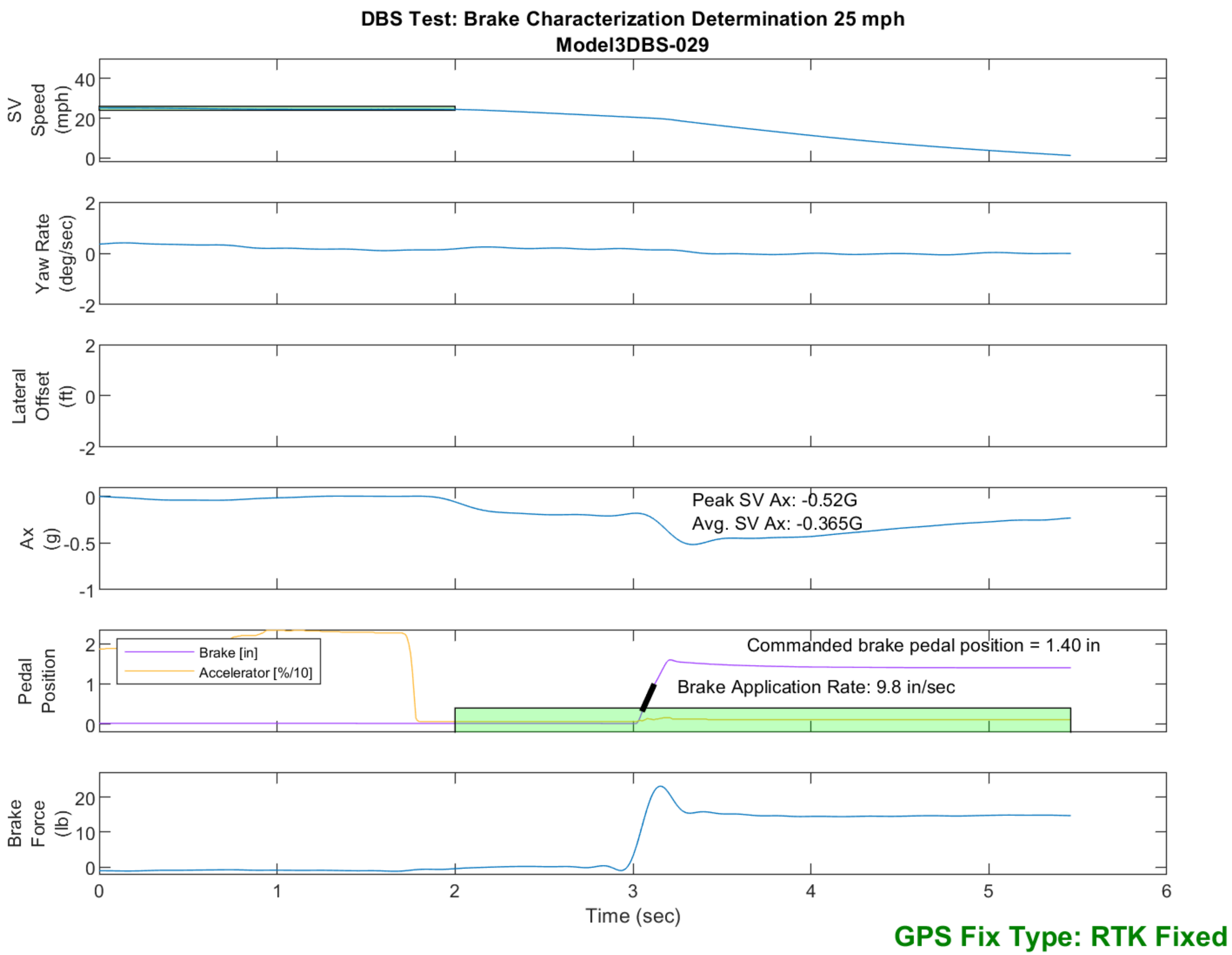


Figure E101. Time History for DBS Run 29, Brake Characterization Determination, Displacement Mode, 25 mph, Roll Mode

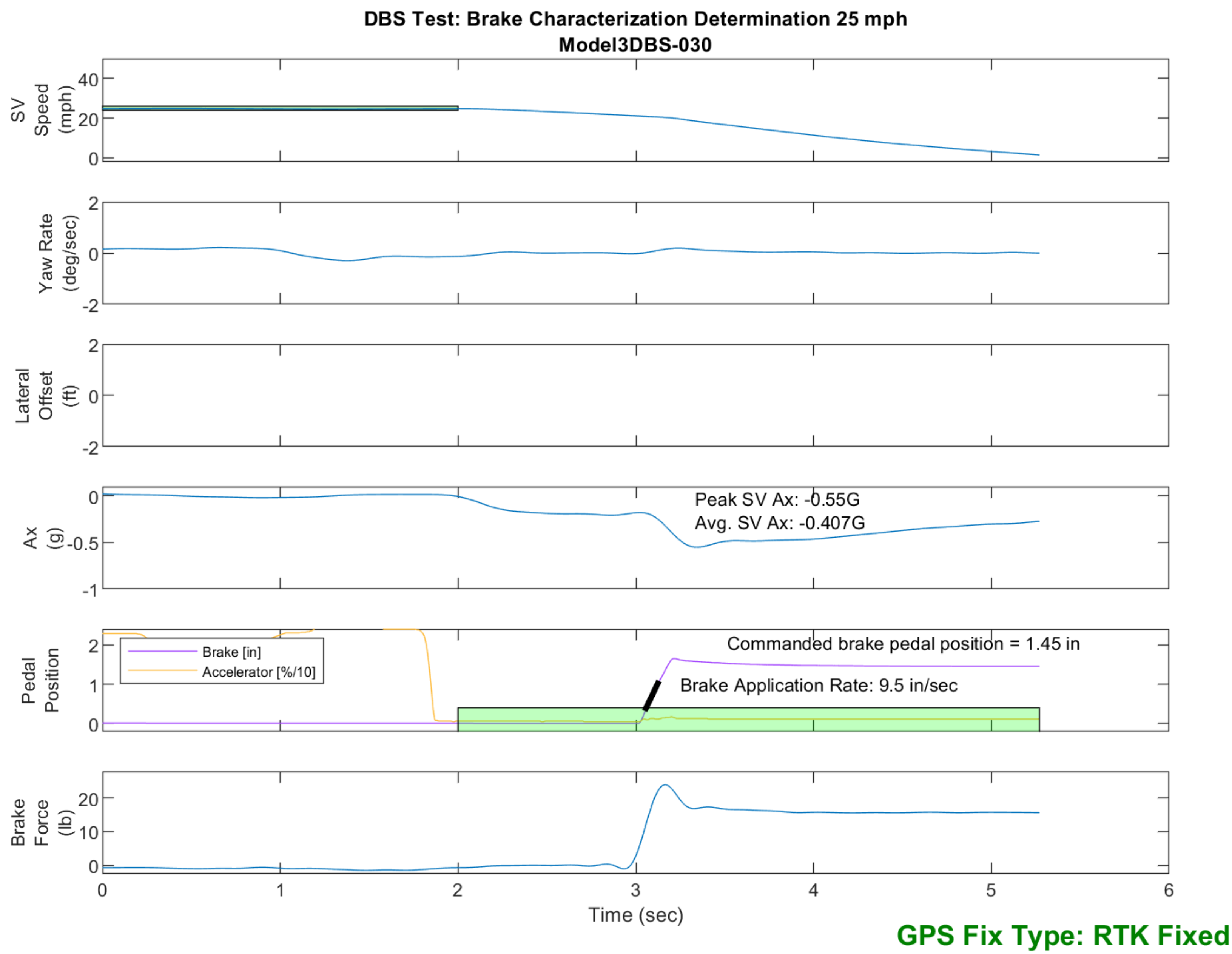


Figure E102. Time History for DBS Run 30, Brake Characterization Determination, Displacement Mode, 25 mph, Roll Mode

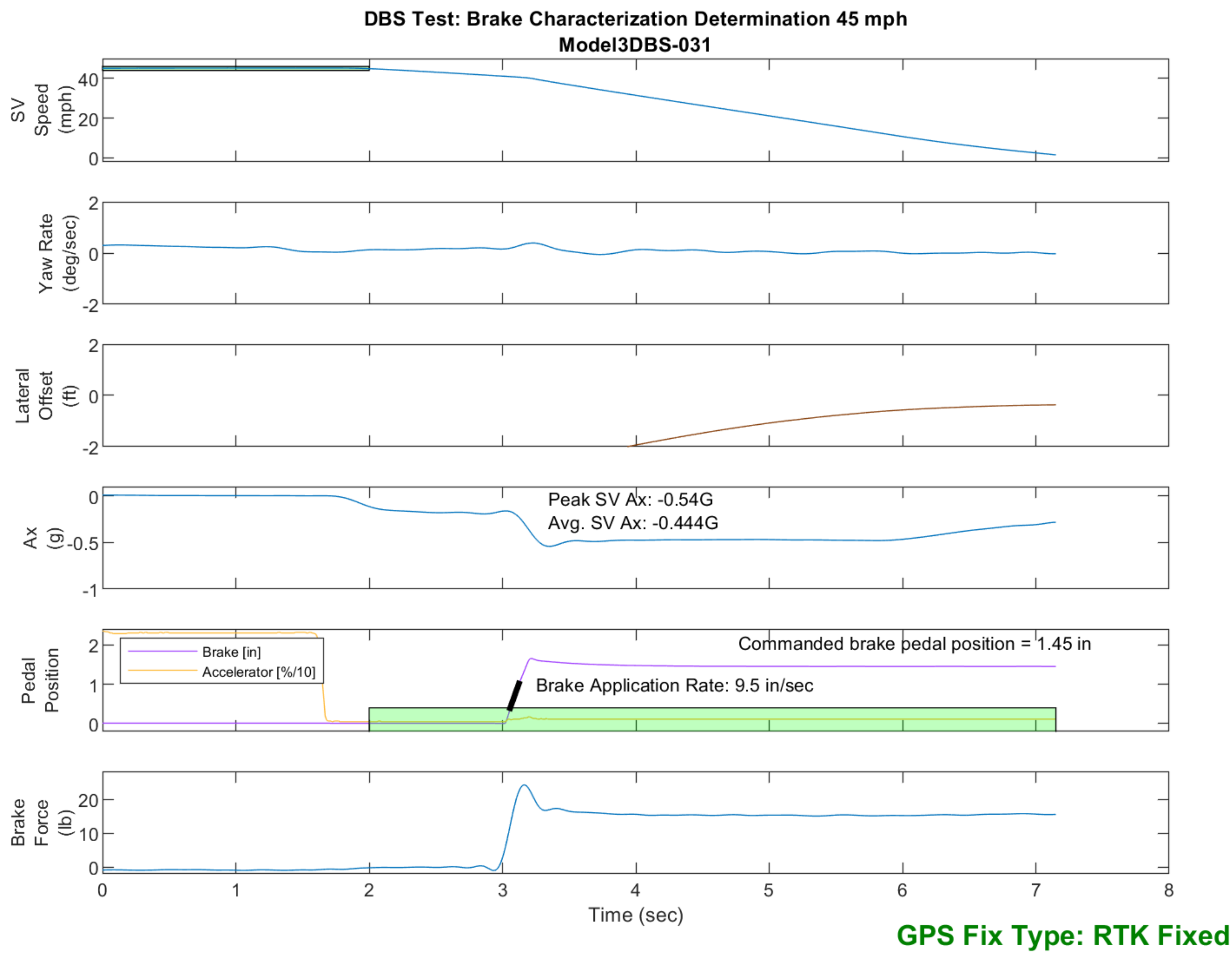


Figure E103. Time History for DBS Run 31, Brake Characterization Determination, Displacement Mode, 45 mph, Roll Mode

