

**NEW CAR ASSESSMENT PROGRAM  
DYNAMIC BRAKE SUPPORT SYSTEM CONFIRMATION TEST  
NCAP-DRI-DBS-21-16**

**2021 Toyota Highlander LE - V6 FWD**

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**7 January 2020**

**Final Report**

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

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16. Abstract These tests were conducted on the subject 2021 Toyota Highlander LE - V6 FWD in accordance with the specifications of the New Car Assessment Program's (NCAP) most current Test Procedure in docket NHTSA-2015-0006-0026; DYNAMIC BRAKE SUPPORT PERFORMANCE EVALUATION CONFIRMATION TEST FOR THE NEW CAR ASSESSMENT PROGRAM, October 2015. The vehicle passed the requirements of the test for all four DBS test scenarios.			
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## 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 when the system determines that the braking applied by the driver is insufficient to avoid a collision.

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

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

The purpose of the testing reported herein was to objectively quantify the performance of a Dynamic Brake Support system installed on a 2021 Toyota Highlander LE - V6 FWD. 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**

(Page 1 of 1)

**2021 Toyota Highlander LE - V6 FWD**

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VIN: 5TDZZRAH1MS51xxxx

Test Date: 12/22/2020

Dynamic Brake Support System setting: Alert range setting "early"

**Test 1 - Subject Vehicle Encounters  
Stopped Principal Other Vehicle**

SV 25 mph: Pass

**Test 2 - Subject Vehicle Encounters  
Slower Principal Other Vehicle**

SV 25 mph POV 10 mph: Pass

SV 45 mph POV 20 mph: Pass

**Test 3 - Subject Vehicle Encounters  
Decelerating Principal Other Vehicle**

SV 35 mph POV 35 mph: Pass

**Test 4 - Subject Vehicle Encounters  
Steel Trench Plate**

SV 25 mph: Pass

SV 45 mph: Pass

**Overall: Pass**

Notes:

**DYNAMIC BRAKE SUPPORT**  
**DATA SHEET 2: VEHICLE DATA**

(Page 1 of 1)

**2021 Toyota Highlander LE - V6 FWD**

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**TEST VEHICLE INFORMATION**

VIN: 5TDZZRAH1MS51xxxx

Body Style: SUV

Color: Silver Metallic/Graphite

Date Received: 12/14/2020

Odometer Reading: 160 mi

**DATA FROM VEHICLE'S CERTIFICATON LABEL**

Vehicle manufactured by: TOYOTA MOTOR MANUFACTURING,  
INDIANA, INC.

Date of manufacture: 11/20

Vehicle Type: MPV

**DATA FROM TIRE PLACARD**

Tires size as stated on Tire Placard: Front: 235/65R18

Rear: 235/65R18

Recommended cold tire pressure: Front: 250 kPa (36 psi)

Rear: 250 kPa (36 psi)

**TIRES**

Tire manufacturer and model: MICHELIN PREMIER LTX

Front tire specification: 235/65R18 106V

Rear tire specification: 235/65R18 106V

Front tire DOT prefix: B9MB 020X

Rear tire DOT prefix: B9MB 020X



**DYNAMIC BRAKE SUPPORT**  
**DATA SHEET 3: TEST CONDITIONS**

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2021 Toyota Highlander LE - V6 FWD

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**GENERAL INFORMATION**

Test date: 12/22/2020

**AMBIENT CONDITIONS**

Air temperature: 8.9 C (48 F)

Wind speed: 3.1 m/s (6.9 mph)

X Wind speed  $\leq$  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: 250 kPa (36 psi)

Rear: 250 kPa (36 psi)

**DYNAMIC BRAKE SUPPORT**  
**DATA SHEET 3: TEST CONDITIONS**

(Page 2 of 2)

**2021 Toyota Highlander LE - V6 FWD**

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**WEIGHT**

Weight of vehicle as tested including driver and instrumentation

Left Front: 595.1 kg (1312 lb)

Right Front: 567.0 kg (1250 lb)

Left Rear: 458.6 kg (1011 lb)

Right Rear: 419.6 kg (925 lb)

Total: 2040.3 kg (4498 lb)



**DYNAMIC BRAKE SUPPORT**

**DATA SHEET 4: DYNAMIC BRAKE SUPPORT SYSTEM OPERATION**

(Page 2 of 3)

**2021 Toyota Highlander LE - V6 FWD**

Will the system deactivate due to repeated AEB activations, impacts or near-misses?  Yes  
 No

If yes, please provide a full description.

How is the Forward Collision Warning presented to the driver?  Warning light  
(Check all that apply)  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 visual alert displays the warning message "BRAKE!" on the multi-information display located in the instrument panel.

The auditory alert is a 2400 Hz tone pulsed at approximately five times per second.

**DYNAMIC BRAKE SUPPORT**  
**DATA SHEET 4: DYNAMIC BRAKE SUPPORT SYSTEM OPERATION**

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**2021 Toyota Highlander LE - V6 FWD**

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Is there a way to deactivate the system?  Yes  
 No

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

Buttons on the left side of the steering wheel can be used to interact with system menus displayed in the multi-information display to enable or disable the system. The system is automatically enabled each time the engine switch is turned to on. See Appendix A, Figures A14 and A15.

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

If yes, please provide a full description.

Buttons on the left side of the steering wheel can be used to interact with system menus displayed in the multi-information display to change the pre-collision warning timing. The warning timing setting is retained when the ignition is cycled. See Appendix A, Figures A14 and A15.

Are there other driving modes or conditions that render DBS inoperable or reduce its effectiveness?  Yes  
 No

If yes, please provide a full description.

System limitations are described on pages 242 through 246 of the Owner's manual, shown in Appendix B, pages B-15 through B-19.

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.

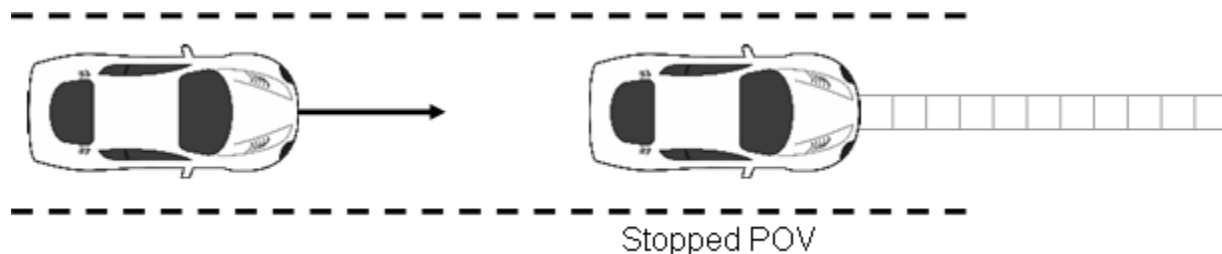


Figure 1. Depiction of Test 1

##### 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. The SV brakes were applied at  $TTC = 1.1$  seconds (SV-to-POV distance of 40 ft (12 m)). The test concluded when either:

- The SV came into contact with the POV or

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

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

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

**Table 1. Nominal Stopped POV DBS Test Choreography**

Test Speeds		SV Speed Held Constant		SV Throttle Fully Released By		SV Brake Application Onset (for each application magnitude)	
SV	POV	TTC (seconds)	SV-to-POV Headway	TTC (seconds)	SV-to-POV Headway	TTC (seconds)	SV-to-POV Headway
25 mph (40.2 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. TEST 2 – SUBJECT VEHICLE ENCOUNTERS SLOWER PRINCIPAL OTHER VEHICLE**

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

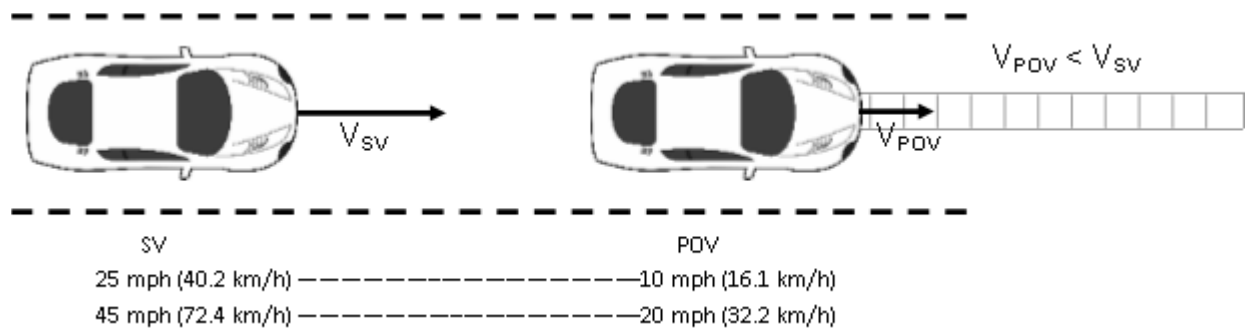


Figure 2. Depiction of Test 2

a. Procedure

The SV ignition was cycled prior to each test run. The tests were conducted two ways. In the first, the POV was driven at a constant 10.0 mph (16.1 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. The SV brakes were applied at  $TTC = 1.0$  seconds, assumed to be SV-to-POV distance of 22 ft (7 m) for an SV speed of 25 mph and 37 ft (11 m) for an SV speed of 45 mph.

The test concluded when either:

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

The SV driver then braked to a stop.

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

- The lateral distance between the centerline of the POV and the center of the travel lane could not deviate more than  $\pm 1$  ft (0.3 m) during the validity period.
- The SV speed could not deviate more than  $\pm 1.0$  mph ( $\pm 1.6$  km/h) during an interval defined by  $TTC = 5.0$  seconds to  $t_{FCW}$ .
- The POV speed could not deviate more than  $\pm 1.0$  mph ( $\pm 1.6$  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 $\rightarrow t_{FCW}$	110 ft (34 m) $\rightarrow t_{FCW}$	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 $\rightarrow t_{FCW}$	183 ft (56 m) $\rightarrow t_{FCW}$	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.

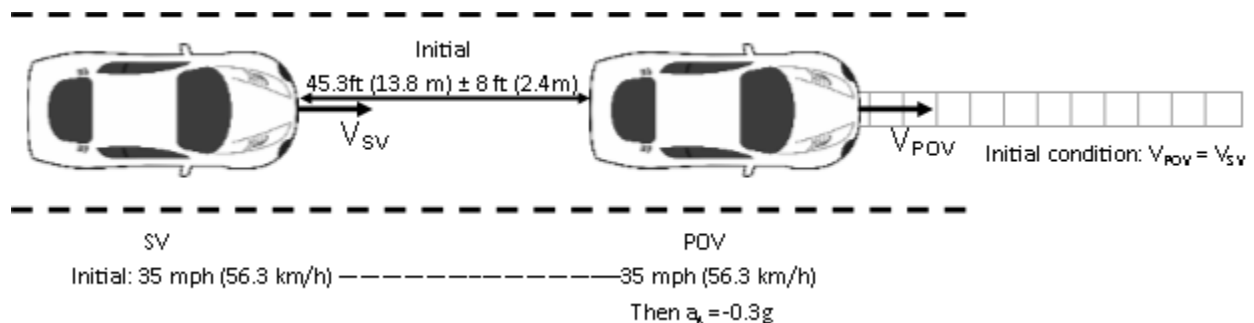


Figure 3. Depiction of Test 3

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  $0.3 \pm 0.03 g$ . The SV throttle pedal was released within 500 ms of  $t_{FCW}$ , and the SV brakes were applied when TTC was 1.4 seconds (31.5 ft (9.6 m)).

The test concluded when either:

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

The SV driver then braked to a stop.

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

- The lateral distance between the centerline of the POV and the center of the travel lane could not deviate more than  $\pm 1$  ft (0.3 m) during the validity period.
- The headway between the SV and POV must have been constant from the onset

of the applicable validity period to the onset of POV braking.

- The SV and POV speed could not deviate more than  $\pm 1.0$  mph (1.6 km/h) 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  $\pm 0.03$  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 $\rightarrow t_{FCW}$	45 ft (14 m) $\rightarrow t_{FCW}$	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 1.25 times the average of the deceleration experienced by the baseline command from the braking actuator for at least five of seven valid test trials.

**B. General Information**

1.  $T_{FCW}$

The time at which the Forward Collision Warning (FCW) activation flag indicates that the system has issued an alert to the SV driver is designated as  $t_{FCW}$ . FCW alerts are typically haptic, visual, or 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**

<b>Warning Type</b>	<b>Filter Order</b>	<b>Peak-to-Peak Ripple</b>	<b>Minimum Stop Band Attenuation</b>	<b>Passband Frequency Range</b>
Auditory	5 <sup>th</sup>	3 dB	60 dB	Identified Center Frequency $\pm$ 5%
Tactile	5 <sup>th</sup>	3 dB	60 dB	Identified Center Frequency $\pm$ 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  $\pm 1.0$  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 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  $\pm 1$  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 each of the test series.

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

For Tests 1, 2, and 3, the SV was positioned such that it just contacted a vertical plane defining the rearmost location of the POV. For Test 4, the front-most location of the SV was positioned such that it just reached a vertical plane defined by the leading edge of

the STP first encountered by the SV (i.e., just before it is driven onto the STP). This is the “zero position.”

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

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

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

## 5. NUMBER OF TRIALS

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

## 6. TRANSMISSION

All trials were performed with SV automatic transmissions in “Drive” or with manual transmissions in the highest gear capable of sustaining the desired test speed. Manual transmission clutches remained engaged during all maneuvers. The brake lights of the POV were not illuminated.

### **C. Principal Other Vehicle**

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

This SSV system was designed specifically for common rear-end crash scenarios which AEB systems address. The key 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  $0.4 \pm 0.025$  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: 8/18/2020 Due: 8/18/2021
Platform Scales	Vehicle Total, Wheel, and Axle Load	2200 lb/platform	0.1% of reading	Intercomp SW wireless	0410MN20001	By: DRI Date: 4/20/2020 Due: 4/20/2021
Linear (string) encoder	Throttle pedal travel	10 in 254 mm	0.1 in 2.54 mm	UniMeasure LX-EP	45040532	By: DRI Date: 7/2/2020 Due: 7/2/2021
Load Cell	Force applied to brake pedal					By: DRI
		0-250 lb 1112 N	0.05% FS	Stellar Technology PNC700	1607338	Date: 7/2/2020 Due: 7/2/2021
		0-250 lb 1112 N	0.05% FS	Stellar Technology PNC700	1607338	Date: 7/2/2020 Due: 7/2/2021
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;	Accels $\pm 10g$ , Angular Rate $\pm 100$ 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
	Lateral, Longitudinal and Vertical Velocities;				2258	Date: 5/3/2019 Due: 5/3/2021
	Roll, Pitch, Yaw Rates; Roll, Pitch, Yaw Angles				2182	Date: 9/16/2019 Due: 9/16/2021
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: $\pm 30$ m Lateral Lane Velocity: $\pm 20$ m/sec Longitudinal Range to POV: $\pm 200$ m Longitudinal Range Rate: $\pm 50$ m/sec	Lateral Distance to Lane Marking: $\pm 2$ cm Lateral Velocity to Lane Marking: $\pm 0.02$ m/sec Longitudinal Range: $\pm 3$ cm Longitudinal Range Rate: $\pm 0.02$ 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)	$\pm 5g$	$\leq 3\%$ 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: 1/6/2020 Due: 1/6/2021
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

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Figure A1. Front View of Subject Vehicle

A-3



Figure A2. Rear View of Subject Vehicle

A-4





DESC.: **HIGHLANDER** LE - V6 FWD  
 VIN: **5TDZZRAH1MS51**  
 YR/MDL: 2021/6946A  
 CLR: SILVER METALLIC/GRAPHITE (01J9/10)  
 FINAL ASSEMBLY POINT: PRINCETON, INDIANA, U.S.A.

**GOVERNMENT 5-STAR SAFETY RATINGS**

**Overall Vehicle Score** ★★★★★  
 Based on the combined ratings of frontal, side and rollover.  
 Should ONLY be compared to other vehicles of similar size and weight.

**Frontal Crash** Driver ★★★★★  
 Passenger ★★★★★  
 Based on the risk of injury in a frontal impact.  
 Should ONLY be compared to other vehicles of similar size and weight.

**Side Crash** Front seat ★★★★★  
 Rear seat ★★★★★  
 Based on the risk of injury in a side impact.

**Rollover** ★★★★★  
 Based on the risk of rollover in a single-vehicle crash.

Star ratings range from 1 to 5 stars (★★★★★) with 5 being the highest.  
 Source: National Highway Traffic Safety Administration (NHTSA)  
[www.safercar.gov](http://www.safercar.gov) or 1-888-327-4236

**STANDARD EQUIPMENT**

- MECHANICAL & PERFORMANCE**  
 - 3.5L V6 Engine, 8 Speed Automatic  
 - 3,000-lb Tow Capacity; 295 Horsepower  
 - 18-in Alloy Wheels w/Temporary Spare
- SAFETY & CONVENIENCE**  
 - Toyota Safety Sense 2.5+: Pre-Collision Sys w/Pedestrian Detection, Full-Speed Range Dynamic Radar Cruise Control, Lane Departure Alert w/Steering Assist, Lane Tracing Assist, Automatic High Beams, Road Sign Assist  
 - Star Safety System  
 - Blind Spot Monitor w/Rear-Cross Traffic Alert  
 - LATCH-Lower Anchor & Tether for Children  
 - 3-Door Smart Key System w/ Push Button Start  
 - Safety & Remote Connect w/1-Year Trial
- EXTERIOR**  
 - LED Headlights, Taillights, Fog Lights  
 - Heated Power Outside Mirrors  
 - Power Liftgate
- INTERIOR**  
 - Audio Plus - 8-in Touchscreen, HandsFree Bluetooth Phone/Music, USB Media Port, 4 USB Charge Ports, SiriusXM w/ 3-Month All Access Trial, Android Auto & Apple CarPlay Compatible  
 - Seating for 8; Fabric-Trimmed Seats  
 - Power Driver's Seat  
 - 3rd Row 60/40 Split Fold-Flat Seats  
 - 3-Zone Auto Climate Control  
 - 12 Cup/Bottle Holders  
 - Lighted Vanity Mirrors  
 - For Full Product Details, Please Visit [Toyota.com/Highlander](http://Toyota.com/Highlander)  
 \*\*\*Full Tank of Gas\*\*\*

**MANUFACTURER'S SUGGESTED RETAIL PRICE \$37,010.00**

OPTIONAL EQUIPMENT		
FE	50 State Emissions	350.00
3T	Cargo Cross Bars	318.00
CF	Carpeted Floor Mats/Carpet Cargo Mat	125.00
D5	Door Edge Guards	69.00
DK	Preferred Owner's Portfolio	
EF	Rear Bumper Applique - Clear	

**EPA DOT Fuel Economy and Environment**

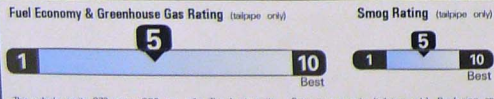
**Gasoline Vehicle**

**Fuel Economy**  
**24** MPG  
 21 29  
 combined city/hwy city highway  
 4.2 gallons per 100 miles

Small SUVs range from 16 to 120 MPG. The best vehicle rates 141 MPG.