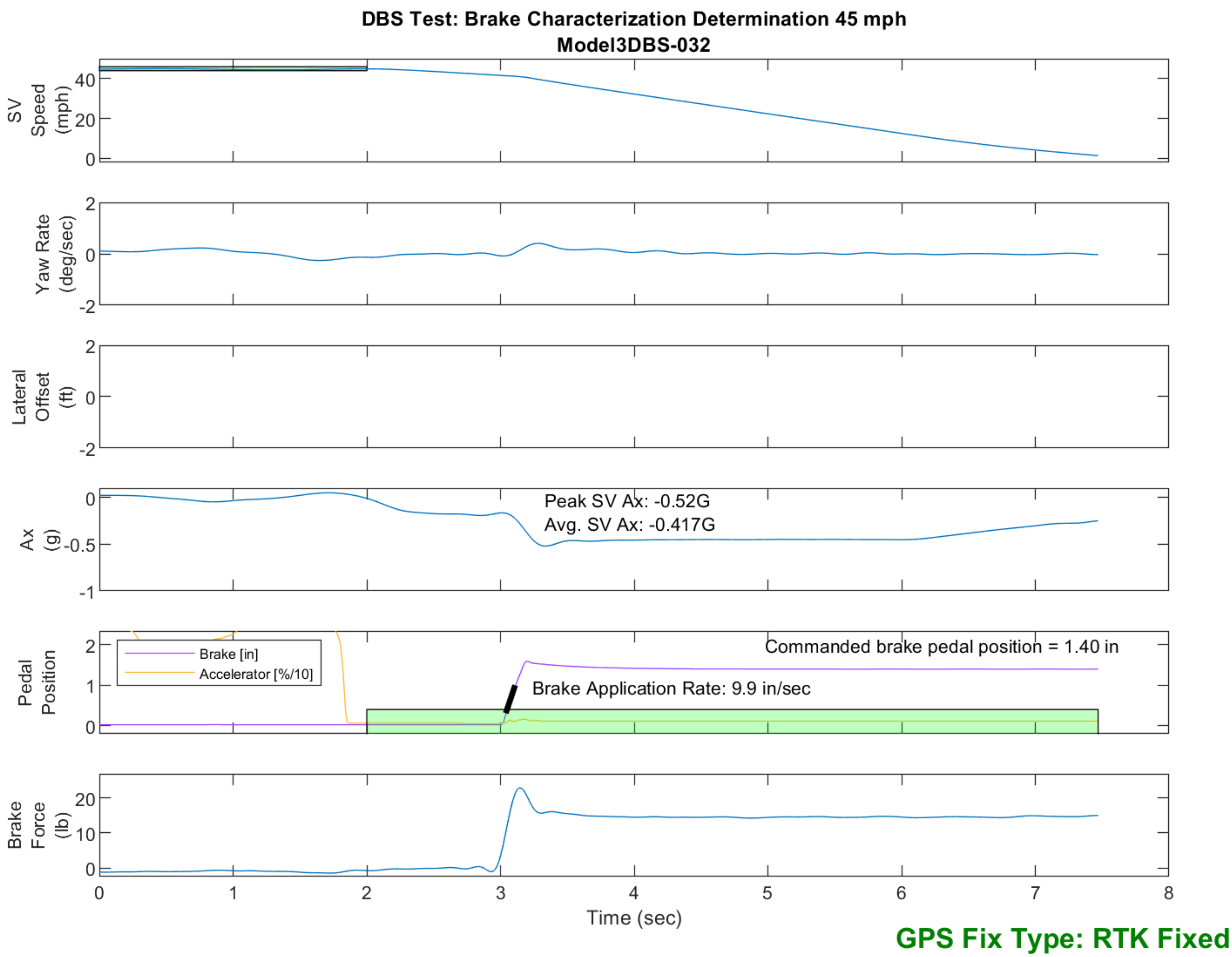


Figure E104. Time History for DBS Run 32, Brake Characterization Determination, Displacement Mode, 45 mph, Roll Mode

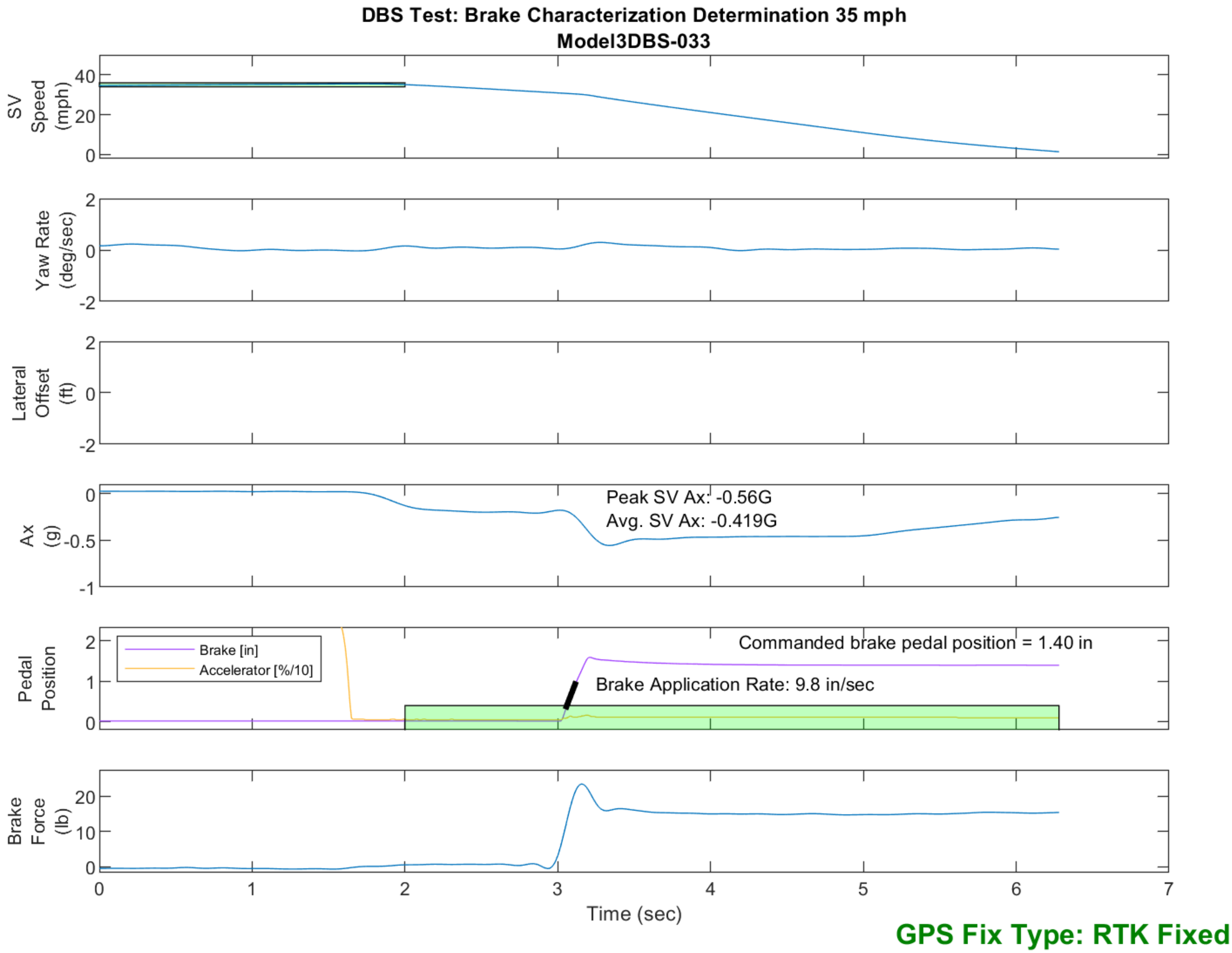


Figure E105. Time History for DBS Run 33, Brake Characterization Determination, Displacement Mode, 35 mph, Roll Mode

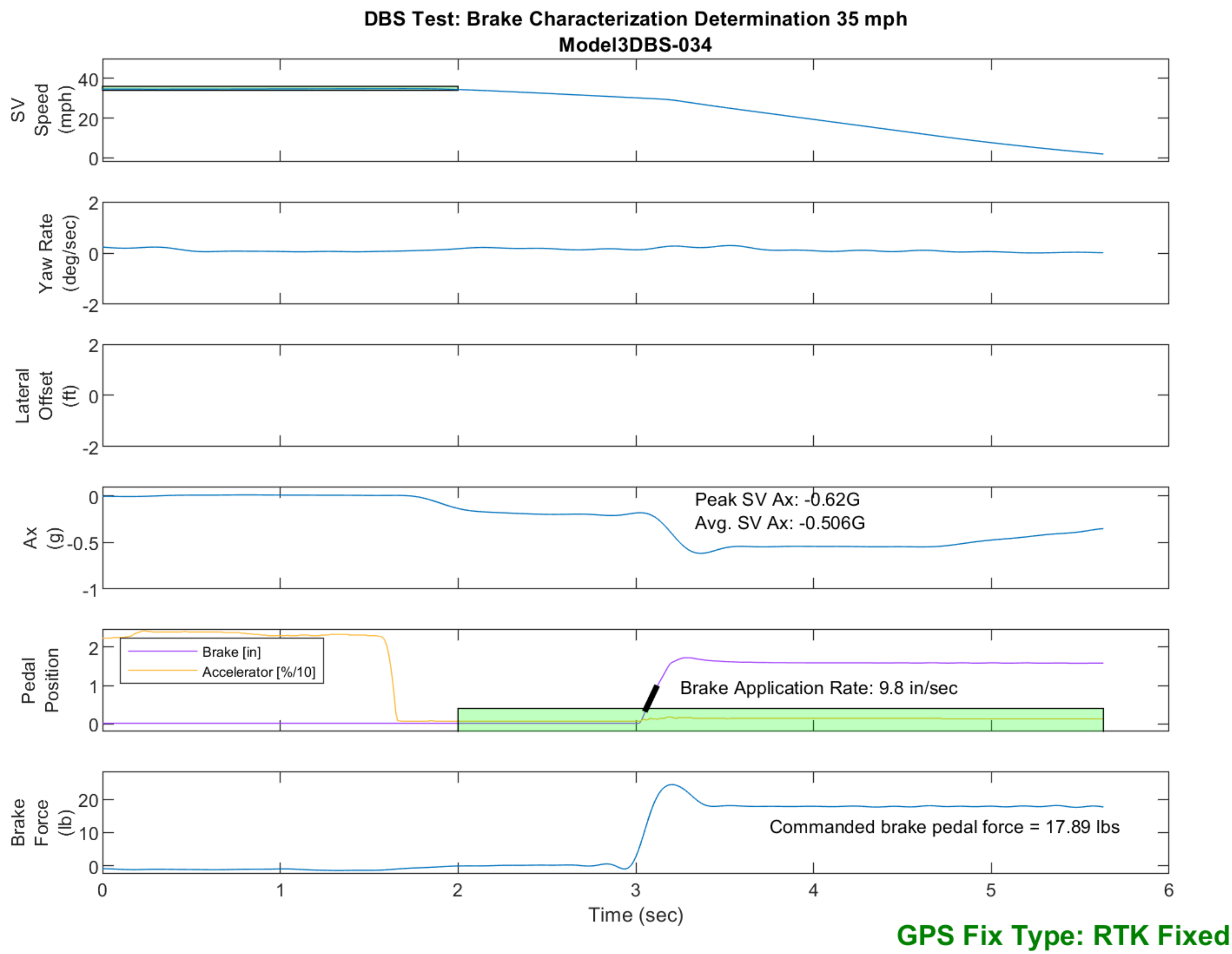


Figure E106. Time History for DBS Run 34, Brake Characterization Determination, Hybrid Mode, 35 mph, Roll Mode

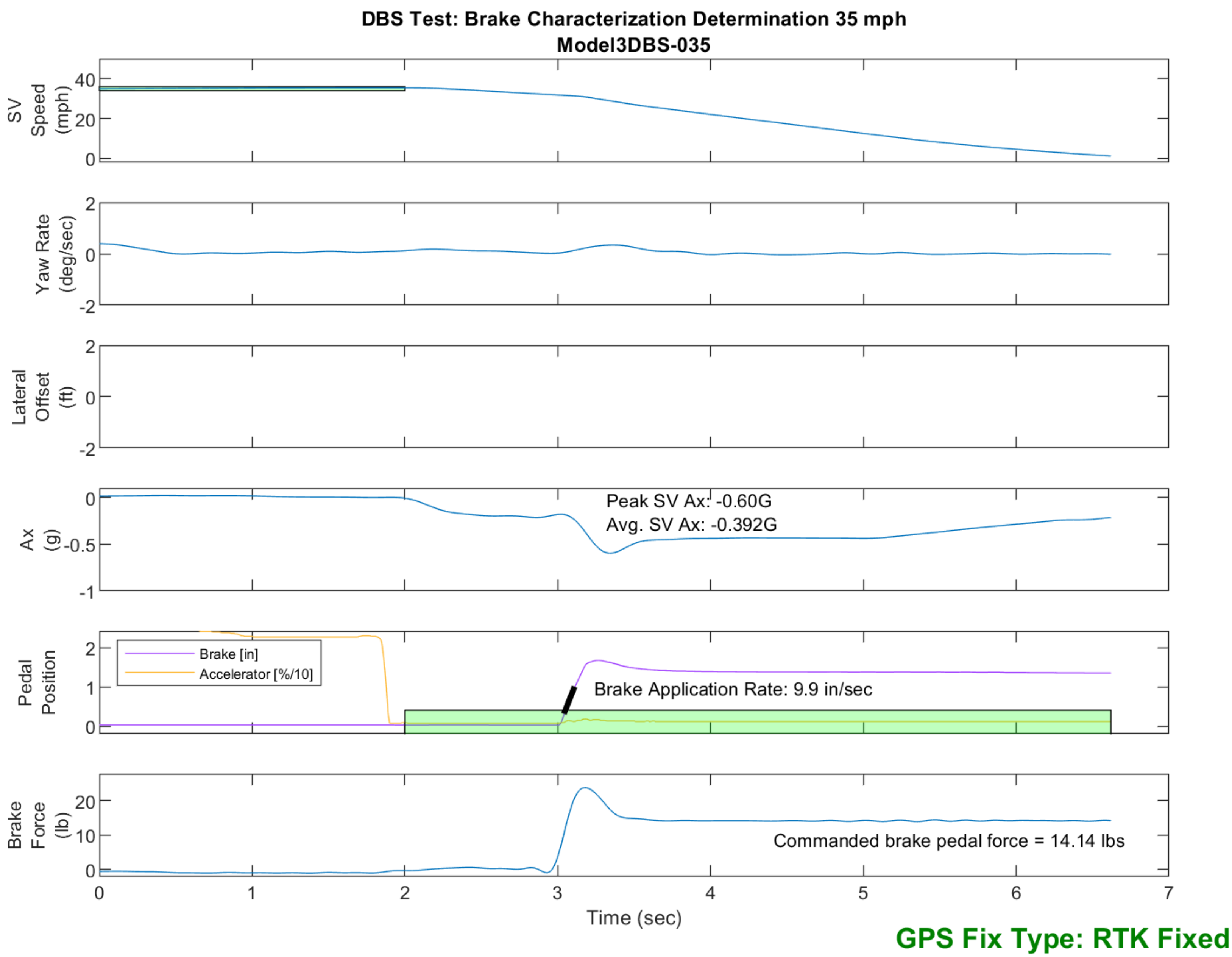


Figure E107. Time History for DBS Run 35, Brake Characterization Determination, Hybrid Mode, 35 mph, Roll Mode

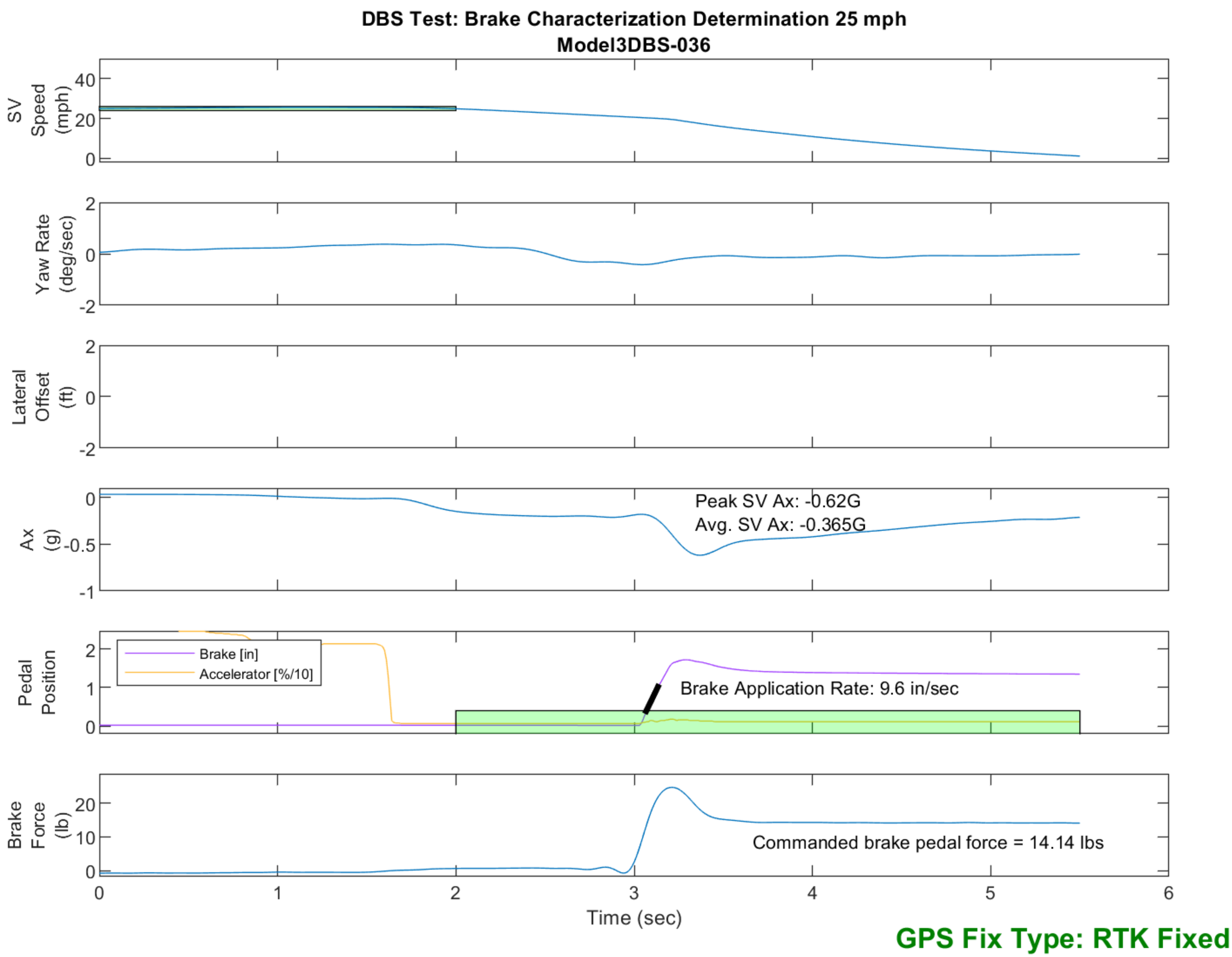


Figure E108. Time History for DBS Run 36, Brake Characterization Determination, Hybrid Mode, 25 mph, Roll Mode