**You spend \$1,000**  
 more in fuel costs over 5 years compared to the average new vehicle.

**Annual fuel cost \$1,700**



This vehicle emits 372 grams CO2 per mile. The best emits 0 grams per mile (tailpipe only). Producing and distributing fuel also creates emissions. Learn more at [fuel-economy.gov](http://fuel-economy.gov). Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle. The average new vehicle gets 27 MPG and costs \$7,500 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at \$2.70 per gallon. MPG is miles per gasoline gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.

**fuel-economy.gov**  
 Calculate personalized estimates and compare vehicles



**TOTAL \$39,047.00**

The New Vehicle Limited Warranty provides 3-year/36,000 mile basic coverage, 5-year/80,000 mile powertrain coverage, plus 5-year/unlimited mile corrosion perforation coverage. See Warranty and Maintenance Guide for details. An extended service contract may be available for the vehicle. Ask dealer for details. Manufacturer's suggested retail price includes manufacturer's recommended pre-delivery service. Gasoline, license and title fees, applicable federal, state and local taxes and dealer and distributor installed options and accessories are not included in the manufacturer's suggested retail price. ToyotaCare, which covers normal factory scheduled maintenance for two years or 25,000 miles, whichever occurs first, is included as part of the sales price of the vehicle for qualifying buyers. See participating dealer for eligibility and coverage details.

DELIVERY PROCESSING AND HANDLING FEE 1,175.00

Delivered by Truck to:



Figure A3. Window Sticker (Monroney Label)

MFD. BY: TOYOTA MOTOR MANUFACTURING, INDIANA, INC.

11/20

GVWR: 2645KG (5830LB)

GAWR: FRT. 1635KG (3605LB) WITH 235/65R18  
18X8J RIMS.

TIRES,

RR. 1635KG (3605LB) WITH 235/65R18  
18X8J RIMS.

TIRES,

THIS VEHICLE CONFORMS TO ALL APPLICABLE FEDERAL MOTOR  
VEHICLE SAFETY AND THEFT PREVENTION STANDARDS IN EFFECT ON  
THE DATE OF MANUFACTURE SHOWN ABOVE.

5TDZZRAH1MS51

MPV



C/TR: 1J9/FB10

GSU70L-ARZNHA

A/TM: /UA80E

MADE IN U.S.A.

237

A

Figure A4. Vehicle Certification Label



# TIRE AND LOADING INFORMATION RENSEIGNEMENTS SUR LES PNEUS ET LE CHARGEMENT

SEATING CAPACITY | TOTAL : 8 | FRONT : 2 | REAR : 6  
NOMBRE DE PLACES | TOTAL : 8 | AVANT : 2 | ARRIÈRE : 6

II 0E710

The combined weight of occupants and cargo should never exceed 630 kg or 1390 lbs.  
Le poids total des occupants et du chargement ne doit jamais dépasser 630 kg ou 1390 lb.

TIRE PNEU	SIZE DIMENSIONS	COLD TIRE PRESSURE PRESSION DES PNEUS À FROID	SEE OWNER'S MANUAL FOR ADDITIONAL INFORMATION  VOIR LE MANUEL DE L'USAGER POUR PLUS DE RENSEIGNEMENTS
FRONT AVANT	235/65R18	250 kPa, 36 PSI	
REAR ARRIÈRE	235/65R18	250 kPa, 36 PSI	
SPARE DE SECOURS	T165/90D18	420 kPa, 60 PSI	



Figure A5. Tire Placard  
A-7



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



Figure A7. Load Frame/Slider of SSV

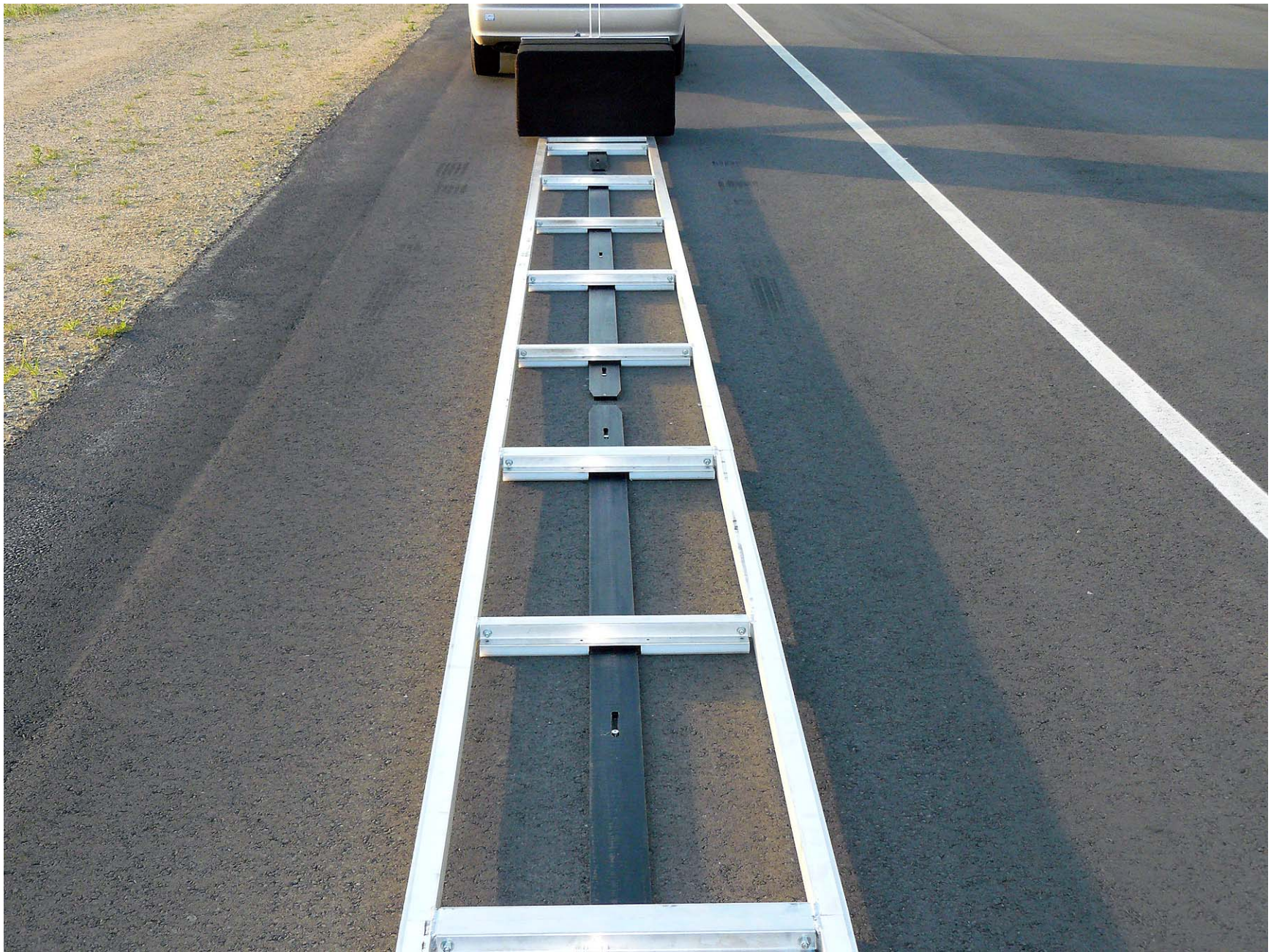


Figure A8. Two-Rail Track and Road-Based Lateral Restraint Track



Figure A9. Steel Trench Plate  
A-11

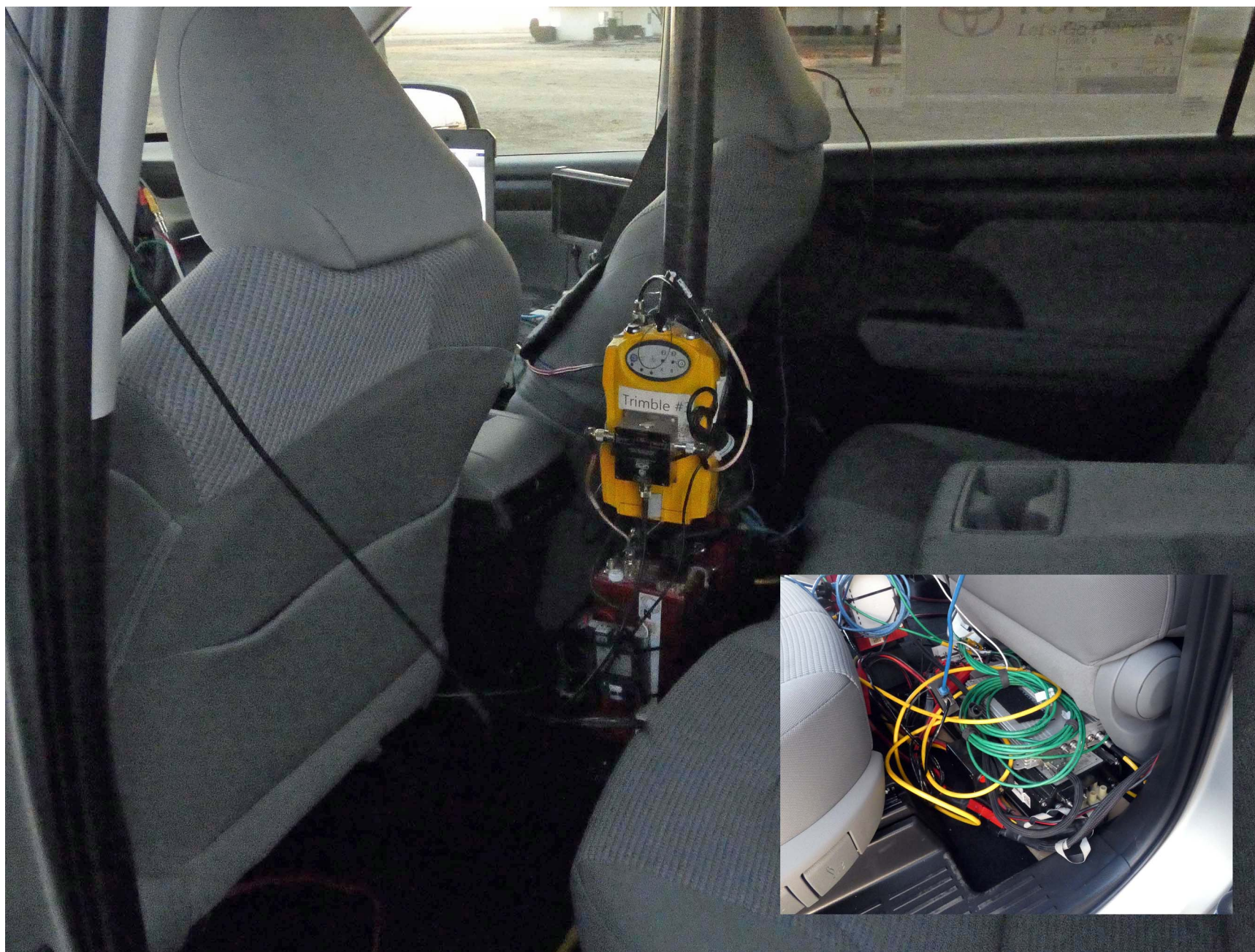


Figure A10. DGPS, Inertial Measurement Unit, and MicroAutoBox Installed in Subject Vehicle





Figure A11. Sensors for Detecting Visual and Auditory Alerts



Figure A12. Computer and Brake Actuator Installed in Subject Vehicle



Figure A13. Brake Actuator Installed in POV System

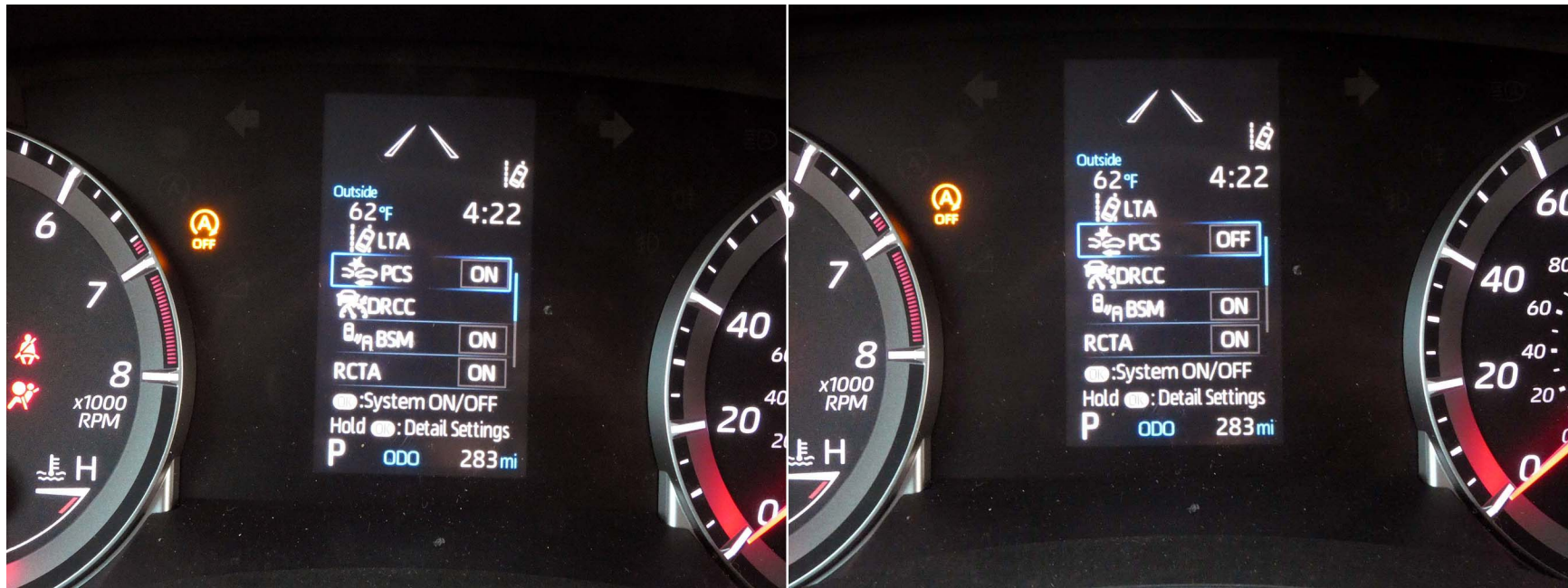


Figure A14. System Setup Menus



Figure A15. Controls for Changing System Setup Parameters



Figure A16. Visual Alert  
A-18

## APPENDIX B

Excerpts from Owner's Manual

## Toyota Safety Sense 2.5 +

The Toyota Safety Sense 2.5 + consists of the following drive assist systems and contributes to a safe and comfortable driving experience:

### Driving assist system

- **PCS (Pre-Collision System)**  
→P.235
  - **LTA (Lane Tracing Assist)**  
→P.246
  - **AHB (Automatic High Beam)**  
→P.219
  - **RSA (Road Sign Assist)\***  
→P.269
- \*: If equipped
- **Dynamic radar cruise control with full-speed range**  
→P.257

### ⚠ WARNING

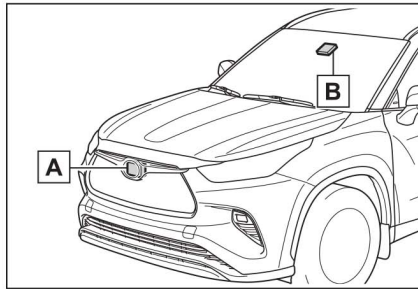
#### ■ Toyota Safety Sense 2.5 +

The Toyota Safety Sense 2.5 + is designed to operate under the assumption that the driver will drive safely, and is designed to help reduce the impact to the occupants and the vehicle in the case of a collision or assist the driver in normal driving conditions.

As there is a limit to the degree of recognition accuracy and control performance that this system can provide, do not overly rely on this system. The driver is always responsible for paying attention to the vehicle's surroundings and driving safely.

### Sensors

Two types of sensors, located behind the front grille and windshield, detect information necessary to operate the drive assist systems.



- A Radar sensor
- B Front camera



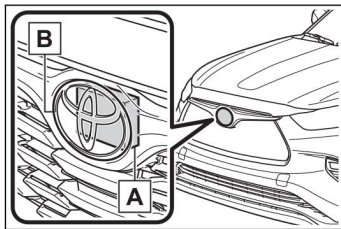
**⚠ WARNING**

**■ To avoid malfunction of the radar sensor**

Observe the following precautions.

Otherwise, the radar sensor may not operate properly, possibly leading to an accident resulting in death or serious injury.

- Keep the radar sensor and the radar sensor cover clean at all times.



**A** Radar sensor

**B** Radar sensor cover

If the front of the radar sensor or the front or back of the radar sensor cover is dirty or covered with water droplets, snow, etc., clean it.

Clean the radar sensor and radar sensor cover with a soft cloth to avoid damaging them.

- Do not attach accessories, stickers (including transparent stickers) or other items to the radar sensor, radar sensor cover or surrounding area.
- Do not subject the radar sensor or its surrounding area to a strong impact.  
If the radar sensor, front grille, or front bumper has been subjected to a strong impact, have the vehicle inspected by your Toyota dealer.

- Do not disassemble the radar sensor.
- Do not modify or paint the radar sensor or radar sensor cover.
- In the following cases, the radar sensor must be recalibrated. Contact your Toyota dealer for details.
  - When the radar sensor or front grille are removed and installed, or replaced
  - When the front bumper is replaced

**■ To avoid malfunction of the front camera**

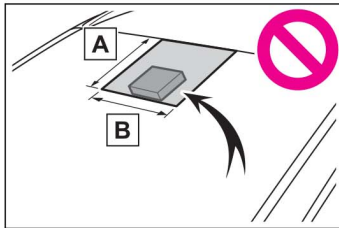
Observe the following precautions.

Otherwise, the front camera may not operate properly, possibly leading to an accident resulting in death or serious injury.

- Keep the windshield clean at all times.
  - If the windshield is dirty or covered with an oily film, water droplets, snow, etc., clean the windshield.
  - If a glass coating agent is applied to the windshield, it will still be necessary to use the windshield wipers to remove water droplets, etc. from the area of the windshield in front of the front camera.
  - If the inner side of the windshield where the front camera is installed is dirty, contact your Toyota dealer.

**⚠ WARNING**

- Do not attach objects, such as stickers, transparent stickers, etc., to the outer side of the windshield in front of the front camera (shaded area in the illustration).



**A** From the top of the windshield to approximately 0.4 in. (1 cm) below the bottom of the front camera

**B** Approximately 7.9 in. (20 cm) (Approximately 4.0 in. [10 cm] to the right and left from the center of the front camera)

- If the part of the windshield in front of the front camera is fogged up or covered with condensation or ice, use the windshield defogger to remove the fog, condensation or ice. (→P.337, 343)
- If water droplets cannot be properly removed from the area of the windshield in front of the front camera by the windshield wipers, replace the wiper insert or wiper blade.
- Do not attach window tint to the windshield.
- Replace the windshield if it is damaged or cracked. After replacing the windshield, the front camera must be recalibrated. Contact your Toyota dealer for details.

- Do not allow liquids to contact the front camera.
- Do not allow bright lights to shine into the front camera.
- Do not dirty or damage the front camera. When cleaning the inside of the windshield, do not allow glass cleaner to contact the lens of the front camera. Also, do not touch the lens. If the lens is dirty or damaged, contact your Toyota dealer.
- Do not subject the front camera to a strong impact.
- Do not change the installation position or direction of the front camera or remove it.
- Do not disassemble the front camera.
- Do not modify any components of the vehicle around the front camera (inside rear view mirror, etc.) or ceiling.
- Do not attach any accessories to the hood, front grille or front bumper that may obstruct the front camera. Contact your Toyota dealer for details.
- If a surfboard or other long object is to be mounted on the roof, make sure that it will not obstruct the front camera.
- Do not modify the headlights or other lights.

■ **Certification**

- ▶ Except for vehicles sold in Canada

FCC ID: HYQDNMWR009

**NOTE:**

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

**FCC WARNING:**

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

**Radiofrequency radiation exposure Information:**

This equipment complies with FCC radiation exposure limits set forth for an uncontrolled environment. This equipment should be installed and operated with minimum distance of 20 cm between the radiator (antenna) and your body. This transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

- ▶ For vehicles sold in Canada

**NOTE:**

This device contains licence-exempt transmitter(s)/receiver(s) that comply with Innovation, Science and Economic Development Canada's licence-exempt RSS(s). Operation is subject to the following two conditions:

- (1) This device may not cause interference.
- (2) This device must accept any interference, including interference that may cause undesired operation of the device.

This equipment complies with ISED radiation exposure limits set forth for an uncontrolled environment and meets RSS-102 of the ISED radio frequency (RF) Exposure rules. This equipment should be installed and operated keeping the radiator at least 20 cm or more away from person's body.

**NOTE:**

L'émetteur/récepteur exempt de licence contenu dans le présent appareil est conforme aux CNR d'Innovation, Sciences et Développement économique Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

- 1) L'appareil ne doit pas produire de brouillage;
- 2) L'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Cet équipement est conforme aux limites d'exposition aux rayonnements énoncées pour un environnement non contrôlé et respecte les règles d'exposition aux fréquences radioélectriques (RF) CNR-102 de l'ISDE. Cet équipement doit être installé et utilisé en gardant une distance de 20 cm ou plus entre le dispositif rayonnant et le corps.

**■ If a warning message is displayed on the multi-information display**

A system may be temporarily unavailable or there may be a malfunction in the system.

- In the following situations, perform the actions specified in the table. When the normal operating conditions are detected, the message will disappear and the system will become operational.

If the message does not disappear, contact your Toyota dealer.

Situation	Actions
When the area around a camera is covered with dirt, moisture (fogged up, covered with condensation, ice, etc.), or other foreign matter	Using the wiper and A/C function, remove the dirt and other attached matter (→P.337, 343).

Situation	Actions
<p>When the temperature around the front camera is outside of the operational range, such as when the vehicle is in the sun or in an extremely cold environment</p>	<p>If the front camera is hot, such as after the vehicle had been parked in the sun, use the air conditioning system to decrease the temperature around the front camera.</p> <p>If a sunshade was used when the vehicle was parked, depending on its type, the sunlight reflected from the surface of the sunshade may cause the temperature of the front camera to become excessively high.</p> <p>If the front camera is cold, such after the vehicle is parked in an extremely cold environment, use the air conditioning system to increase the temperature around the front camera.</p>
<p>The area in front of the front camera is obstructed, such as when the hood is open or a sticker is attached to the part of the windshield in front of the front camera.</p>	<p>Close the hood, remove the sticker, etc. to clear the obstruction.</p>
<p>When "Pre-Collision System Radar In Self Calibration Unavailable See Owner's Manual" is displayed.</p>	<p>Check whether there is attached materials on the radar sensor and radar sensor cover, and if there is, remove it.</p>

- In the following situations, if the situation has changed (or the vehicle has been driven for some time) and the normal operating conditions are detected, the message will disappear and the system will become operational.  
If the message does not disappear, contact your Toyota dealer.
- When the temperature around the radar sensor is outside of the operational range, such as when the vehicle is in the sun or in an extremely cold environment
- When the front camera cannot detect objects in front of the vehicle, such as when driving in the dark, snow, or fog, or when bright lights are shining into the front camera
- Depending on the conditions in the vicinity of the vehicle, the radar may judge the surrounding environment can not be properly recognized. In that case, "Pre-Collision System Unavailable See Owner's Manual" is displayed.

## PCS (Pre-Collision System)

The pre-collision system uses a radar sensor and front camera to detect objects (→P.235) in front of the vehicle. When the system determines that the possibility of a frontal collision with an object is high, a warning operates to urge the driver to take evasive action and the potential brake pressure is increased to help the driver avoid the collision. If the system determines that the possibility of a frontal collision with an object is extremely high, the brakes are automatically applied to help avoid the collision or help reduce the impact of the collision.

The pre-collision system can be disabled/enabled and the warning timing can be changed. (→P.238)

### Detectable objects

The system can detect the following (The detectable objects differs depending on the function.):

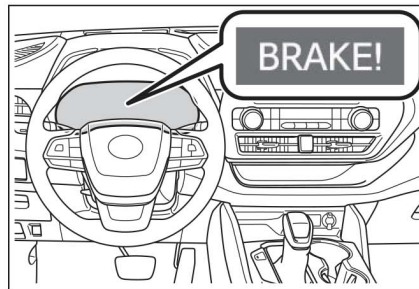
- Vehicles
- Bicyclists

- Pedestrians

### System functions

#### ■ Pre-collision warning

When the system determines that the possibility of a frontal collision is high, a buzzer will sound and a warning message will be displayed on the multi-information display to urge the driver to take evasive action.



#### ■ Pre-collision brake assist

When the system determines that the possibility of a frontal collision is high, the system applies greater braking force in relation to how strongly the brake pedal is depressed.

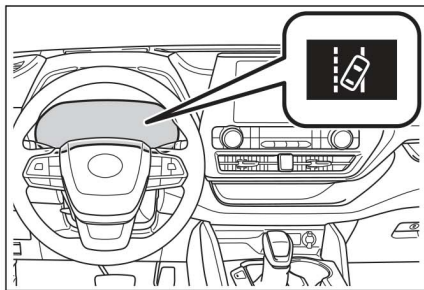
#### ■ Pre-collision braking

If the system determines that the possibility of a frontal collision is extremely high, the brakes are automatically applied to help avoid the collision or reduce the impact of the collision.

#### ■ Emergency steering assist

If the system determines that the possibility of a frontal collision is extremely high, the system

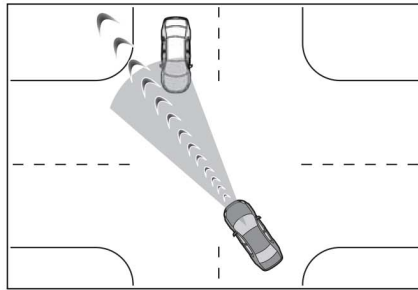
sion is high and that there is sufficient space for the vehicle to be steered into within its lane, and the driver has begun evasive maneuver or steering, emergency steering assist will assist the steering movements to help enhance the vehicle stability and for lane departure prevention. During operation, the indicator will illuminate in green.



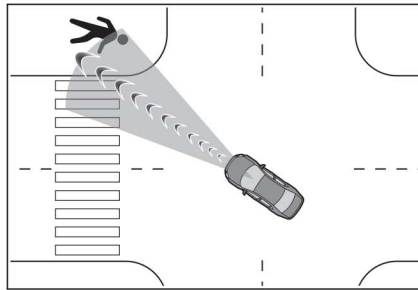
■ **Intersection right/left turn assistance**

If the system determines that there is a high possibility of a collision in the following situations, it will assist with Pre-collision warning and, if necessary Pre-collision braking. Depending on the configuration of the intersection, it may not be possible to support.

- When you turn right/left at an intersection and cross the path of an oncoming vehicle



- When you turn right/left, pedestrian is detected in the forward direction and estimated to enter your vehicle's path (bicyclists are not detected.)



**⚠ WARNING**

■ **Limitations of the pre-collision system**

- The driver is solely responsible for safe driving. Always drive safely, taking care to observe your surroundings. Do not use the pre-collision system instead of normal braking operations under any circumstances. This system will not prevent collisions or lessen collision damage or injury in every situation. Do not overly rely on this system. Failure to do so may lead to an accident, resulting in death or serious injury.

**⚠ WARNING**

- Although this system is designed to help avoid a collision or help reduce the impact of the collision, its effectiveness may change according to various conditions, therefore the system may not always be able to achieve the same level of performance.  
Read the following conditions carefully. Do not overly rely on this system and always drive carefully.
- Conditions under which the system may operate even if there is no possibility of a collision:  
→P.242
- Conditions under which the system may not operate properly:  
→P.243
- Do not attempt to test the operation of the pre-collision system yourself.  
Depending on the objects used for testing (dummies, cardboard objects imitating detectable objects, etc.), the system may not operate properly, possibly leading to an accident.
- **Pre-collision braking**
- When the pre-collision braking function is operating, a large amount of braking force will be applied.
- If the vehicle is stopped by the operation of the pre-collision braking function, the pre-collision braking function operation will be canceled after approximately 2 seconds. Depress the brake pedal as necessary.

- The pre-collision braking function may not operate if certain operations are performed by the driver. If the accelerator pedal is being depressed strongly or the steering wheel is being turned, the system may determine that the driver is taking evasive action and possibly prevent the pre-collision braking function from operating.
- In some situations, while the pre-collision braking function is operating, operation of the function may be canceled if the accelerator pedal is depressed strongly or the steering wheel is turned and the system determines that the driver is taking evasive action.
- If the brake pedal is being depressed, the system may determine that the driver is taking evasive action and possibly delay the operation timing of the pre-collision braking function.
- **Emergency steering assist**
- As emergency steering assist operation will be canceled when the system determines that lane departure prevention function has been completed.
- Emergency steering assist may not operate or may be cancel in the following cases as the system may determine the driver is taking actions.
- If the accelerator pedal is being depressed strongly, the steering wheel is being operated sharply, the brake pedal is being depressed or the turn signal lever is being operated. In this case, the system may determine that the driver is taking evasive action and the emergency steering assist may not operate.



**⚠ WARNING**

- In some situations, while the emergency steering assist is operating, operation of the function may be canceled if the accelerator pedal is depressed strongly, the steering wheel is operated sharply or the brake pedal is being depressed and the system determines that the driver is taking evasive action.
- When the emergency steering assist is operating, if the steering wheel is held firmly or is operated in the opposite direction to that which the system is generating torque, the function may be canceled.

**■ When to disable the pre-collision system**


In the following situations, disable the system, as it may not operate properly, possibly leading to an accident resulting in death or serious injury:

- When the vehicle is being towed
- When your vehicle is towing another vehicle
- When transporting the vehicle via truck, boat, train or similar means of transportation
- When the vehicle is raised on a lift with the engine running and the tires are allowed to rotate freely
- When inspecting the vehicle using a drum tester such as a chassis dynamometer or speedometer tester, or when using an on vehicle wheel balancer
- When a strong impact is applied to the front bumper or front grille, due to an accident or other reasons

- If the vehicle cannot be driven in a stable manner, such as when the vehicle has been in an accident or is malfunctioning
- When the vehicle is driven in a sporty manner or off-road
- When the tires are not properly inflated
- When the tires are very worn
- When tires of a size other than specified are installed
- When tire chains are installed
- When a compact spare tire or an emergency tire puncture repair kit is used
- If equipment (snow plow, etc.) that may obstruct the radar sensor or front camera is temporarily installed to the vehicle

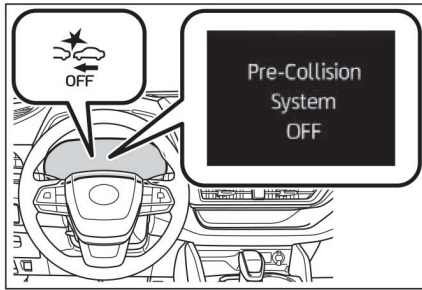
**Changing settings of the pre-collision system**

**■ Enabling/disabling the pre-collision system**


The pre-collision system can be enabled/disabled on  (→P.89, 98) of the multi-information display.

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

If the system is disabled, the PCS warning light will turn on and a message will be displayed on the multi-information display.



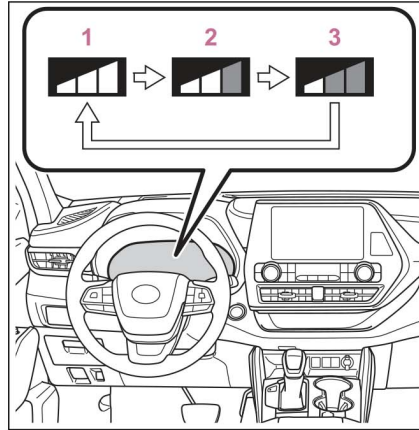
■ **Changing the pre-collision warning timing**

The pre-collision warning timing can be changed on  (→P.89, 98) of the multi-information display.

The warning timing setting is retained when the engine switch is turned OFF. However, if the pre-collision system is disabled and re-enabled, the operation timing will return to the default setting (middle).

If the pre-collision warning timing is changed, emergency

steering assist timing will also be changed accordingly. If late is selected, emergency steering assist would not operate in case of an emergency.



- 1** Early
- 2** Middle
- 3** Late

This is the default setting.

■ **Operational conditions for each pre-collision function**

The pre-collision system is enabled and the system determines that the possibility of a frontal collision with a detected object is high.

The system may not operate in the following situations:

- If a battery terminal has been disconnected and reconnected and then the vehicle has not been driven for a certain amount of time
- If the shift lever is in R
- When the VSC OFF indicator is illuminated (only the pre-collision warning function will be operational)

The operation speeds and operation cancellation for each function is listed below.

- Pre-collision warning

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Detectable objects	Vehicle speed	Relative speed between your vehicle and object
preceding and stopped vehicles	Approx. 7 to 110 mph (10 to 180 km/h)	Approx. 7 to 110 mph (10 to 180 km/h)
Oncoming vehicles	Approx. 7 to 110 mph (10 to 180 km/h)	Approx. 13 to 110 mph (20 to 180 km/h)
Bicyclists and pedestrians	Approx. 7 to 50 mph (10 to 80 km/h)	Approx. 7 to 50 mph (10 to 80 km/h)

While the pre-collision warning function is operating, if the steering wheel is operated heavily or suddenly, the pre-collision warning may be cancelled.

● Pre-collision brake assist

Detectable objects	Vehicle speed	Relative speed between your vehicle and object
Preceding and stopped vehicles	Approx. 20 to 110 mph (30 to 180 km/h)	Approx. 20 to 110 mph (30 to 180 km/h)
Bicyclists and pedestrians	Approx. 20 to 50 mph (30 to 80 km/h)	Approx. 20 to 50 mph (30 to 80 km/h)

● Pre-collision braking

Detectable objects	Vehicle speed	Relative speed between your vehicle and object
Preceding and stopped vehicles	Approx. 7 to 110 mph (10 to 180 km/h)	Approx. 7 to 110 mph (10 to 180 km/h)
Oncoming vehicles	Approx. 7 to 110 mph (10 to 180 km/h)	Approx. 13 to 110 mph (20 to 180 km/h)
Bicyclists and pedestrians	Approx. 7 to 50 mph (10 to 80 km/h)	Approx. 7 to 50 mph (10 to 80 km/h)

If either of the following occur while the pre-collision braking function is operating, it will be canceled:

- The accelerator pedal is depressed strongly.
- The steering wheel is turned sharply or abruptly.

● Emergency steering assist

When the turn signal lights are flashing, emergency steering assist will not operate in case of an emergency.

Detectable objects	Vehicle speed	Relative speed between your vehicle and object
Preceding and stopped vehicles, bicyclists and pedestrians	Approx. 25 to 50 mph (40 to 80 km/h)	Approx. 25 to 50 mph (40 to 80 km/h)

If any of the following occur while the emergency steering assist function is operating, it will be canceled:

- The accelerator pedal is depressed strongly.
- The steering wheel is turned sharply or abruptly.
- The brake pedal is depressed.
- Intersection right/left turn assistance (pre-collision warning)

When the turn signal lights are not flashing, support for turning left or right at an intersection which targets oncoming vehicles does not work.

Detectable objects	Vehicle speed	Oncoming vehicle speed	Relative speed between your vehicle and object
Oncoming vehicles	Approx. 7 to 15 mph (10 to 25 km/h)	Approx. 20 to 35 mph (30 to 55 km/h)	Approx. 25 to 50 mph (40 to 80 km/h)
Pedestrians	Approx. 7 to 15 mph (10 to 25 km/h)	—	Approx. 7 to 15 mph (10 to 25 km/h)

- Intersection right/left turn assistance (pre-collision braking)

When the turn signal lights are not flashing, support for turning left or right at an intersection which targets oncoming vehicles does not work.

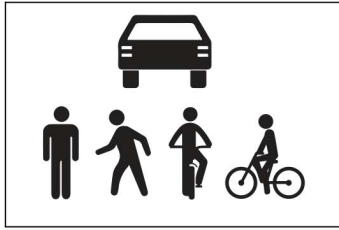
Detectable objects	Vehicle speed	Oncoming vehicle speed	Relative speed between your vehicle and object
Oncoming vehicles	Approx. 10 to 15 mph (15 to 25 km/h)	Approx. 20 to 28 mph (30 to 45 km/h)	Approx. 28 to 43 mph (45 to 70 km/h)
Pedestrians	Approx. 7 to 15 mph (10 to 25 km/h)	—	Approx. 7 to 15 mph (10 to 25 km/h)

■ **Object detection function**

The system detects objects based on their size, profile, motion, etc. However, an object may not be detected depending on the sur-

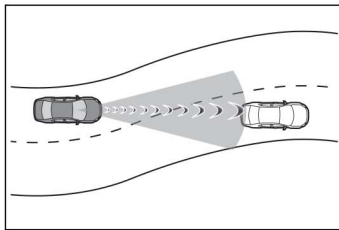
rounding brightness and the motion, posture, and angle of the detected object, preventing the system from operating properly. (→P.243)  
The illustration shows an image of

detectable objects.