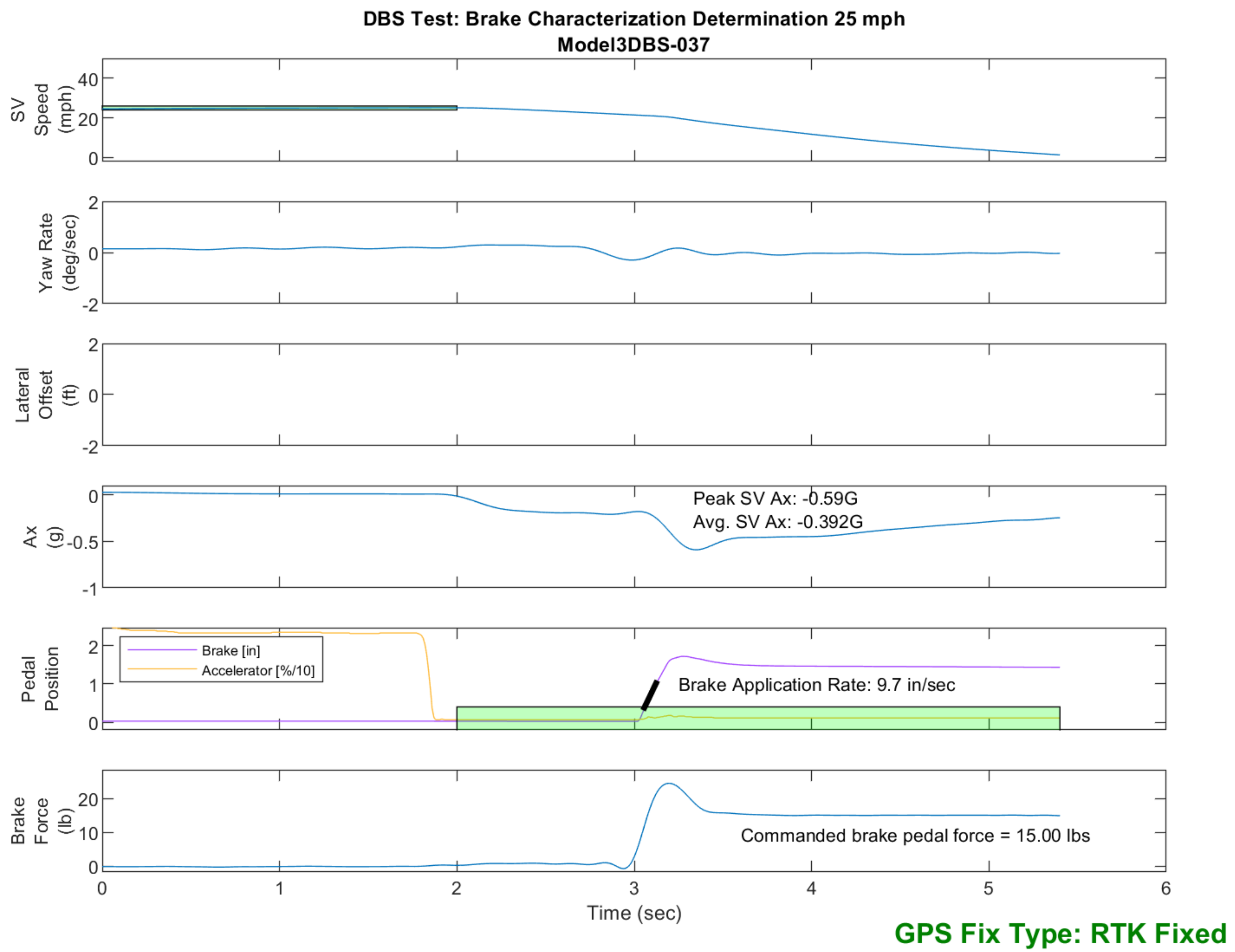


Figure E109. Time History for DBS Run 37, Brake Characterization Determination, Hybrid Mode, 25 mph, Roll Mode

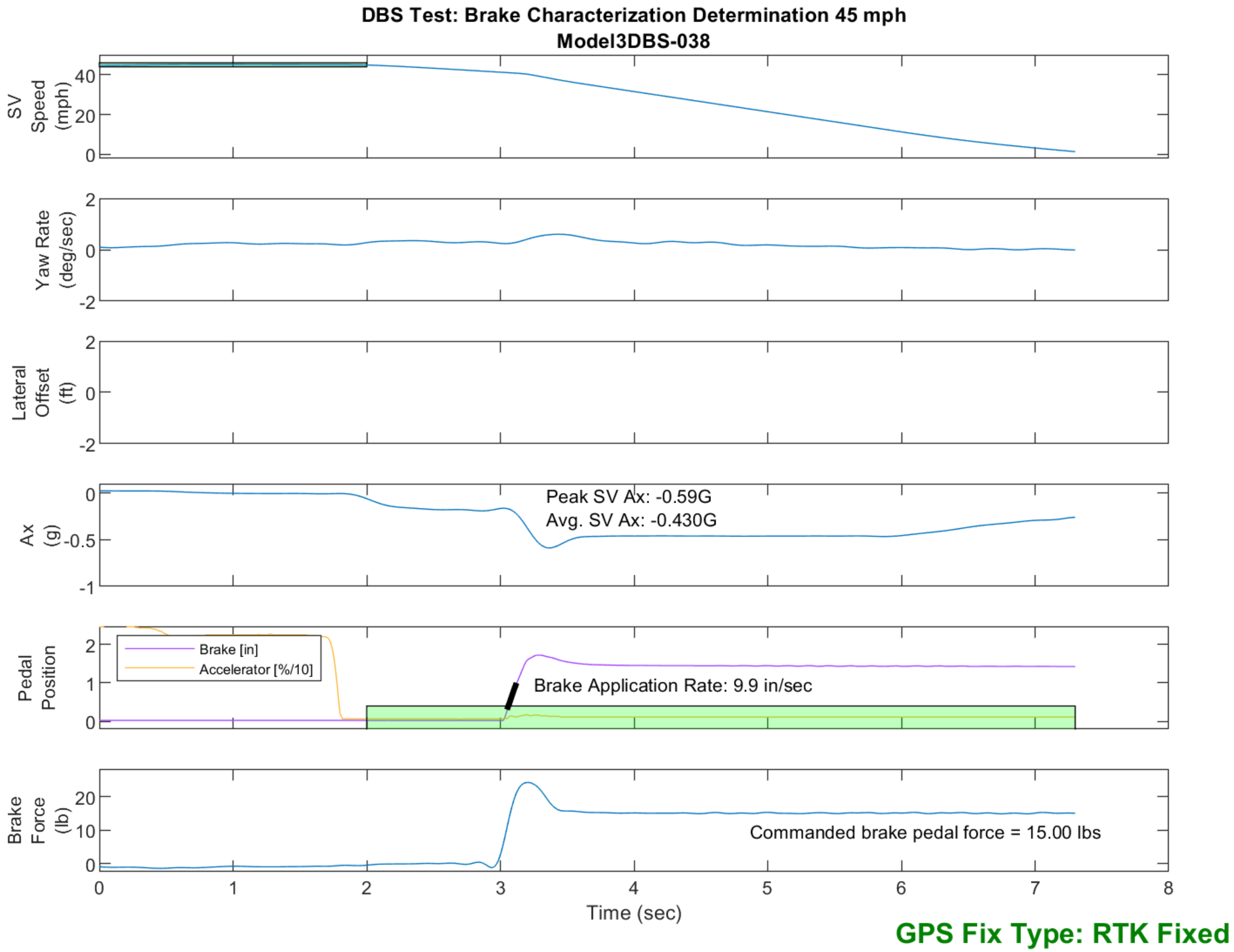


Figure E110. Time History for DBS Run 38, Brake Characterization Determination, Hybrid Mode, 45 mph, Roll Mode