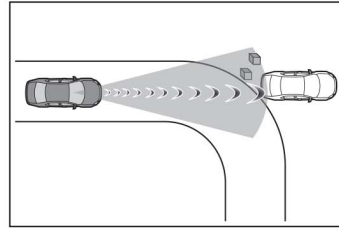


■ **Conditions under which the system may operate even if there is no possibility of a collision**

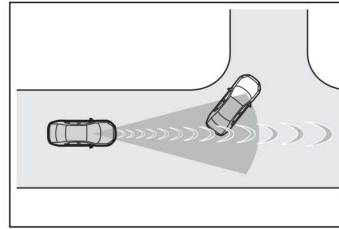
- In some situations such as the following, the system may determine that there is a possibility of a frontal collision and operate.
- When passing a detectable object, etc.
- When changing lanes while overtaking a detectable object, etc.
- When approaching a detectable object in an adjacent lane or on the roadside, such as when changing the course of travel or driving on a winding road



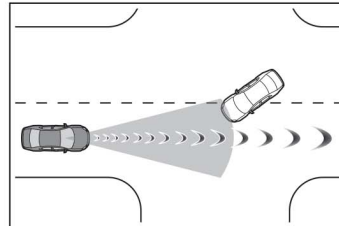
- When rapidly closing on a detectable object, etc.
- When approaching objects on the roadside, such as detectable objects, guardrails, utility poles, trees, or walls
- When there is a detectable object or other object by the roadside at the entrance of a curve



- When there are patterns or paint in front of your vehicle that may be mistaken for a detectable object
- When the front of your vehicle is hit by water, snow, dust, etc.
- When overtaking a detectable object that is changing lanes or making a right/left turn

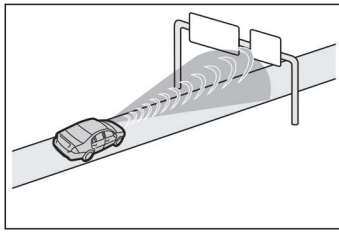


- When passing a detectable object in an oncoming lane that is stopped to make a right/left turn

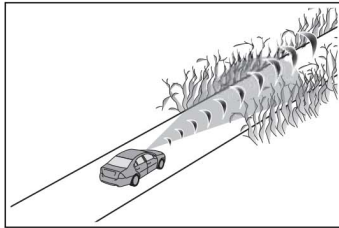


- When a detectable object approaches very close and then stops before entering the path of your vehicle
- If the front of your vehicle is raised or lowered, such as when on an uneven or undulating road surface
- When driving on a road surrounded by a structure, such as in a tunnel or on an iron bridge
- When there is a metal object (manhole cover, steel plate, etc.), steps, or a protrusion in front of your vehicle
- When passing under an object

(road sign, billboard, etc.)

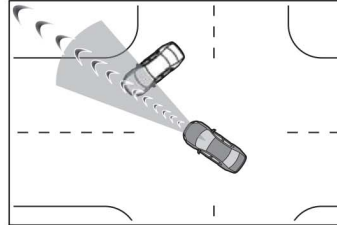


- When approaching an electric toll gate barrier, parking area barrier, or other barrier that opens and closes
- When using an automatic car wash
- When driving through or under objects that may contact your vehicle, such as thick grass, tree branches, or a banner



- When driving through steam or smoke
- When driving near an object that reflects radio waves, such as a large truck or guardrail
- When driving near a TV tower, broadcasting station, electric power plant, radar equipped vehicles, etc., or other location where strong radio waves or electrical noise may be present
- When there are many things which can reflect the radio waves of the radar in the vicinity (tunnels, truss bridges, gravel roads, snow covered road that have tracks, etc.)
- While making a right/left turn, when an oncoming vehicle or a crossing pedestrian has already exited the path of your vehicle
- While making a right/left turn, closely in front of an oncoming vehicle or a crossing pedestrian.

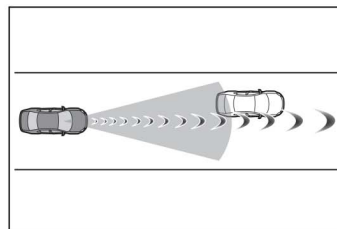
- While making a right/left turn, when an oncoming vehicle or a crossing pedestrian stops before entering the path of your vehicle
- While making a right/left turn, when an oncoming vehicle turns right/left in front of your vehicle



- While steering into the direction of oncoming traffic

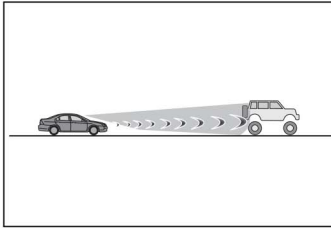
**Situations in which the system may not operate properly**

- In some situations such as the following, an object may not be detected by the radar sensor and front camera, preventing the system from operating properly:
  - When a detectable object is approaching your vehicle
  - When your vehicle or a detectable object is wobbling
  - If a detectable object makes an abrupt maneuver (such as sudden swerving, acceleration or deceleration)
  - When your vehicle approaches a detectable object rapidly
  - When a detectable object is not directly in front of your vehicle

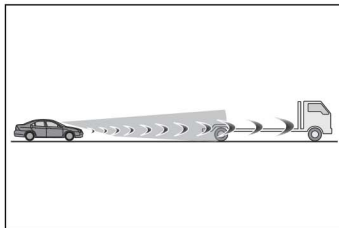


- When a detectable object is near a wall, fence, guardrail, manhole cover, vehicle, steel plate on the road, etc.
- When a detectable object is under a structure

- When part of a detectable object is hidden by an object, such as large baggage, an umbrella, or guardrail
- When there are many things which can reflect the radio waves of the radar in the vicinity (tunnels, truss bridges, gravel roads, snow covered road that have tracks, etc.)
- When there is an effect on the radio waves to the radar that is installed on another vehicle
- When multiple detectable objects are close together
- If the sun or other light is shining directly on a detectable object
- When a detectable object is a shade of white and looks extremely bright
- When a detectable object appears to be nearly the same color or brightness as its surroundings
- If a detectable object cuts or suddenly emerges in front of your vehicle
- When the front of your vehicle is hit by water, snow, dust, etc.
- When a very bright light ahead, such as the sun or the headlights of oncoming traffic, shines directly into the front camera
- When approaching the side or front of a vehicle ahead
- If a vehicle ahead is a motorcycle
- If a vehicle ahead is narrow, such as a personal mobility vehicle
- If a preceding vehicle has a small rear end, such as an unloaded truck
- If a preceding vehicle has a low rear end, such as a low bed trailer

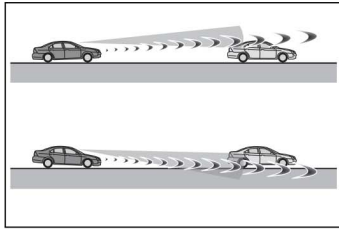


- If a vehicle ahead is carrying a load which protrudes past its rear bumper
- If a vehicle ahead is irregularly shaped, such as a tractor or side car
- If a vehicle ahead is a child sized bicycle, a bicycle that is carrying a large load, a bicycle ridden by more than one person, or a uniquely shaped bicycle (bicycle with a child seat, tandem bicycle, etc.)
- If a pedestrian/or the riding height of a bicyclist ahead is shorter than approximately 3.2 ft. (1 m) or taller than approximately 6.5 ft. (2 m)
- If a pedestrian/bicyclist is wearing oversized clothing (a rain coat, long skirt, etc.), making their silhouette obscure
- If a pedestrian is bending forward or squatting or bicyclist is bending forward
- If a pedestrian/bicyclist is moving fast
- If a pedestrian is pushing a stroller, wheelchair, bicycle or other vehicle
- When driving in inclement weather such as heavy rain, fog, snow or a sandstorm
- When driving through steam or smoke
- When the surrounding area is dim, such as at dawn or dusk, or while at night or in a tunnel, making a detectable object appear to be nearly the same color as its surroundings
- When driving in a place where the surrounding brightness changes suddenly, such as at the entrance or exit of a tunnel
- After the engine has started the

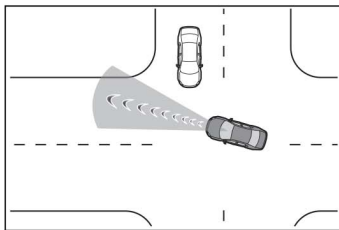


- If a vehicle ahead has extremely high ground clearance

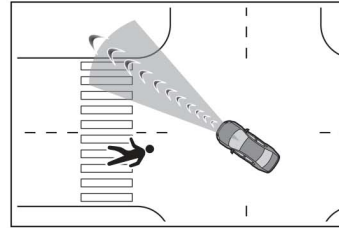
- vehicle has not been driven for a certain amount of time
- While making a left/right turn and for a few seconds after making a left/right turn
- While driving on a curve and for a few seconds after driving on a curve
- If your vehicle is skidding
- If the front of the vehicle is raised or lowered



- If the wheels are misaligned
- If a wiper blade is blocking the front camera
- The vehicle is being driven at extremely high speeds
- When driving on a hill
- If the radar sensor or front camera is misaligned
- When driving in a traffic lane separated by more than one lane where oncoming vehicles are driving while making a right/left turn
- When largely out of place with the opposite facing targeted oncoming vehicle during a right/left turn



- While making a right/left turn, when a pedestrian approaches from behind or side of your vehicle



- In addition to the above, in some situations, such as the following, the emergency steering assist may not operate.
- When the white (yellow) lane lines are difficult to see, such as when they are faint, diverging/merging, or a shadow is cast upon them
- When the lane is wider or narrower than normal
- When there is a light and dark pattern on the road surface, such as due to road repairs
- When the target is too close
- When there is insufficient safe or unobstructed space for the vehicle to be steered into
- If oncoming vehicle is present
- If VSC function is operating
- In some situations such as the following, sufficient braking force or steering force may not be obtained, preventing the system from performing properly:
- If the braking functions cannot operate to their full extent, such as when the brake parts are extremely cold, extremely hot, or wet
- If the vehicle is not properly maintained (brakes or tires are excessively worn, improper tire inflation pressure, etc.)
- When the vehicle is being driven on a gravel road or other slippery surface
- When the road surface has deep wheel tracks
- When driving on a hill road
- When driving on a road that has inclines to the left or right

■ **If VSC is disabled**

- If VSC is disabled (→P.323), the



pre-collision brake assist and pre-collision braking functions are also disabled.

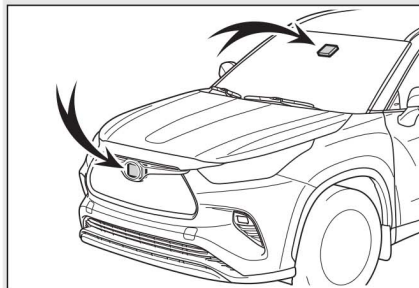
- The PCS warning light will turn on and “VSC Turned OFF Pre-Collision Brake System Unavailable” will be displayed on the multi-information display.

### LTA (Lane Tracing Assist)

While driving on a road with clear white (yellow) lane lines, the LTA system warns the driver if the vehicle may deviate from the current lane or course\*, and also can slightly operate the steering wheel to help avoid deviation from the lane or course\*. Also, while the dynamic radar cruise control with full-speed range (→P.257) is operating, this system will operate the steering wheel to maintain the vehicle’s lane position.

The LTA system recognizes white (yellow) lane lines or a course\* using the front camera. Additionally, it detects preceding vehicles using the front camera and radar.

\*: Boundary between asphalt and the side of the road, such as grass, soil, or a curb



## APPENDIX C

### Run Log

Subject Vehicle: **2021 Toyota Highlander LE - V6 FWD**

Test Date: **12/22/2020**

Principal Other Vehicle: **SSV**

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
1-13	Brake characterization and determination						See Appendix D
14	Static Run						
15	<b>Stopped POV</b>	Y	2.40	12.47	1.10	Pass	
16		N					Brake force
17		N					Brake force
18		Y	2.45	10.81	1.06	Pass	
19		Y	2.46	10.98	1.04	Pass	
20		Y	2.47	11.30	1.05	Pass	
21		Y	2.45	11.74	1.05	Pass	
22		Y	2.40	12.40	1.05	Pass	
23		Y	2.41	12.61	1.04	Pass	
24		Static Run					
25	<b>Slower POV, 25 vs 10</b>	Y	1.86	7.38	0.68	Pass	
26		Y	1.92	8.49	0.69	Pass	
27		Y	1.86	8.17	0.75	Pass	
28		Y	2.00	9.48	0.82	Pass	
29		Y	2.01	8.82	1.05	Pass	
30		Y	1.89	9.42	1.06	Pass	

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
31		Y	1.89	9.08	0.75	Pass	
32	Static run						
33	<b>Slower POV, 45 vs 20</b>	Y	2.36	12.26	1.07	Pass	
34		Y	2.38	12.04	1.07	Pass	
35		Y	2.39	12.62	1.06	Pass	
36		Y	2.39	12.22	1.06	Pass	
37		Y	2.48	12.30	1.07	Pass	
38		Y	2.40	12.53	1.08	Pass	
39		Y	2.34	11.92	1.07	Pass	
40	Static run						
41	<b>Decelerating POV, 35</b>	N					Throttle
42		Y	1.59	12.10	0.64	Pass	
43		Y	1.52	11.41	0.65	Pass	
44		Y	1.65	10.79	0.65	Pass	
45		Y	1.71	10.45	0.65	Pass	
46		Y	1.85	4.67	0.60	Pass	
47		Y	1.68	7.75	0.62	Pass	
48		N					Brake force
49		Y	1.68	9.54	0.62	Pass	
50	Static run						

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes	
51	STP - Static run							
52	<b>Baseline, 25</b>	N					Brake force timing	
53		N					Brake force timing	
54		Y			0.42			
55		Y			0.42			
56		Y			0.42			
57		Y			0.43			
58		Y			0.43			
59		STP - Static run						
69		Y				0.44		
70		N						
60	<b>Baseline, 45</b>	N					SV speed	
61		Y			0.46			
62		Y			0.47			
63		Y			0.48			
64		Y			0.46			
65		Y			0.47			
66		Y			0.46			
67		Y			0.48			
68	STP - Static run							

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
71	<b>STP False Positive, 25</b>	Y			0.42	Pass	
72		Y			0.41	Pass	
73		Y			0.37	Pass	
74		Y			0.39	Pass	
75		Y			0.41	Pass	
76		Y			0.40	Pass	
77		Y			0.39	Pass	
78	STP - Static run						
79	<b>STP False Positive, 45</b>	N					Brake force timing
80		Y			0.42	Pass	
81		Y			0.40	Pass	
82		Y			0.40	Pass	
83		Y			0.42	Pass	
84		Y			0.41	Pass	
85		Y			0.42	Pass	
86	Y			0.41	Pass		
87	STP - Static run						

## APPENDIX D

### Brake Characterization

Subject Vehicle: 2021 Toyota Highlander LE - V6 FWD

Test Date: 12/22/2020

DBS Initial Brake Characterization				
Run Number	Stroke at 0.4 g (in)	Force at 0.4 g (lb)	Slope	Intercept
1	1.218686	17.21643	1.058522	0.439439
2	1.246172	17.48073	0.981785	0.456298
3	1.23673	17.38252	1.006387	0.416141

DBS Brake Characterization Determination								
Run	DBS Mode	Speed	Valid Run	Average Decel. (g)	0.4 g Stroke Value (in)	0.4 g Force Value (lb)	Stroke/Force Calculator (in)	Notes
4	Displacement	35	N					Brake Rate
5			Y	0.435	1.23		1.13	
6			Y	0.365	1.13		1.24	
7			Y	0.418	1.20		1.15	
8		25	Y	0.425	1.20		1.13	
9		45	Y	0.400	1.20		1.20	
10	Hybrid	35	Y	0.474		17.36	14.65	
11			Y	0.415		14.65	14.12	



DBS Brake Characterization Determination								
Run	DBS Mode	Speed	Valid Run	Average Decel. (g)	0.4 g Stroke Value (in)	0.4 g Force Value (lb)	Stroke/Force Calculator (in)	Notes
12	Hybrid	25	Y	0.414		14.65	14.15	
13		45	Y	0.417		14.65	14.05	

Appendix E

TIME HISTORY PLOTS

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## 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.,  $0.30 \text{ g} \pm 0.03 \text{ g}$ ). 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.



For the brake force plots:

- If the tests are done in Hybrid mode, the brake force plot shows a dashed black threshold line indicating a brake force of 2.5 lbs. For the time period where the DBS controller is active, the brake force at the pedal must not fall below this 2.5 lb threshold. Exceedances of this threshold are indicated by red shading in the area between the measured time-varying data and the dashed threshold line. A blue envelope represents the target average brake force necessary to be valid
- If the tests are done in Displacement mode, there are no relevant brake force level thresholds or average brake force calculations.

In the instance of the “last second” braking applied by the brake robot, a thick vertical red line will appear on the plots at the moment the brake robot 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 Figures 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.

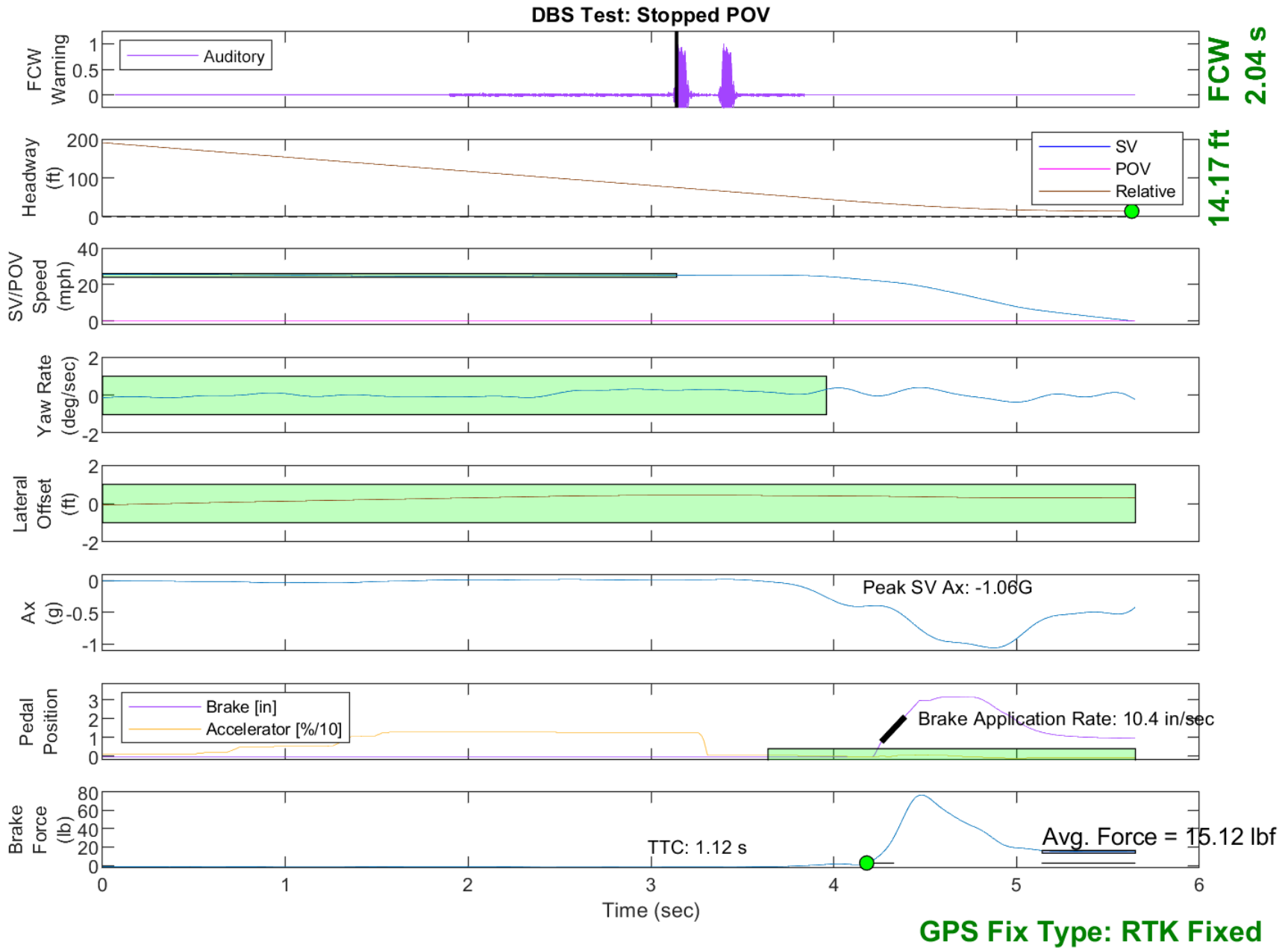


Figure E1. Example Time History for Stopped POV, Passing

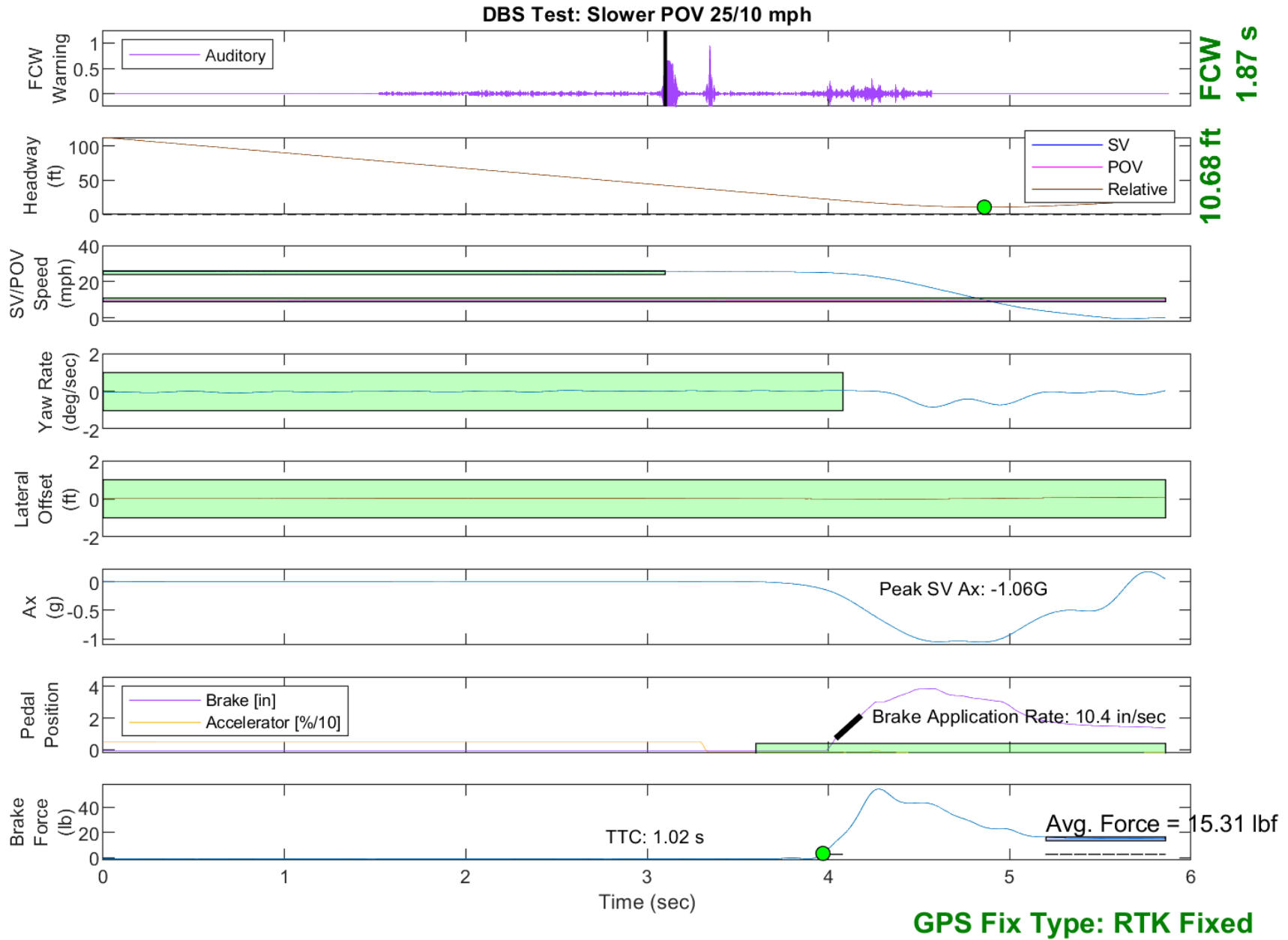


Figure E2. Example Time History for Slower POV 25 vs. 10, Passing

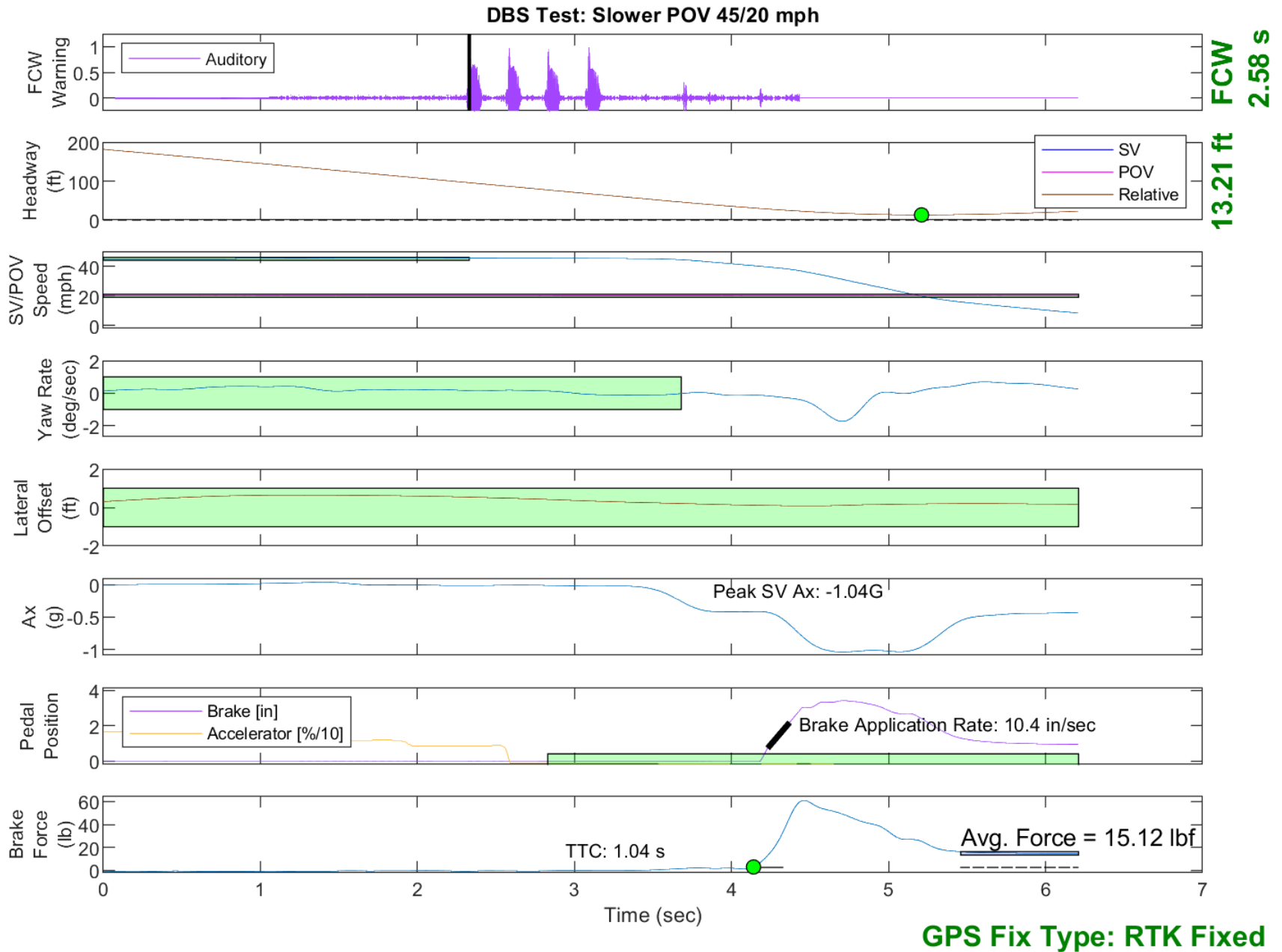


Figure E3. Example Time History for Slower POV 45 vs. 20, Passing

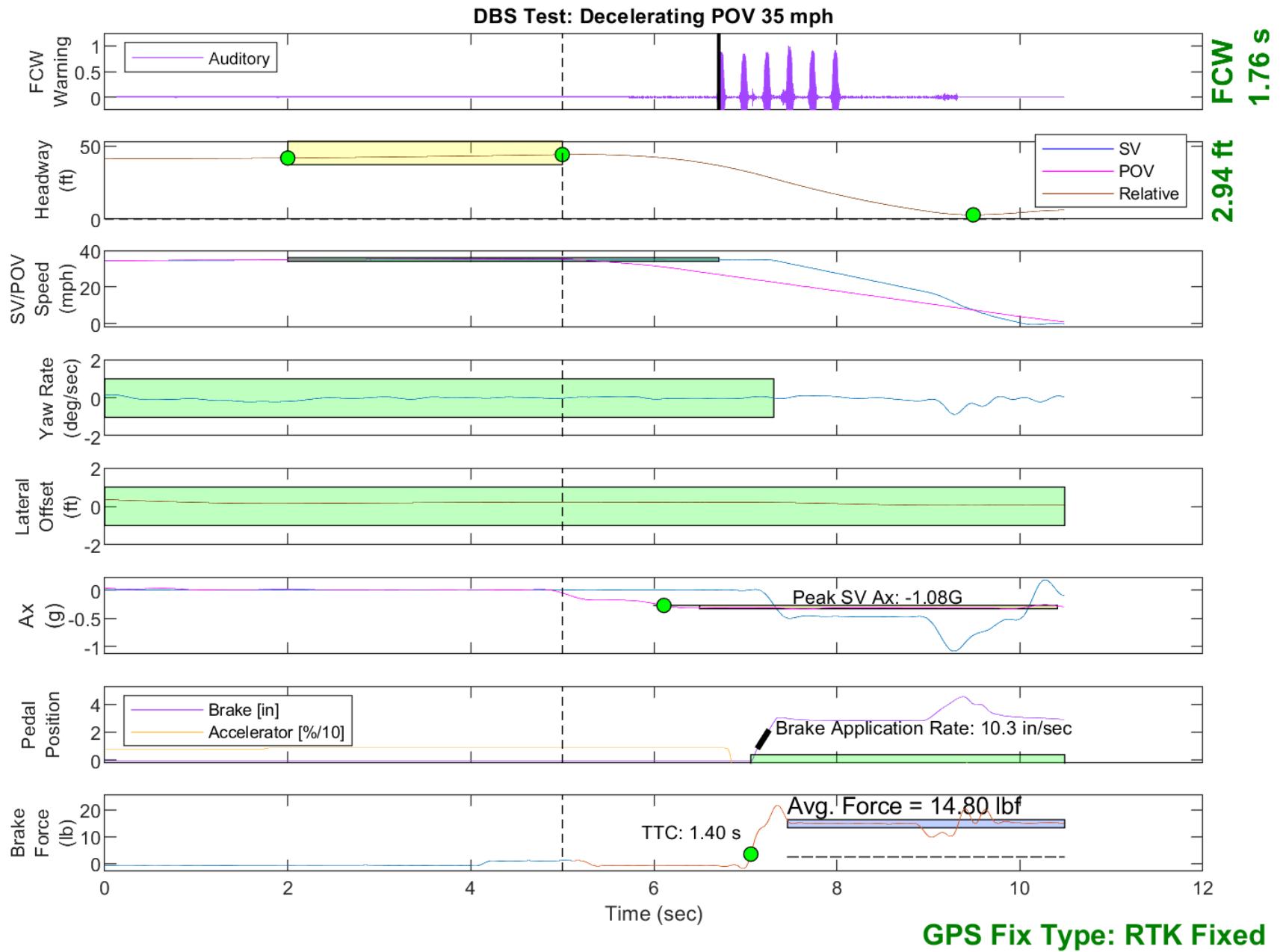
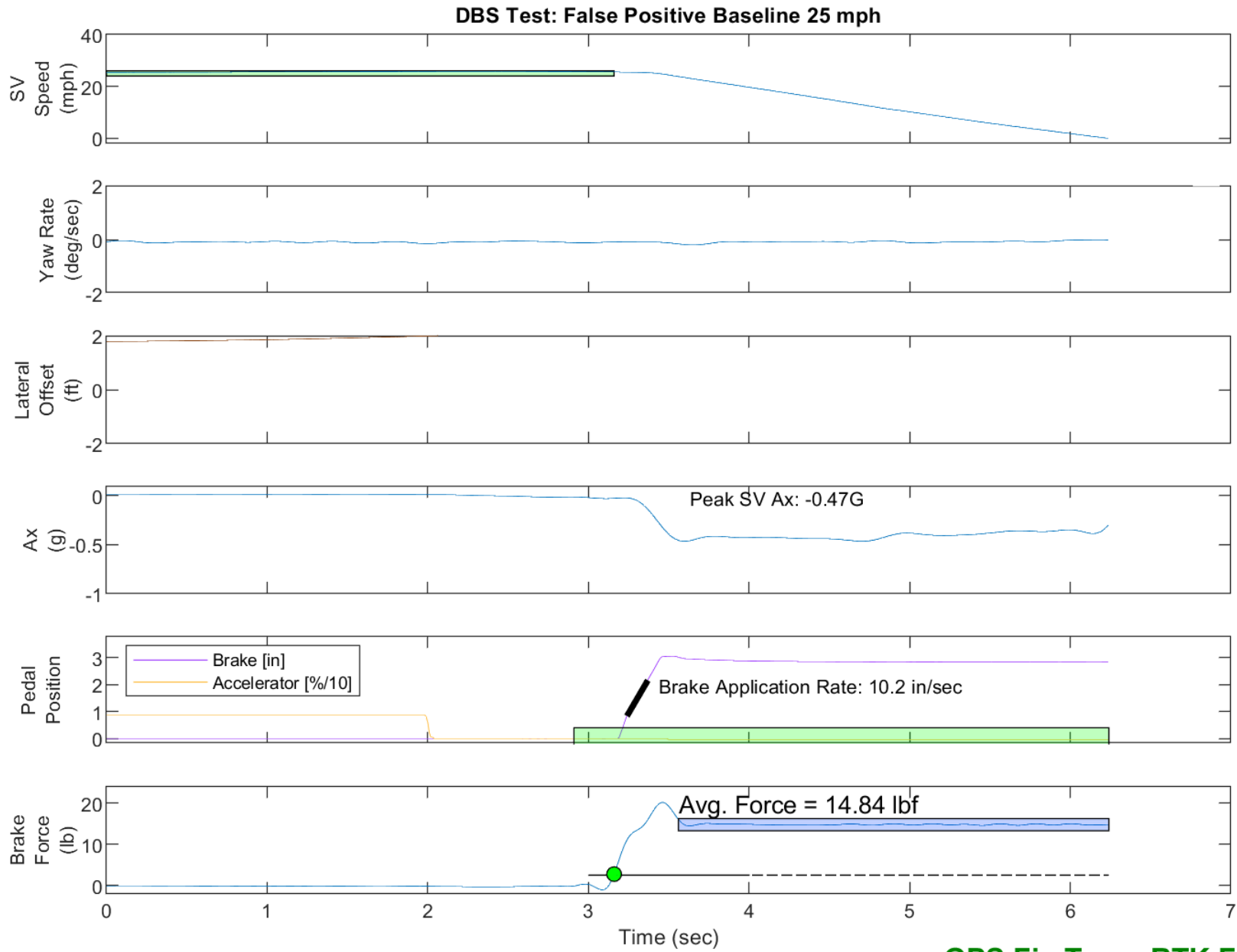