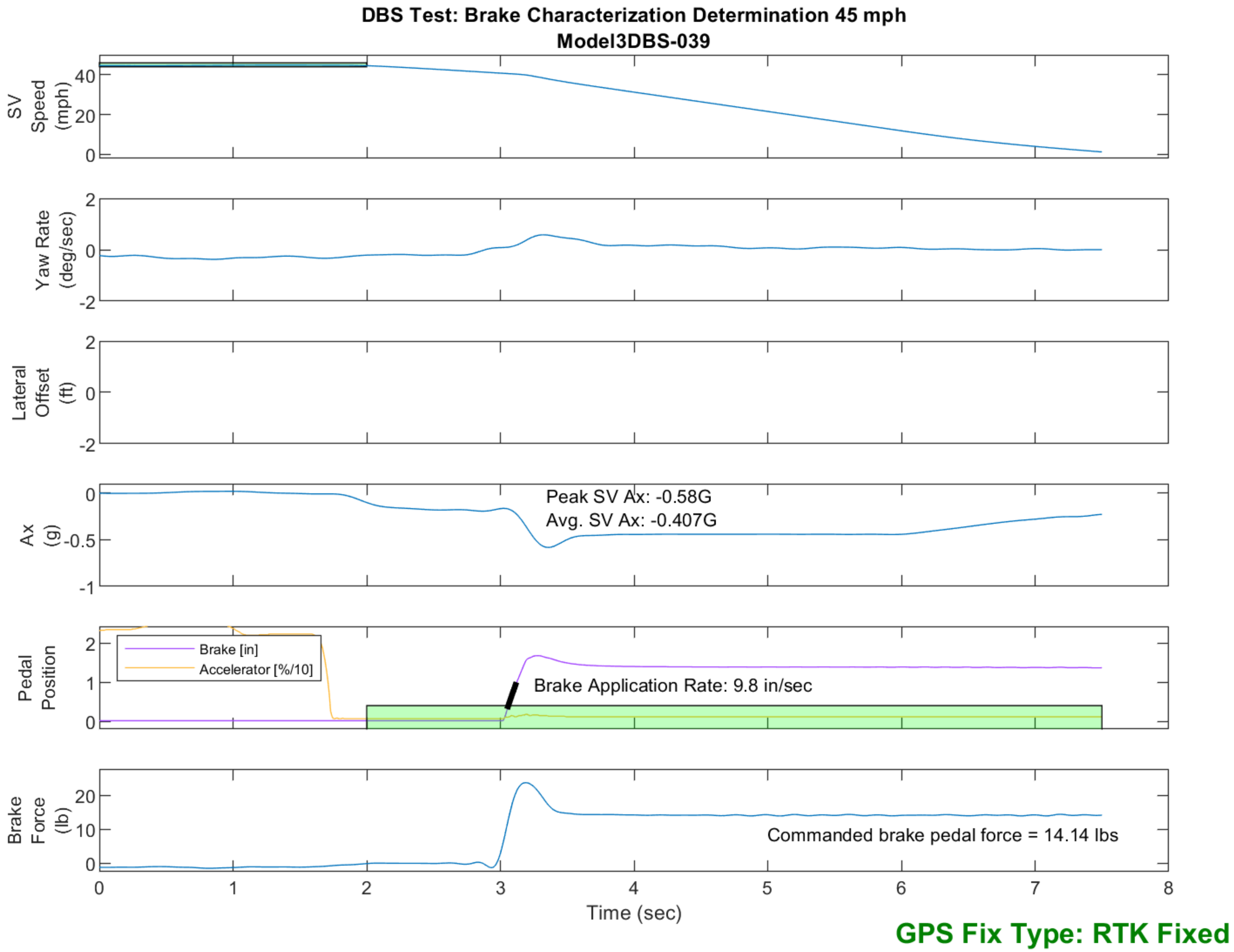


Figure E111. Time History for DBS Run 39, Brake Characterization Determination, Hybrid Mode, 45 mph, Roll Mode

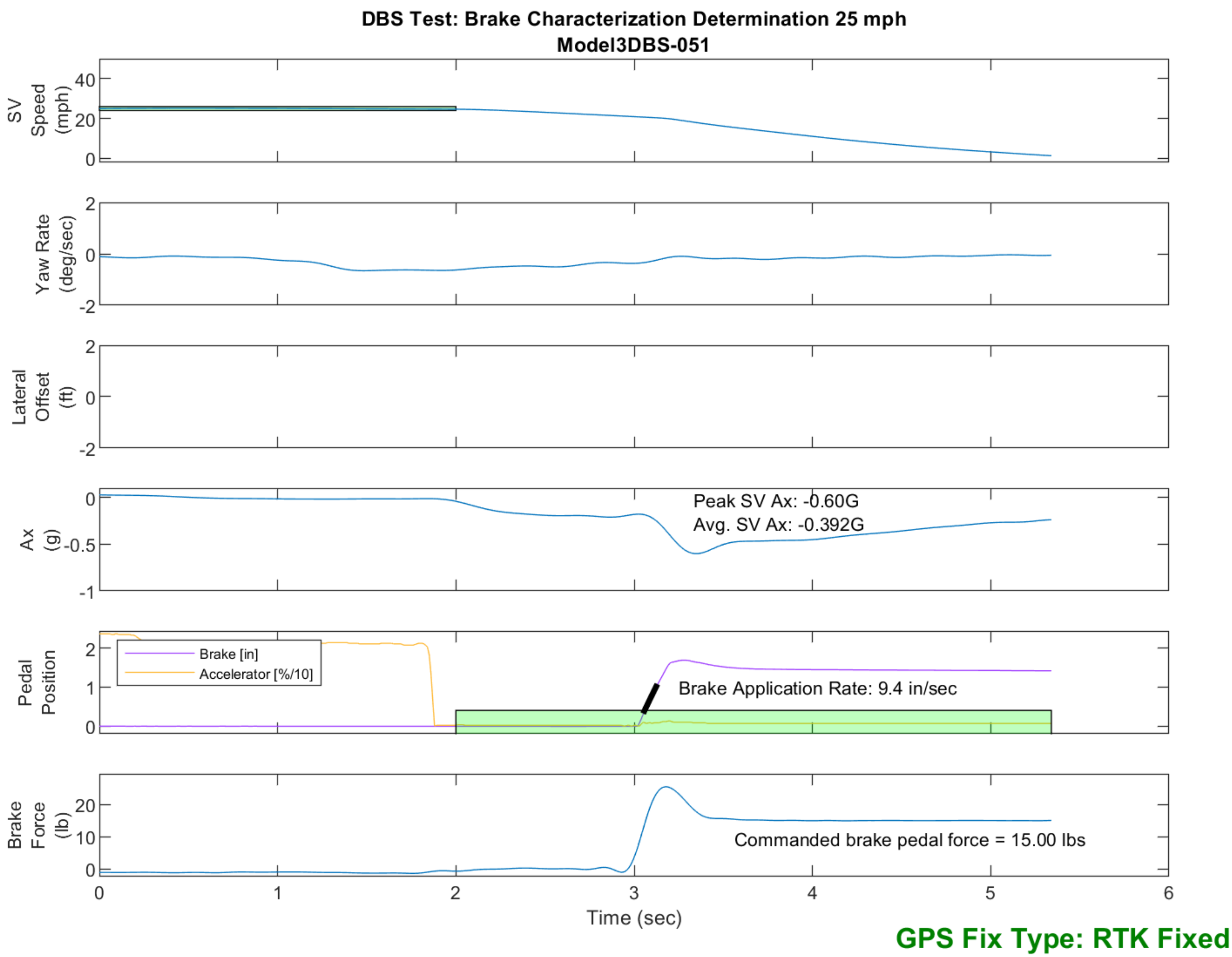


Figure E112. Time History for DBS Run 51, Brake Characterization Determination, Hybrid Mode, 25 mph, Roll Mode

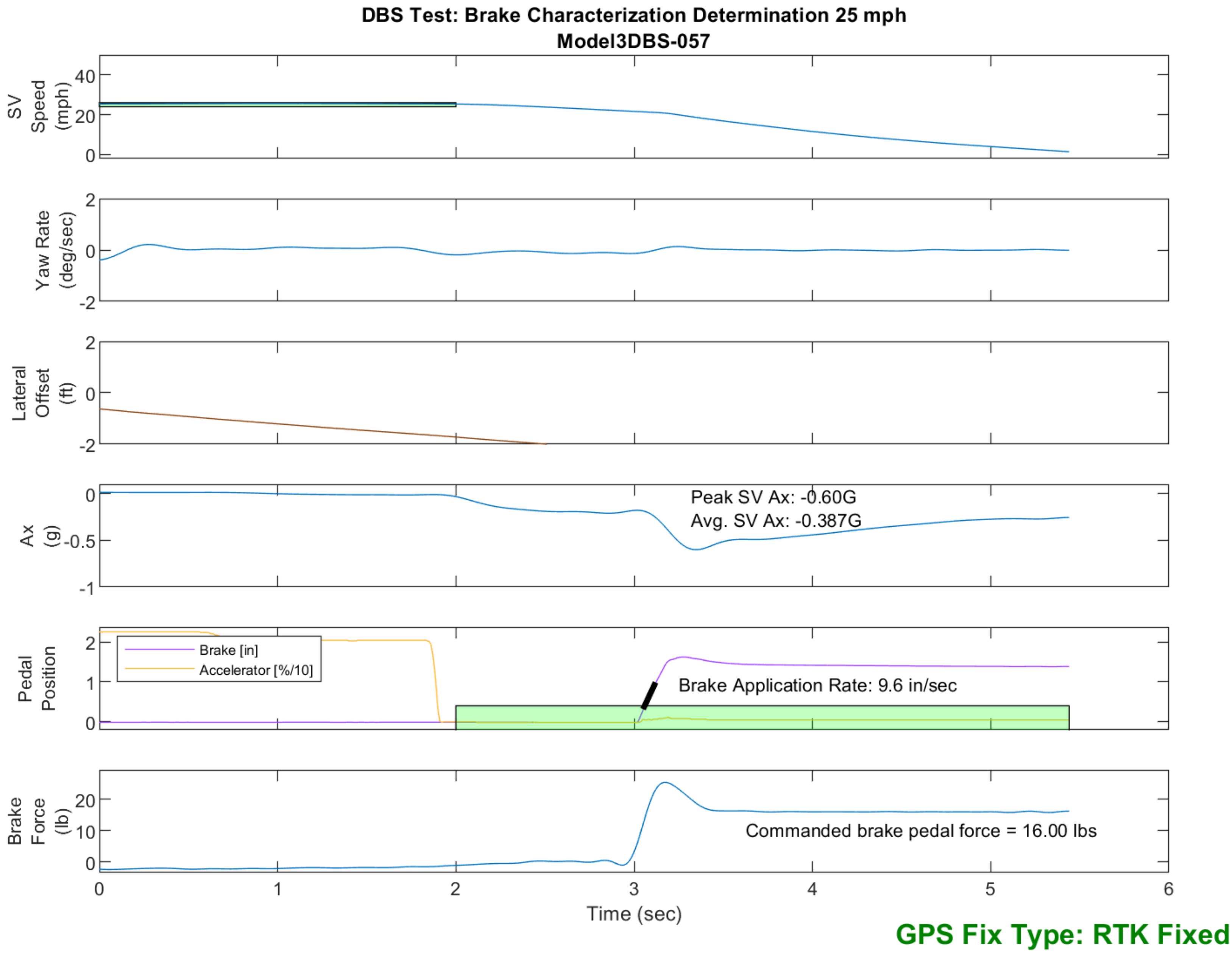


Figure E113. Time History for DBS Run 57, Brake Characterization Determination, Hybrid Mode, 25 mph, Creep Mode