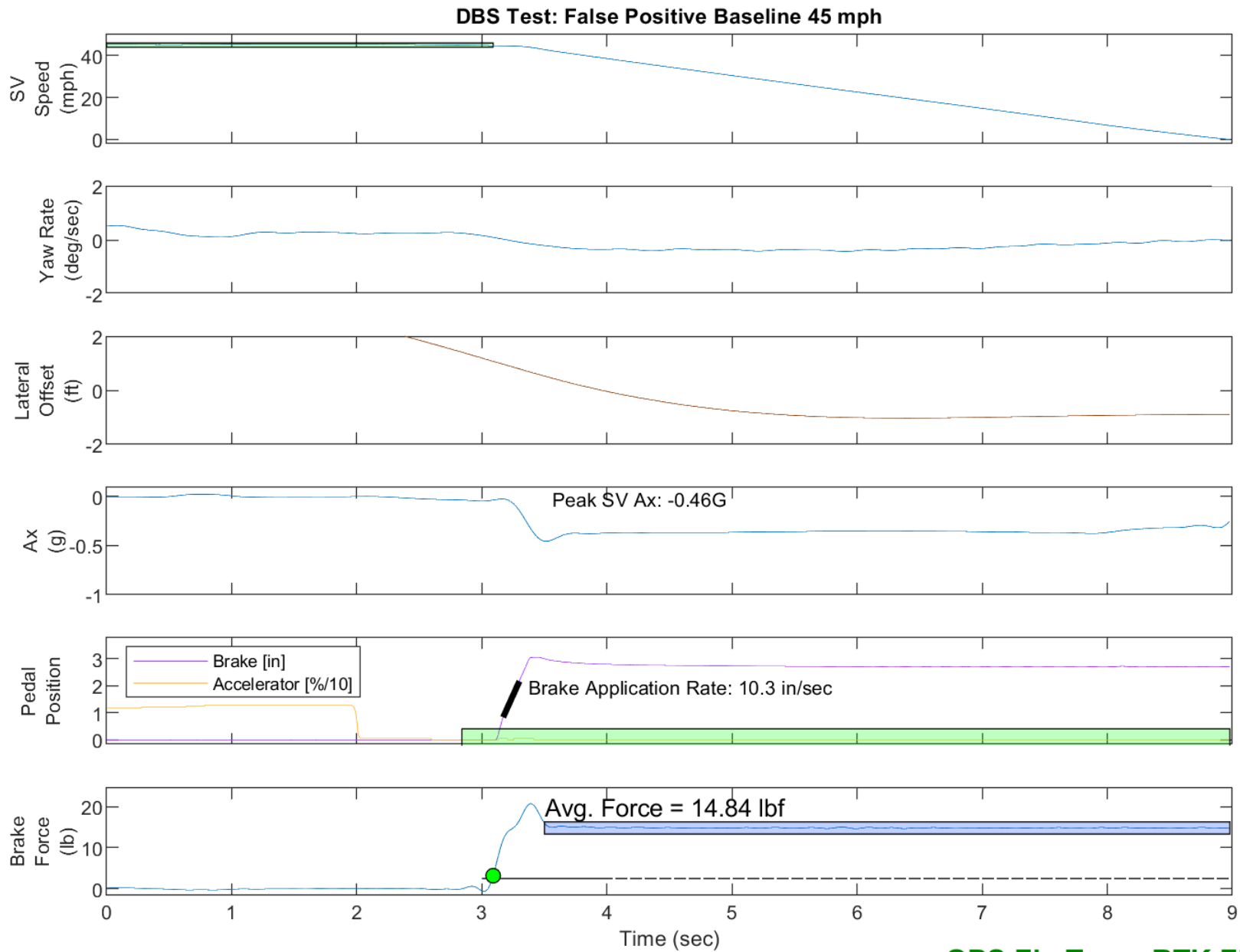
Figure E4. Example Time History for Decelerating POV 35, Passing



**GPS Fix Type: RTK Fixed**

Figure E5. Example Time History for False Positive Baseline 25





**GPS Fix Type: RTK Fixed**

Figure E6. Example Time History for False Positive Baseline 45

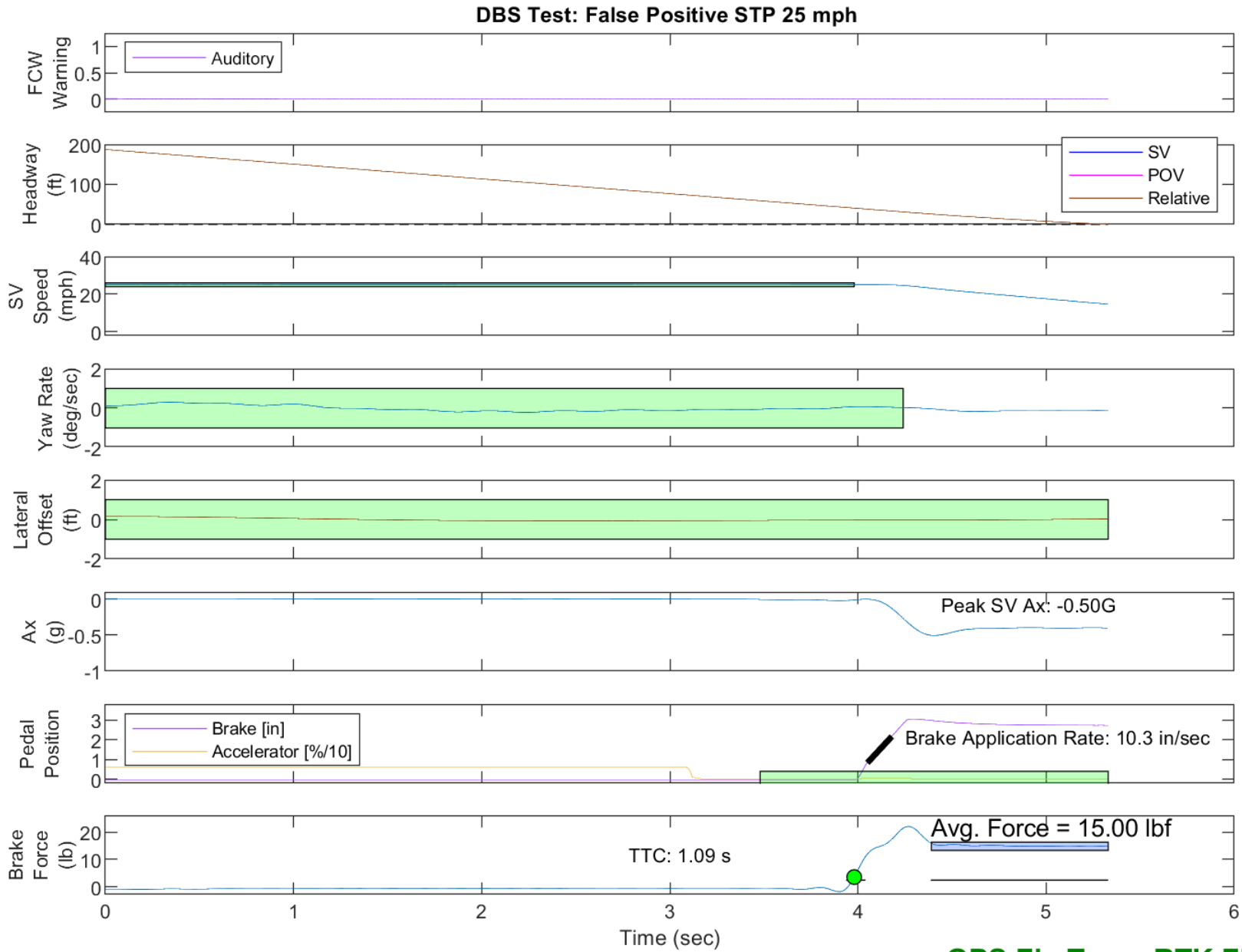
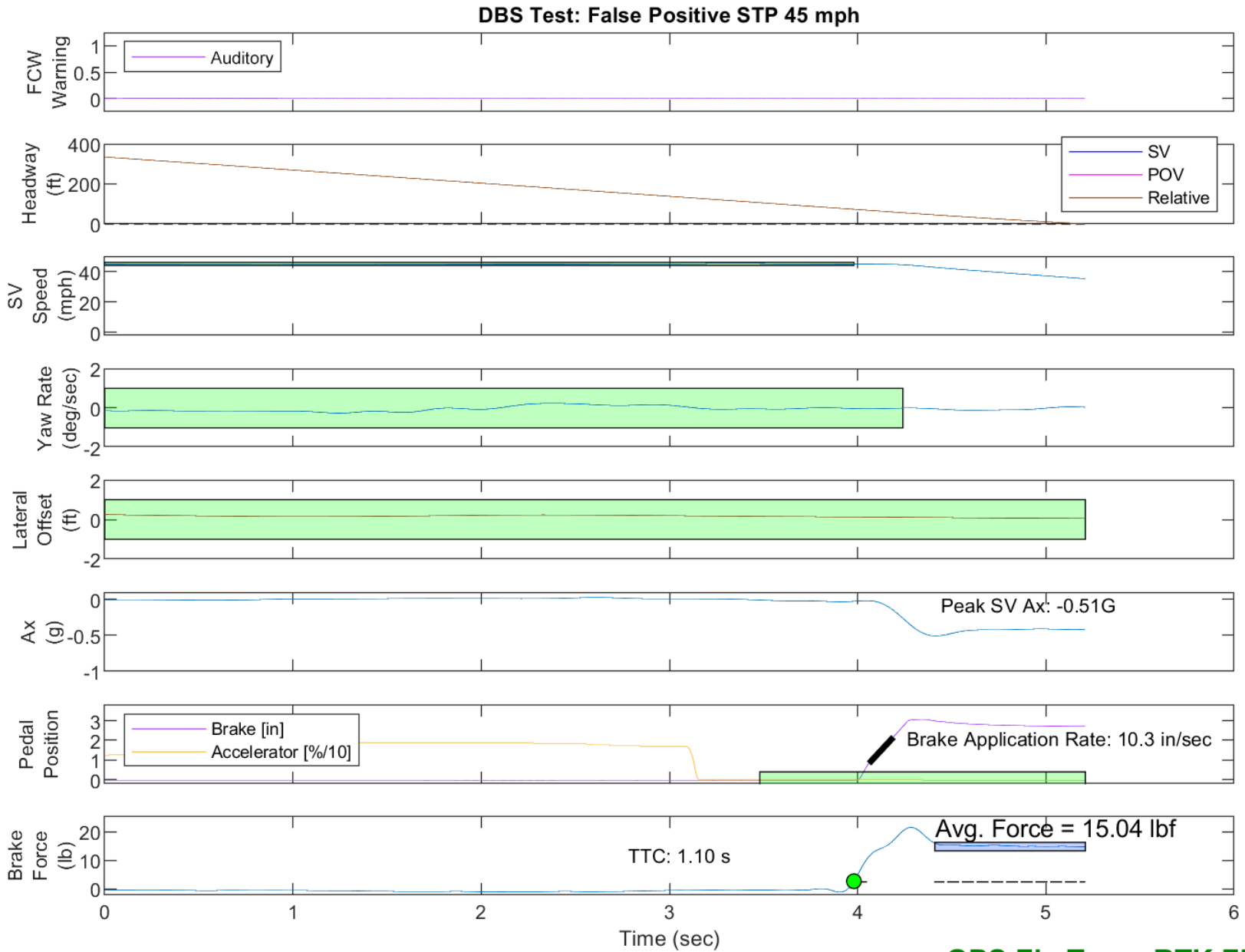


Figure E7. Example Time History for False Positive Steel Plate 25, Passing



GPS Fix Type: RTK Fixed

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

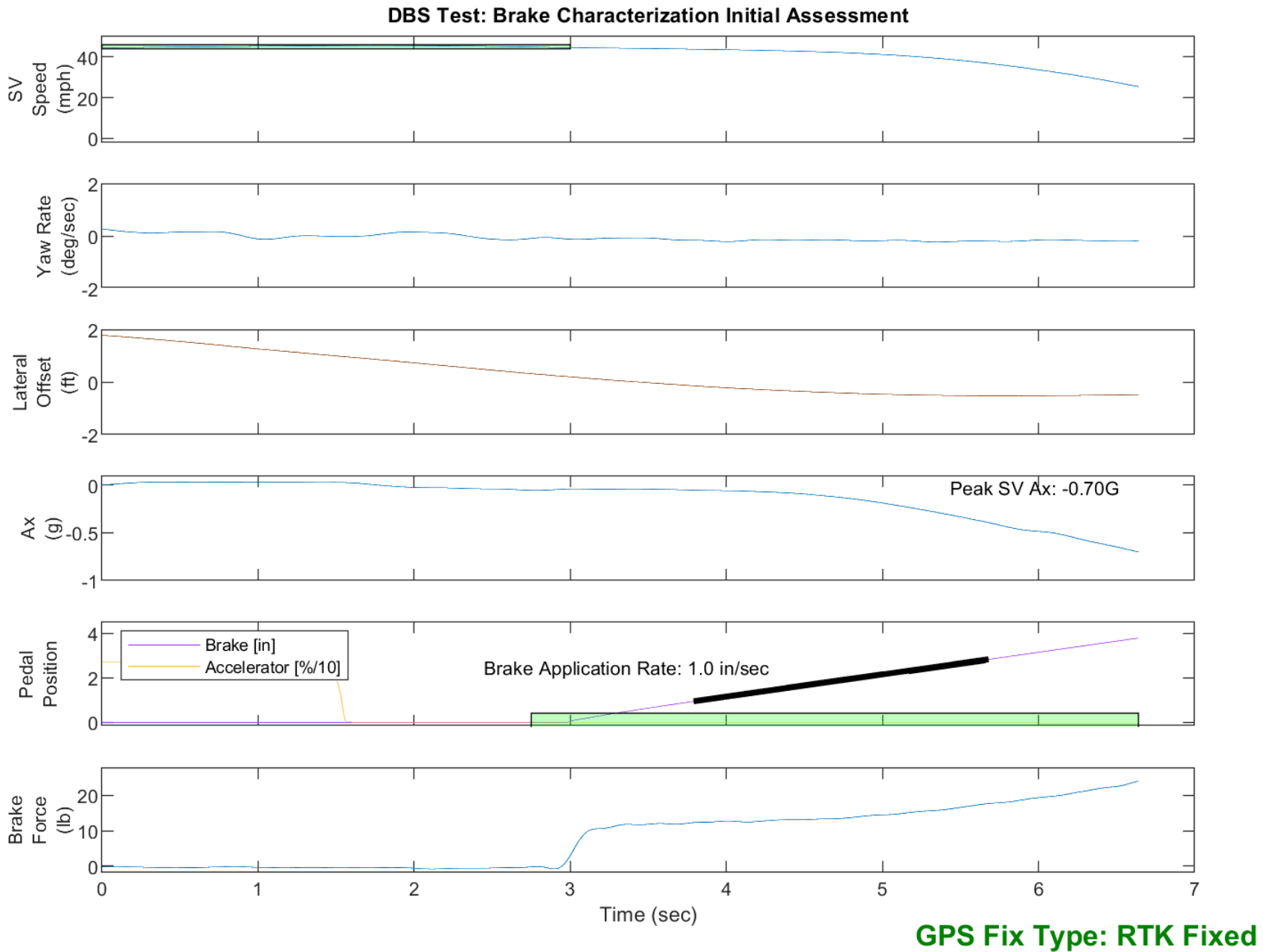


Figure E9. Example Time History for DBS Brake Characterization, Passing

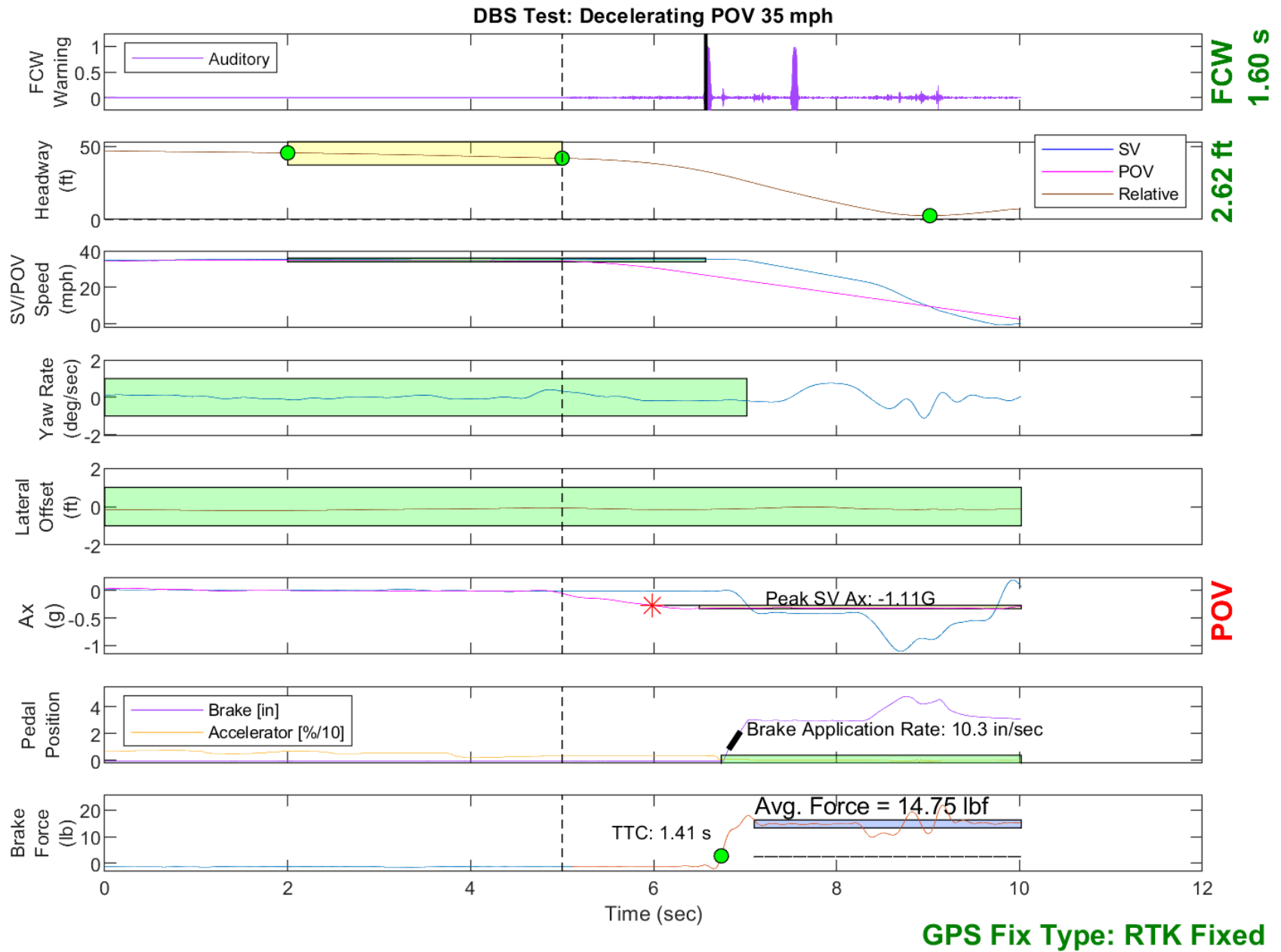
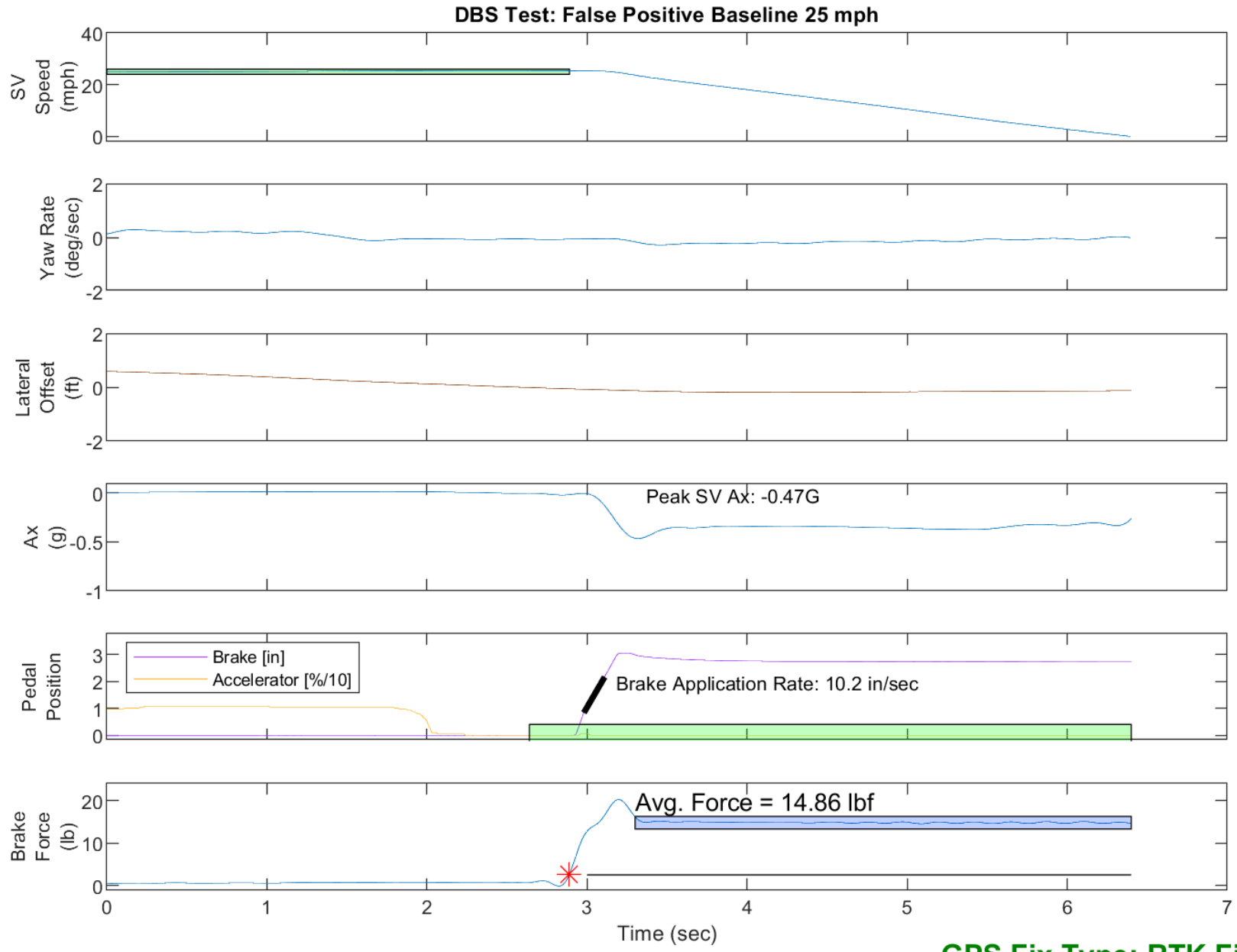