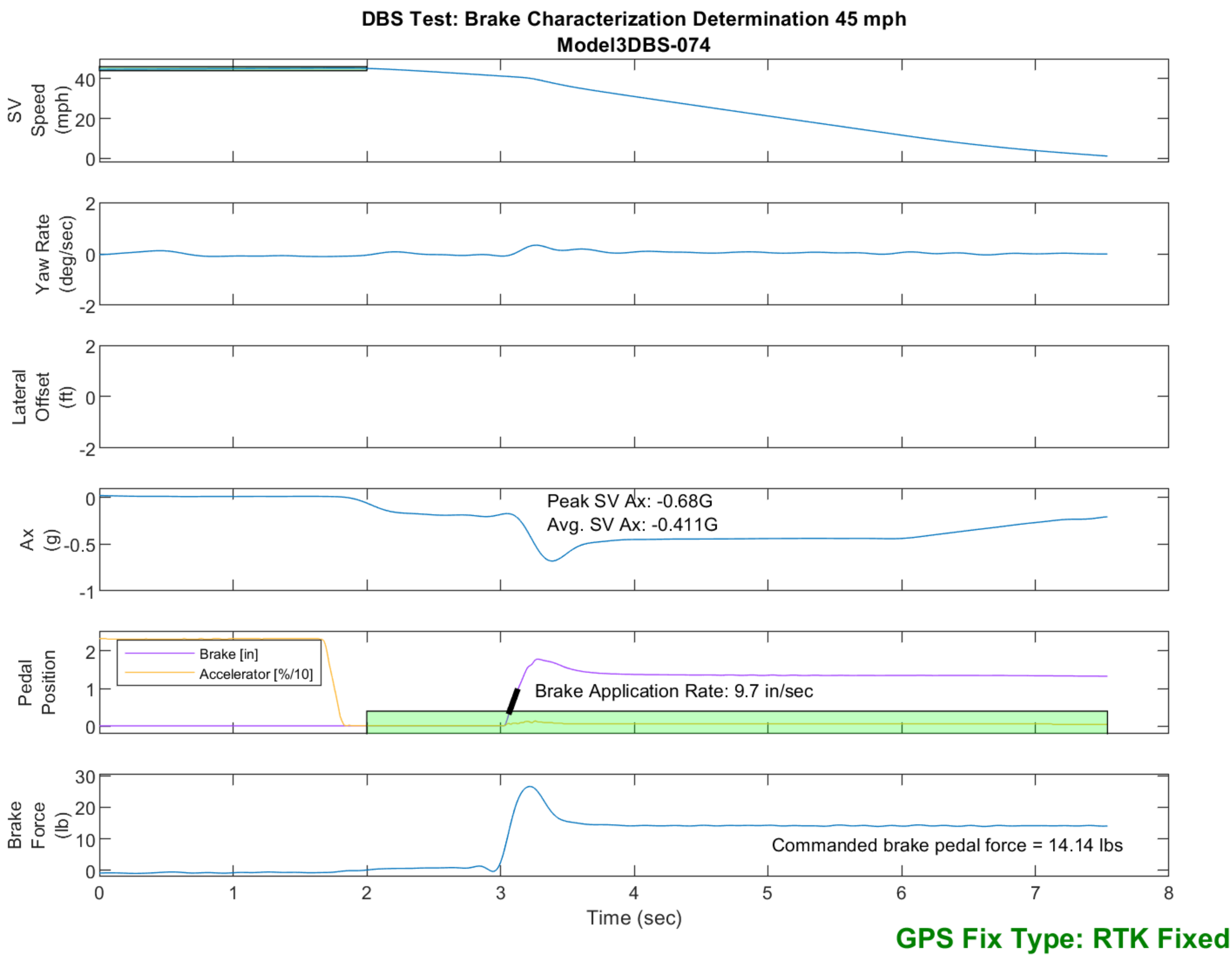


Figure E114. Time History for DBS Run 74, Brake Characterization Determination, Hybrid Mode, 45 mph, Roll Mode

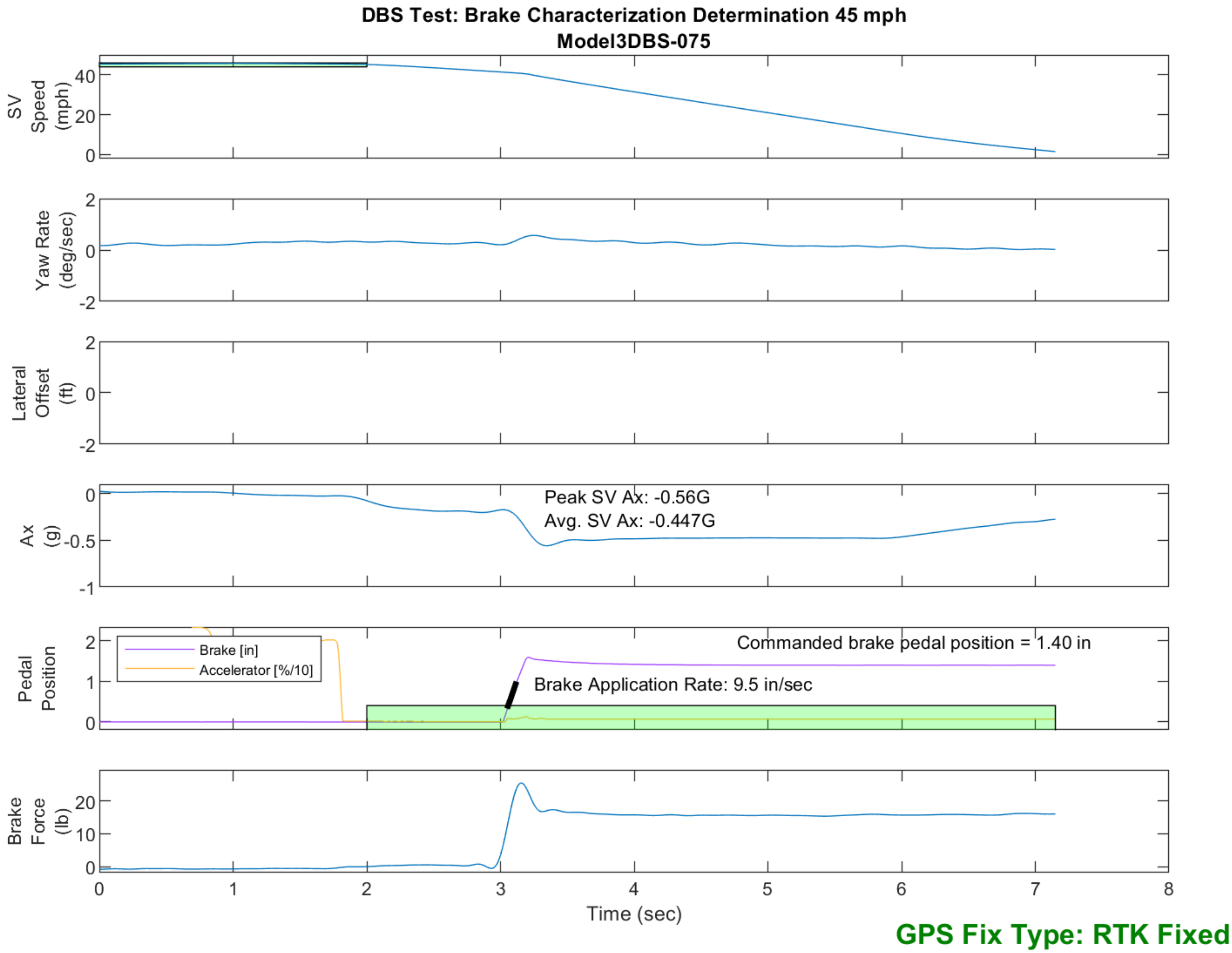


Figure E115. Time History for DBS Run 75, Brake Characterization Determination, Displacement Mode, 45 mph, Roll Mode

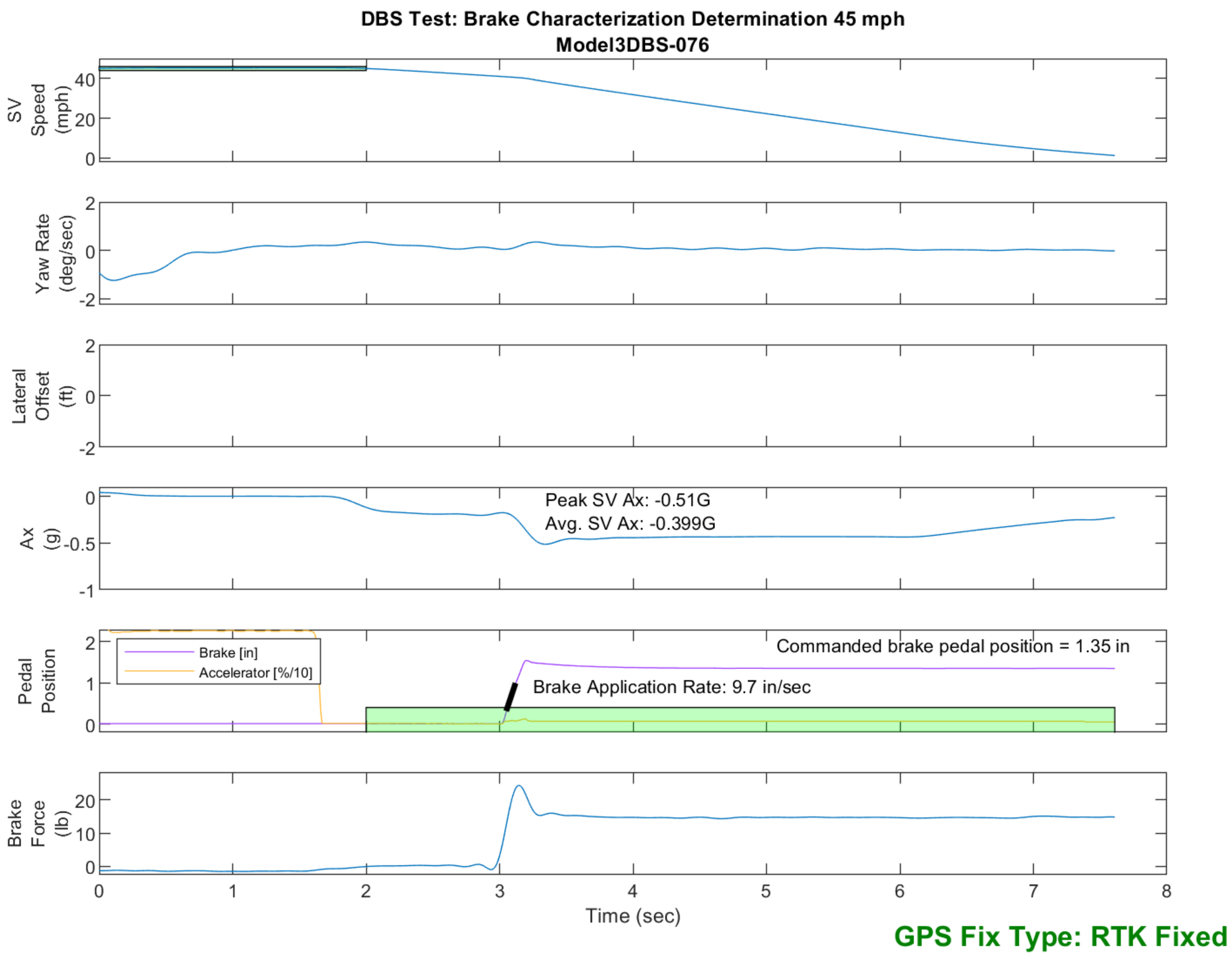


Figure E116. Time History for DBS Run 76, Brake Characterization Determination, Displacement Mode, 45 mph, Roll Mode