Figure E10. Example Time History Displaying Invalid POV Acceleration Criteria



**GPS Fix Type: RTK Fixed**

Figure E11. Example Time History Displaying Invalid Brake Force Criteria

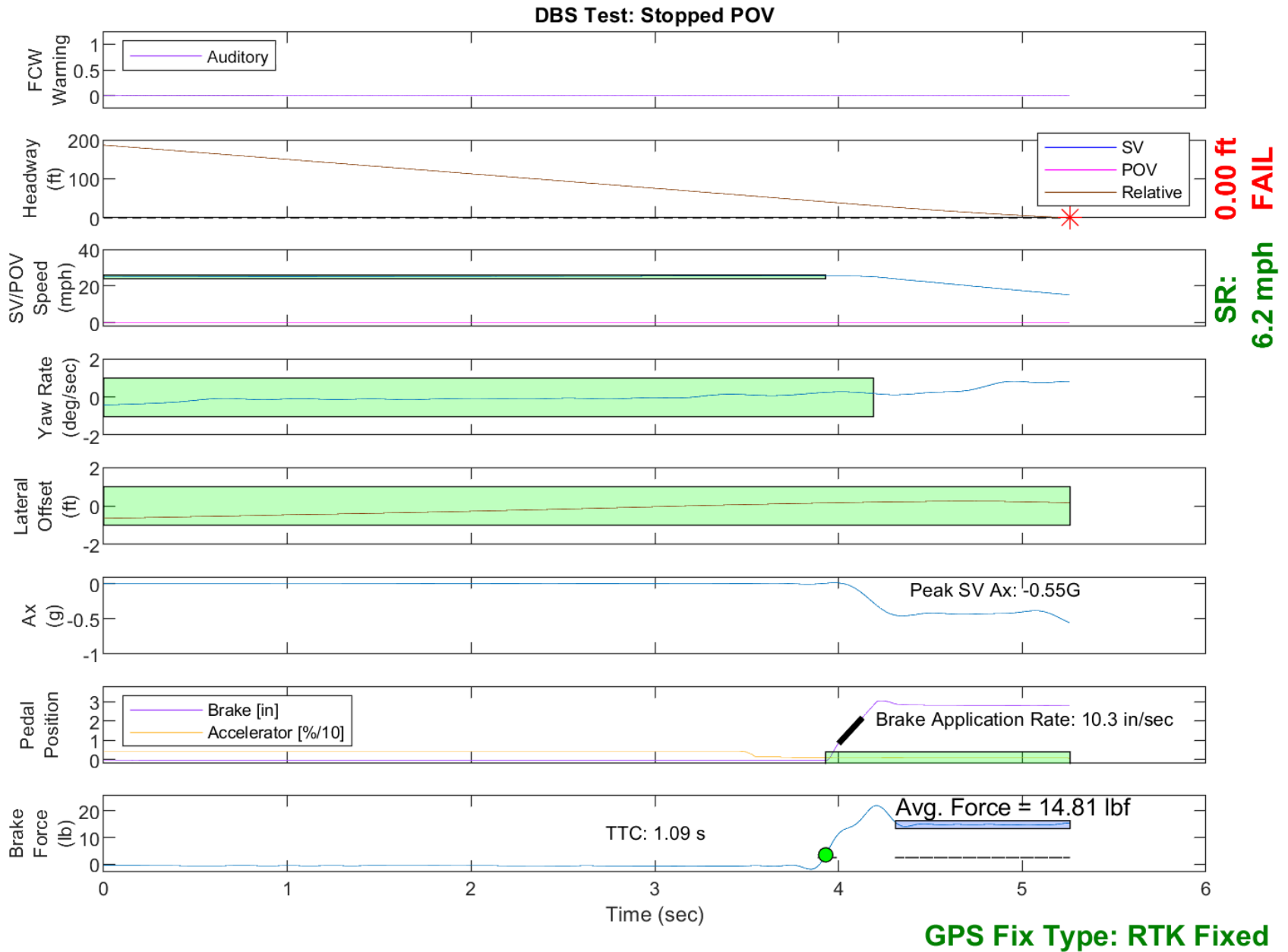


Figure E12. Example Time History for a Failed Run

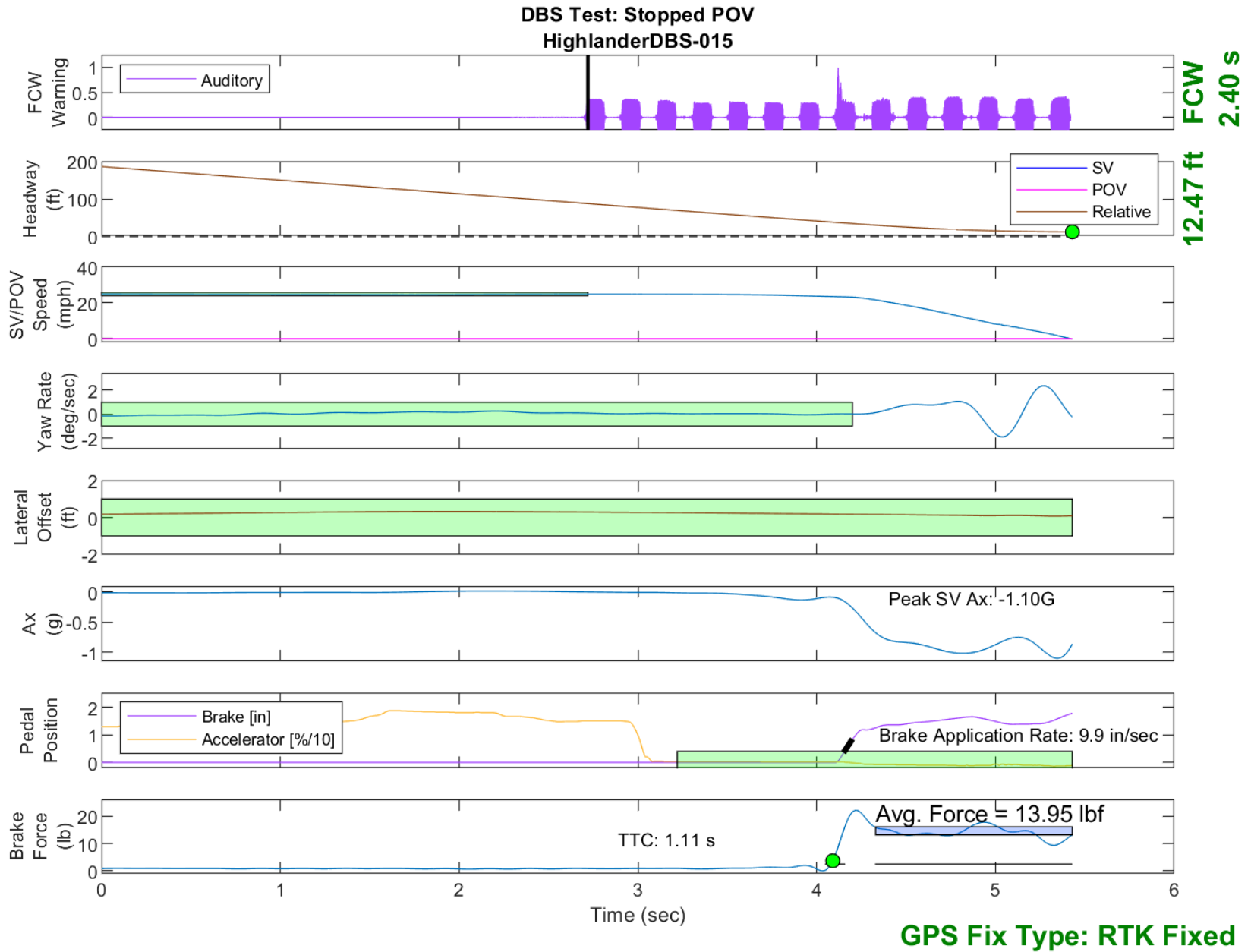


Figure E13. Time History for DBS Run 15, SV Encounters Stopped POV

**GPS Fix Type: RTK Fixed**



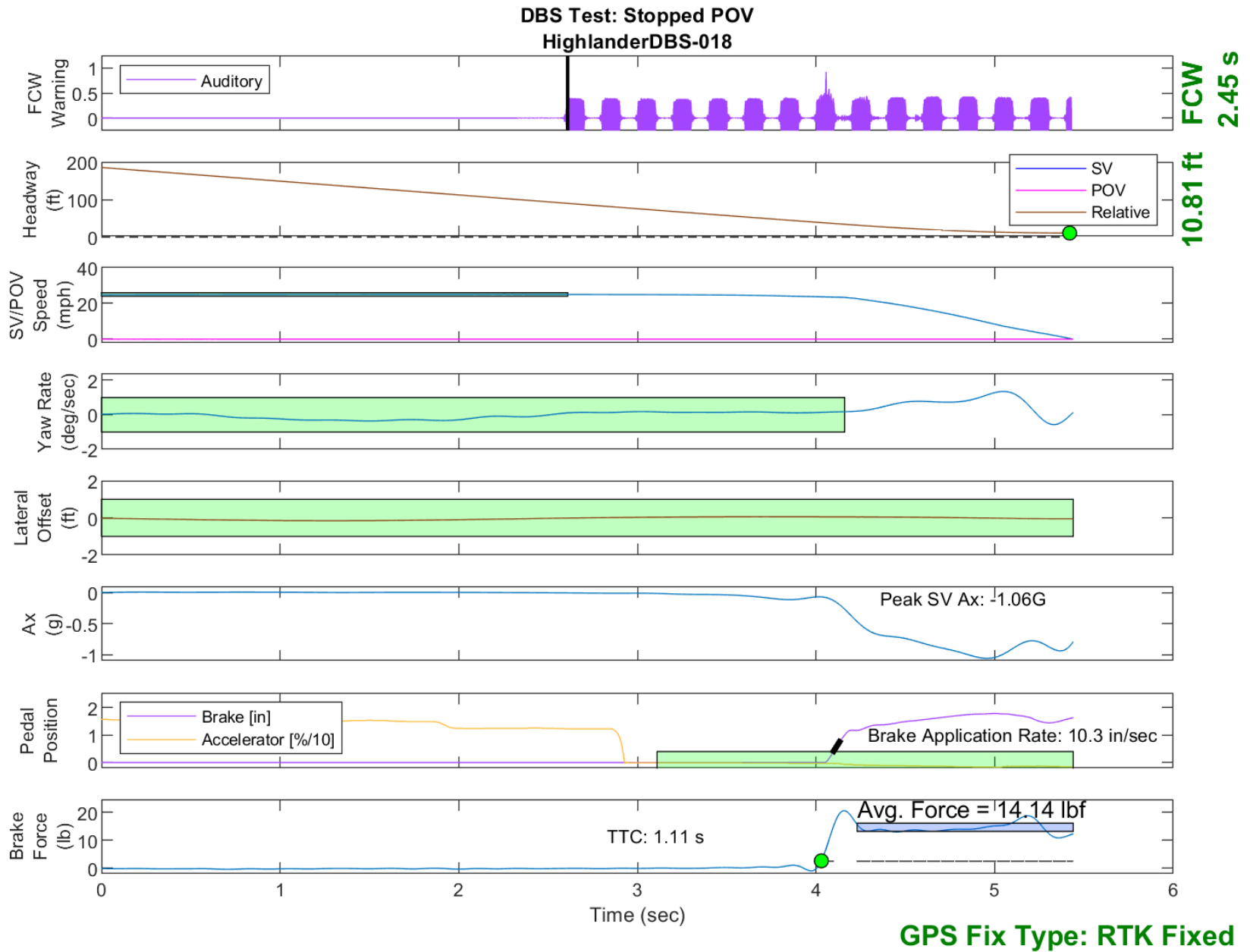


Figure E14. Time History for DBS Run 18, SV Encounters Stopped POV

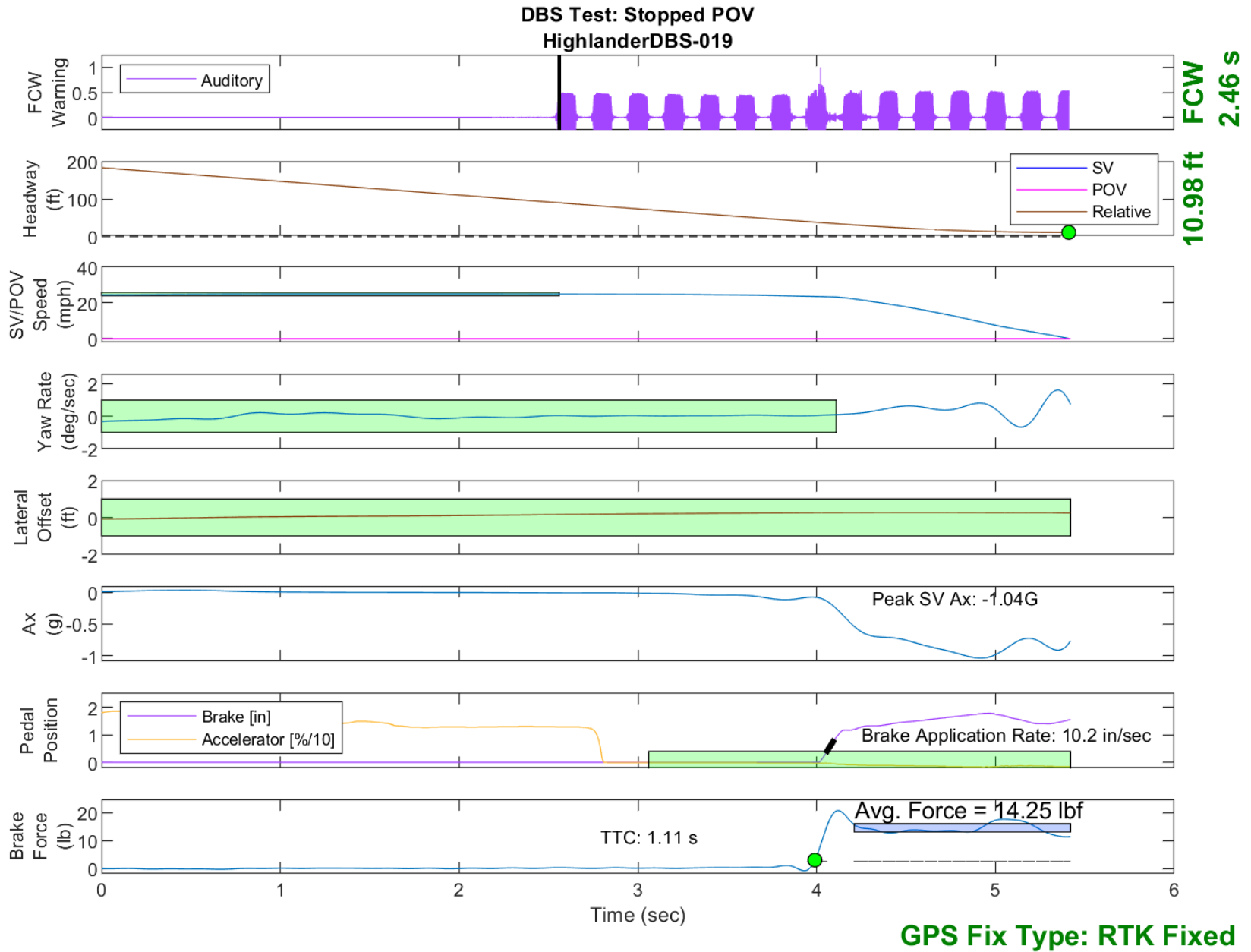


Figure E15. Time History for DBS Run 19, SV Encounters Stopped POV