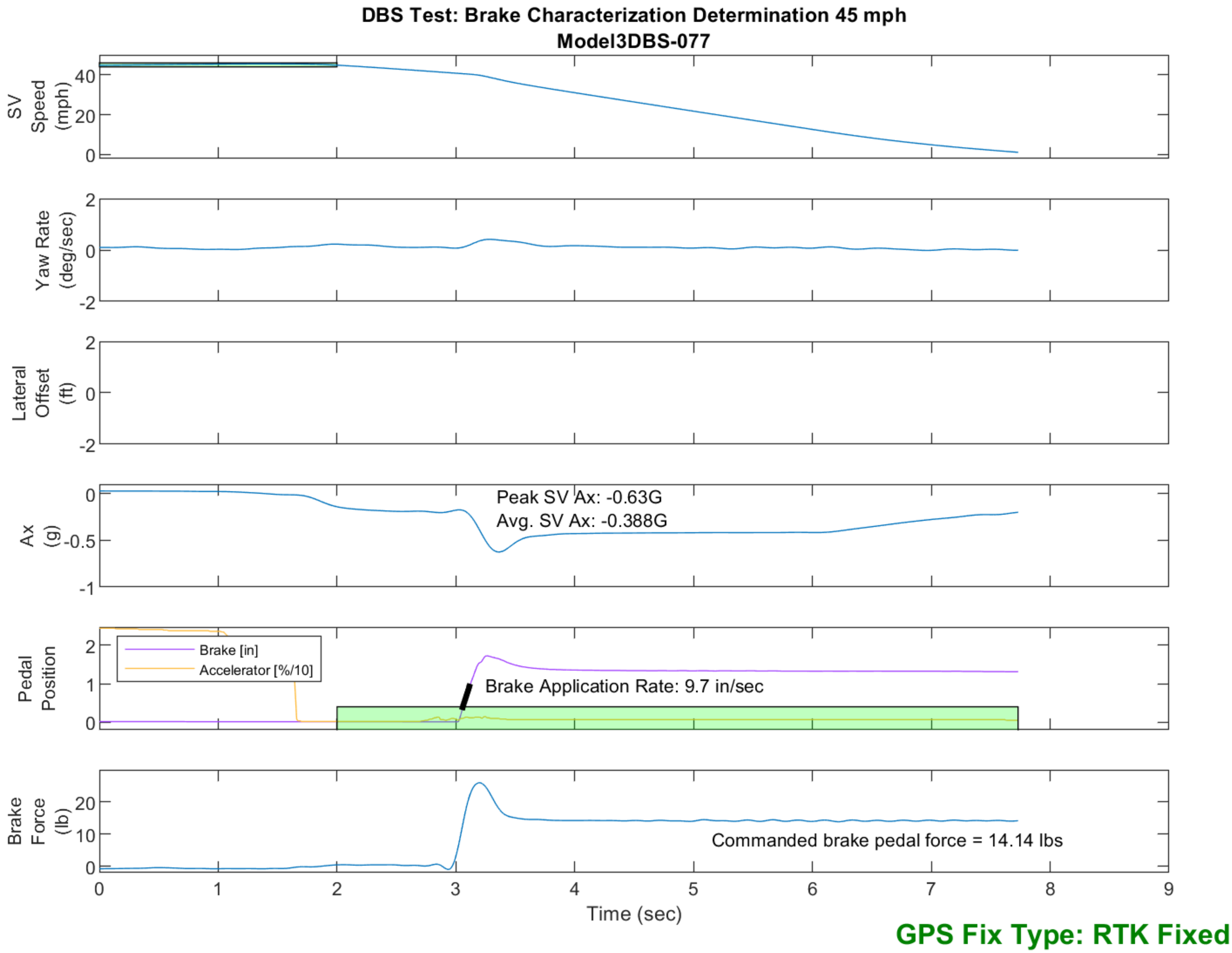


Figure E117. Time History for DBS Run 77, Brake Characterization Determination, Hybrid Mode, 45 mph, Roll Mode

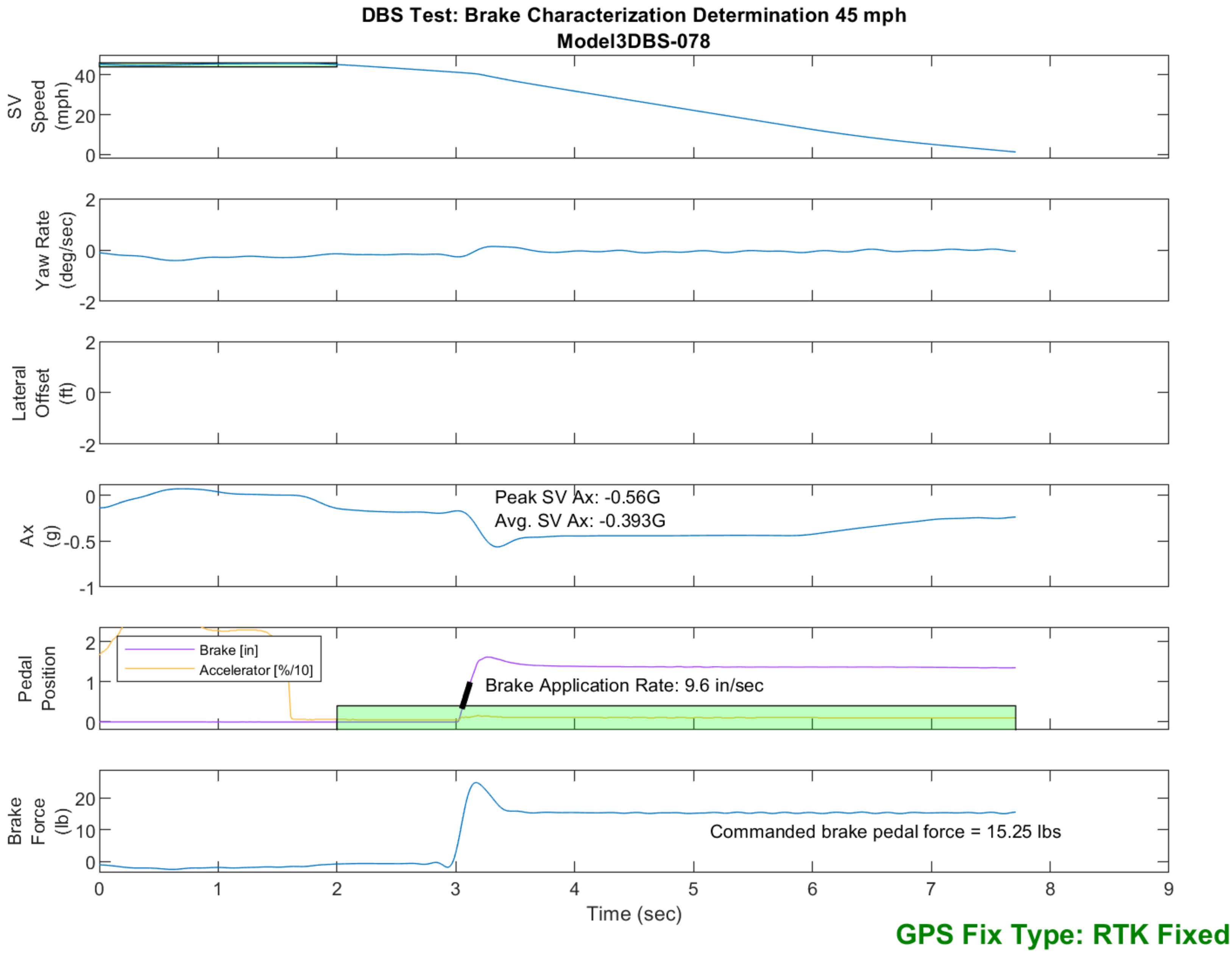


Figure E118. Time History for DBS Run 78, Brake Characterization Determination, Hybrid Mode, 45 mph, Creep Mode

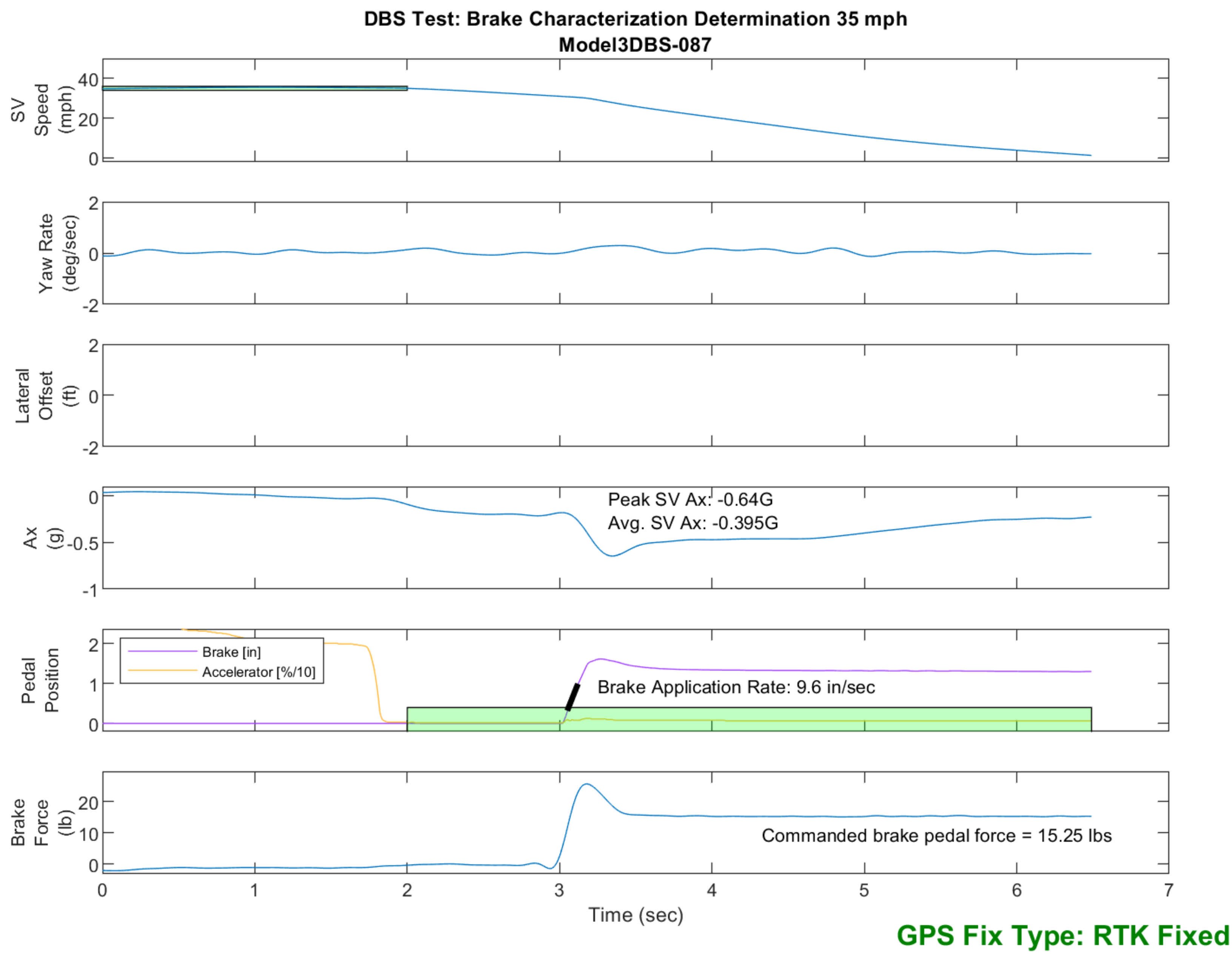


Figure E119. Time History for DBS Run 87, Brake Characterization Determination, Hybrid Mode, 35 mph, Creep Mode

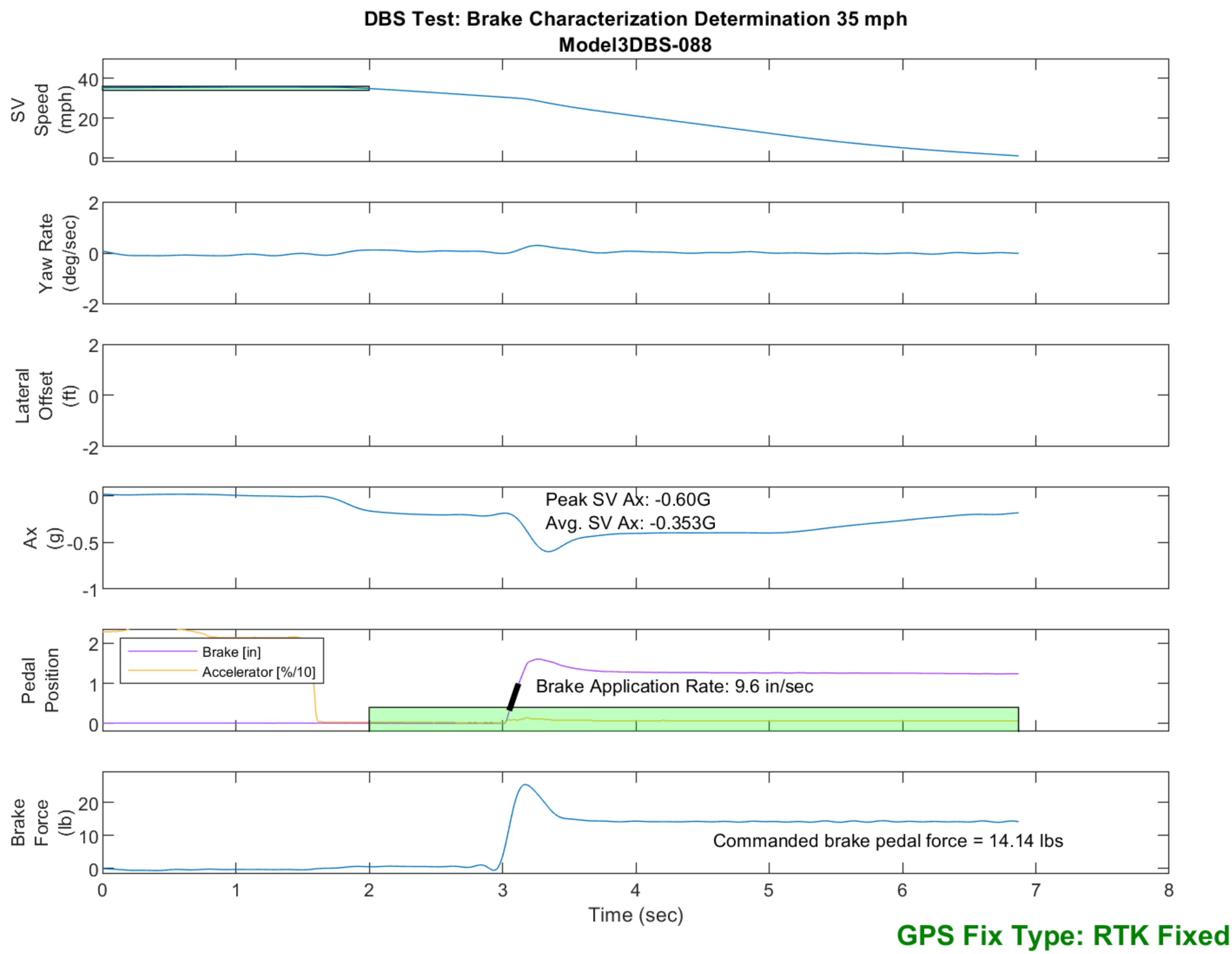


Figure E120. Time History for DBS Run 88, Brake Characterization Determination, Hybrid Mode, 35 mph, Roll Mode

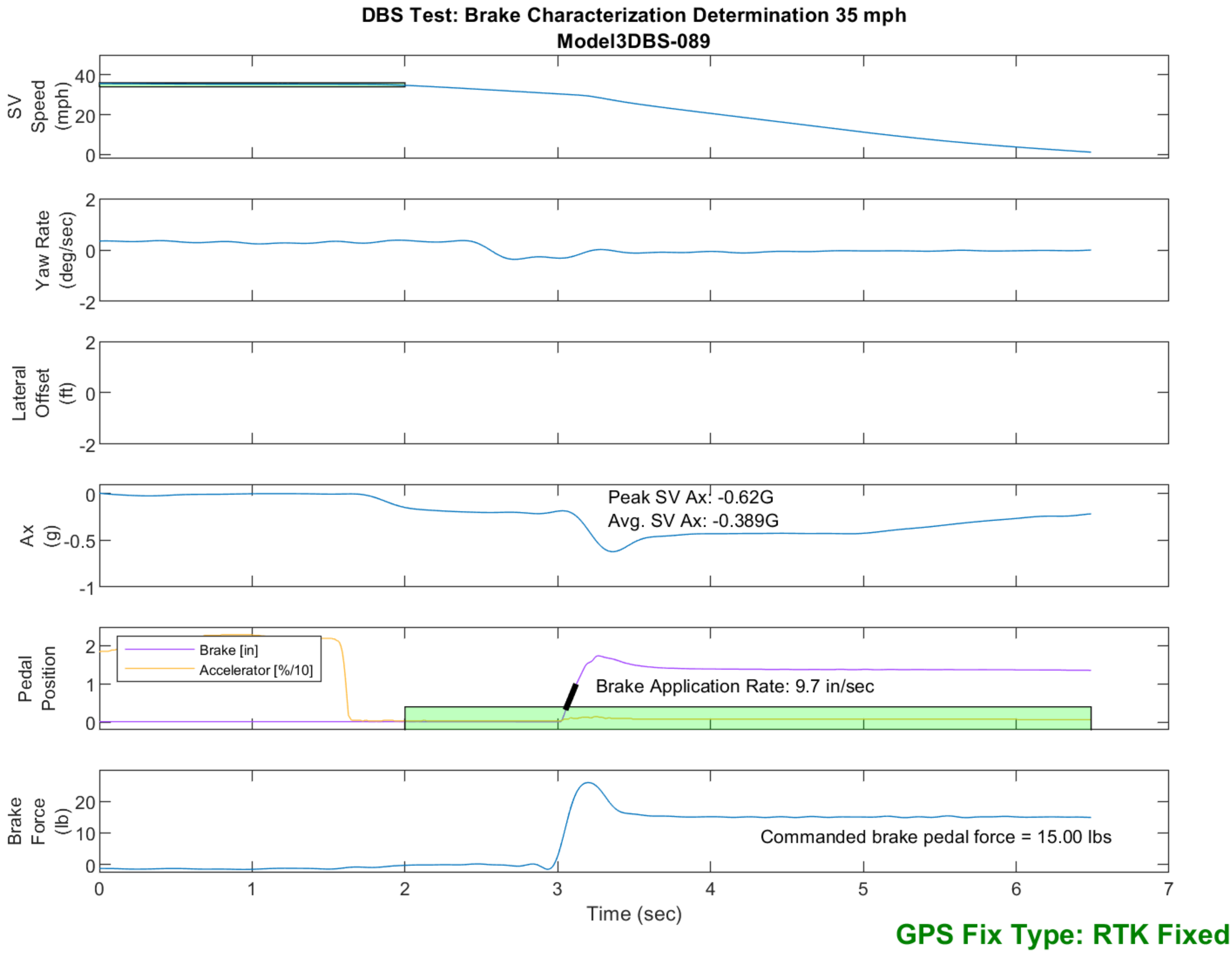


Figure E121. Time History for DBS Run 89, Brake Characterization Determination, Hybrid Mode, 35 mph, Roll Mode