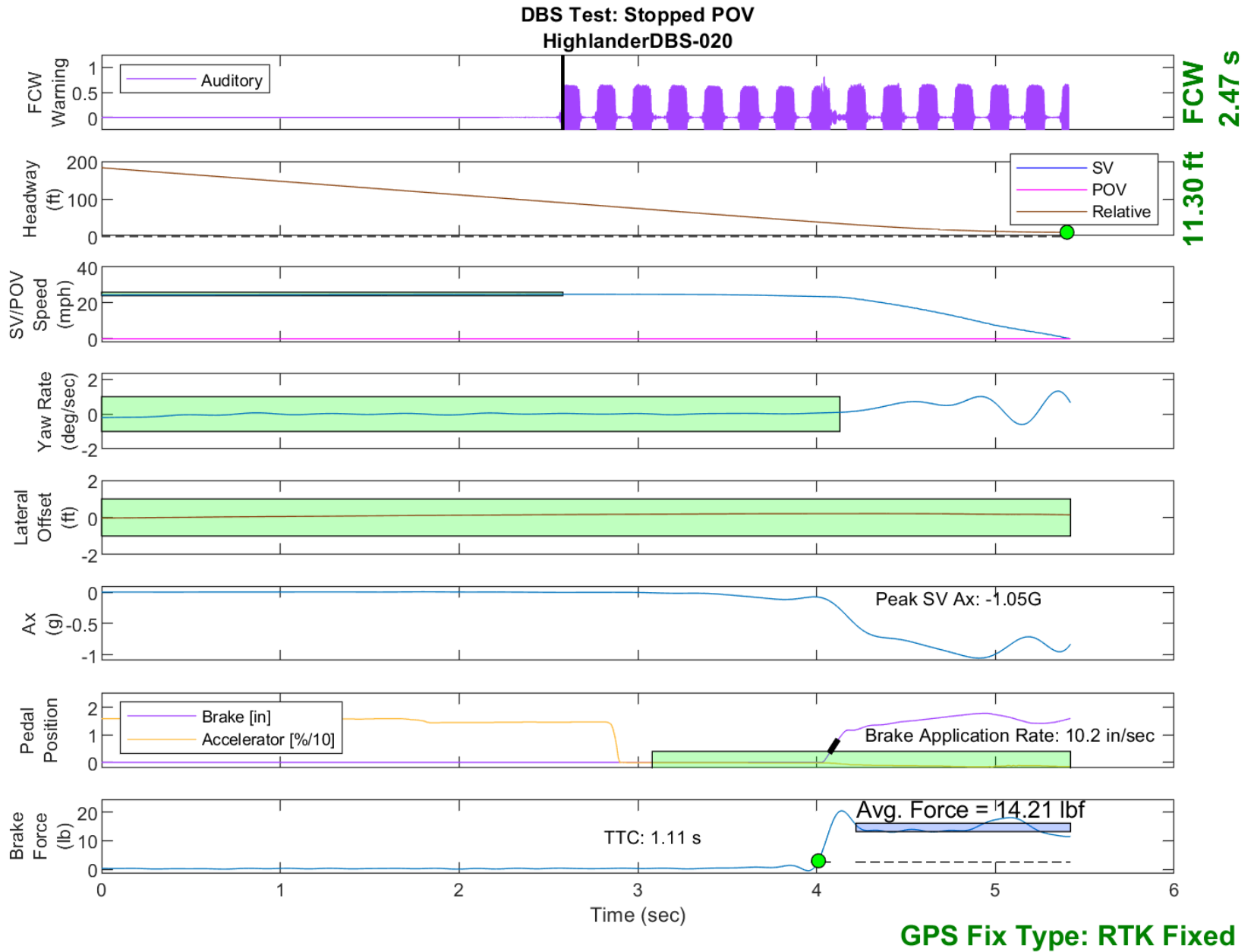


Figure E16. Time History for DBS Run 20, SV Encounters Stopped POV

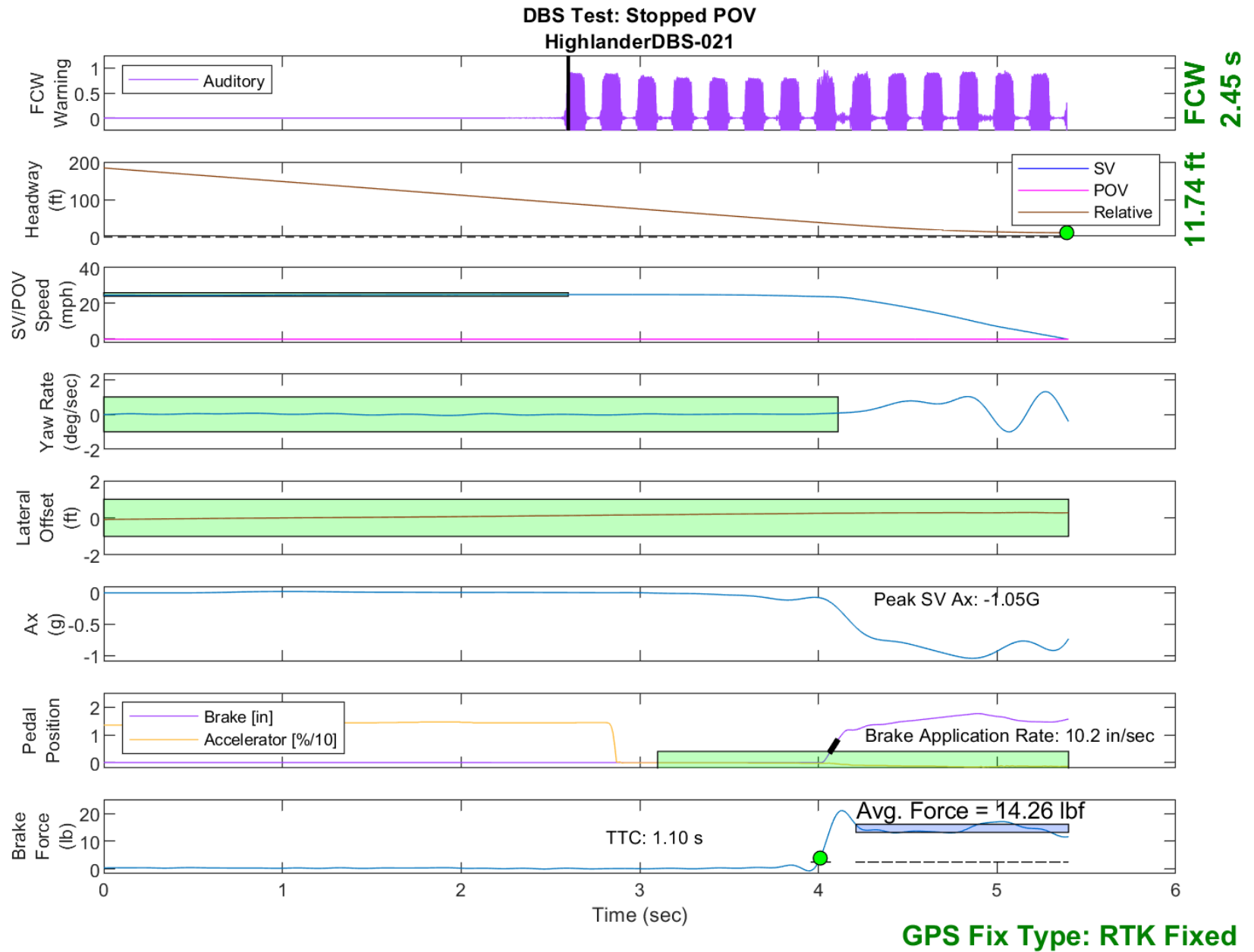


Figure E17. Time History for DBS Run 21, SV Encounters Stopped POV

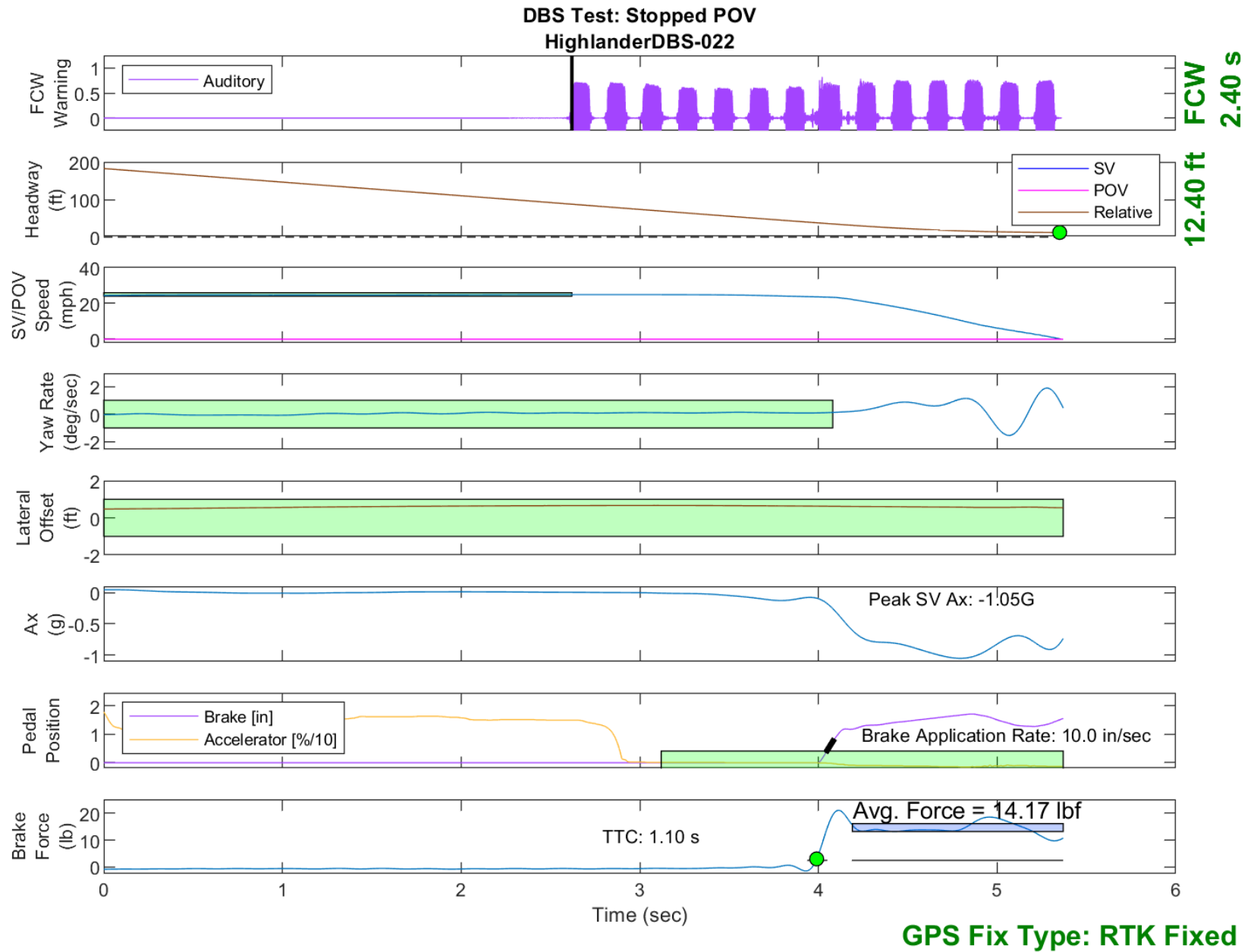


Figure E18. Time History for DBS Run 22, SV Encounters Stopped POV

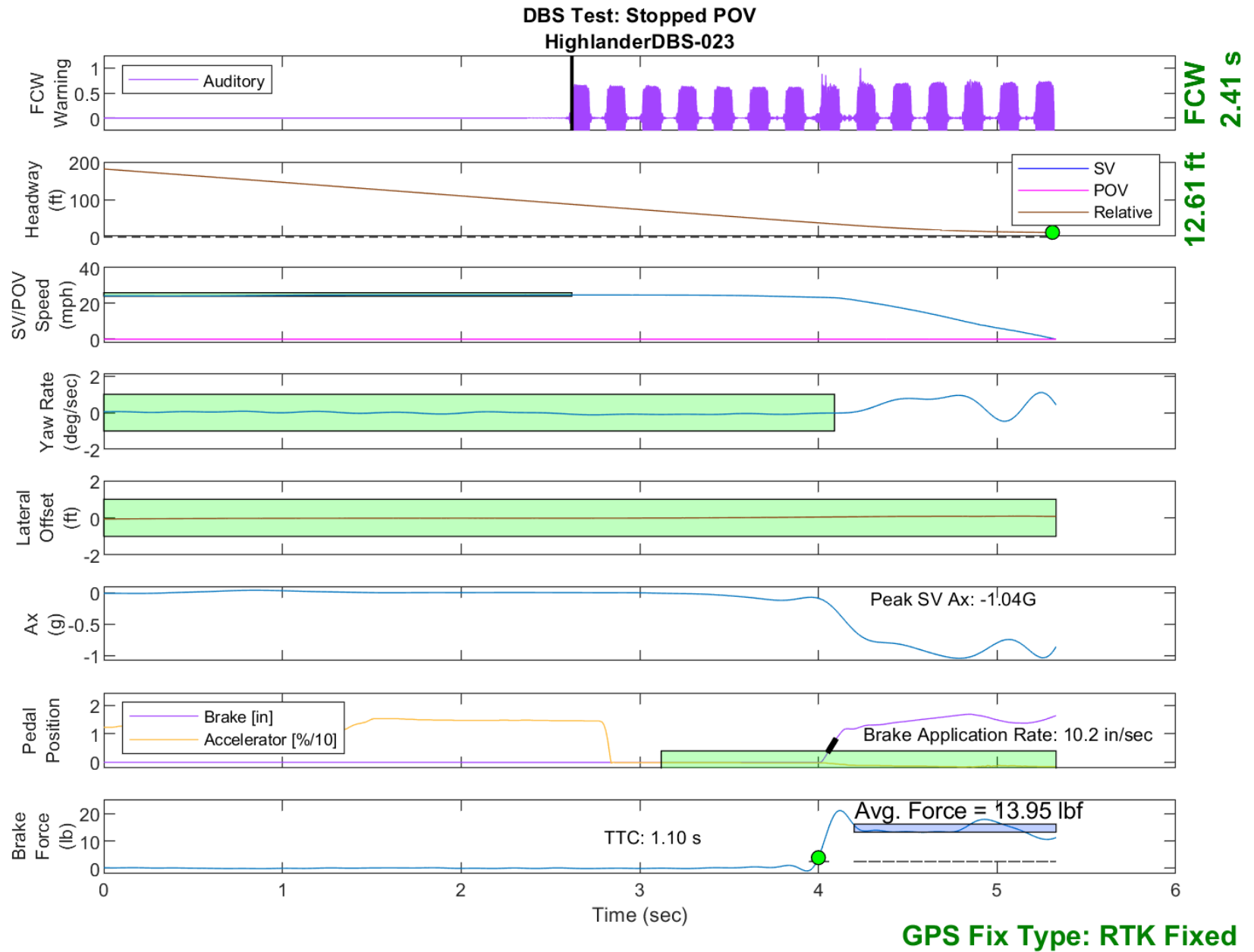


Figure E19. Time History for DBS Run 23, SV Encounters Stopped POV

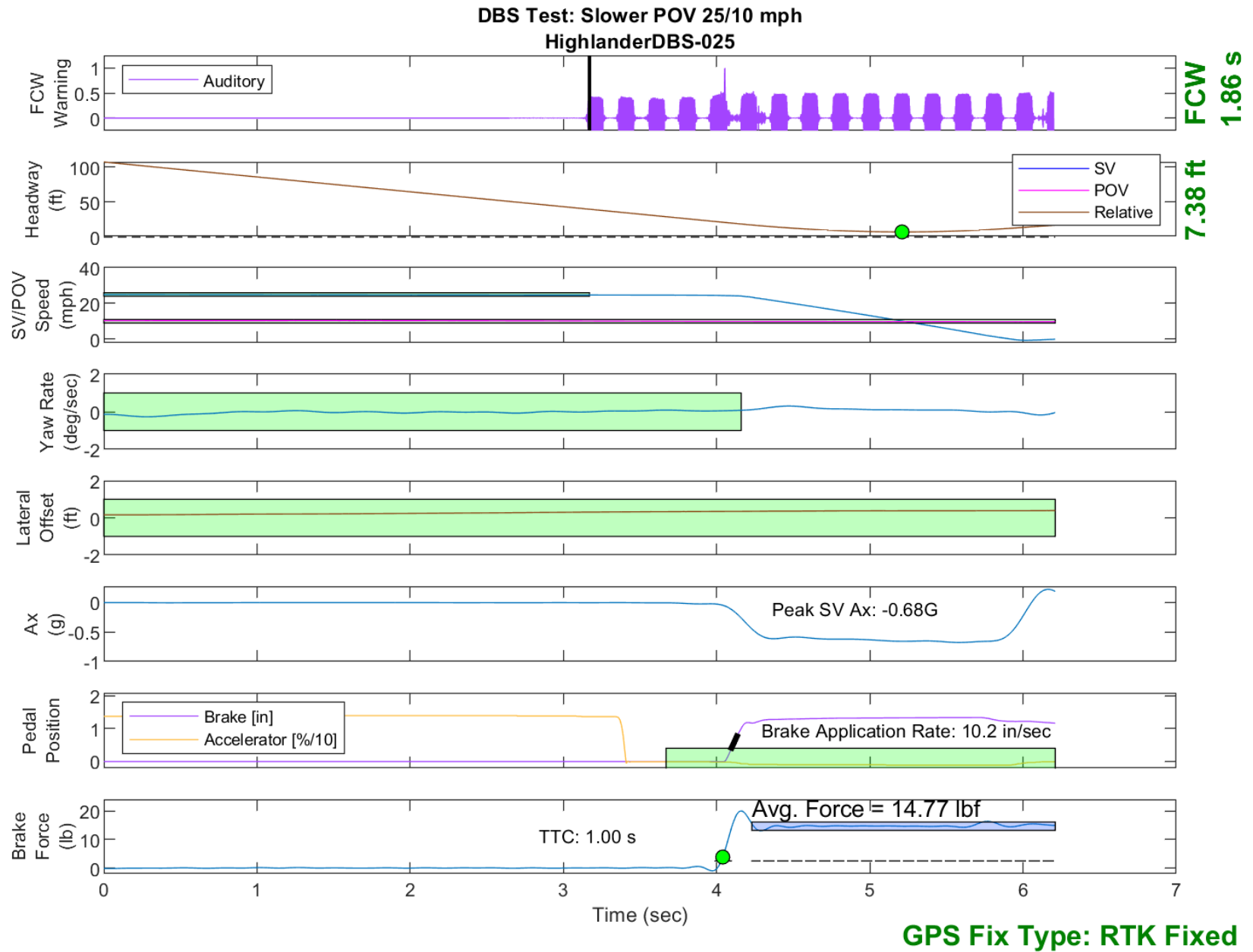


Figure E20. Time History for DBS Run 25, SV Encounters Slower POV, SV 25 mph, POV 10 mph

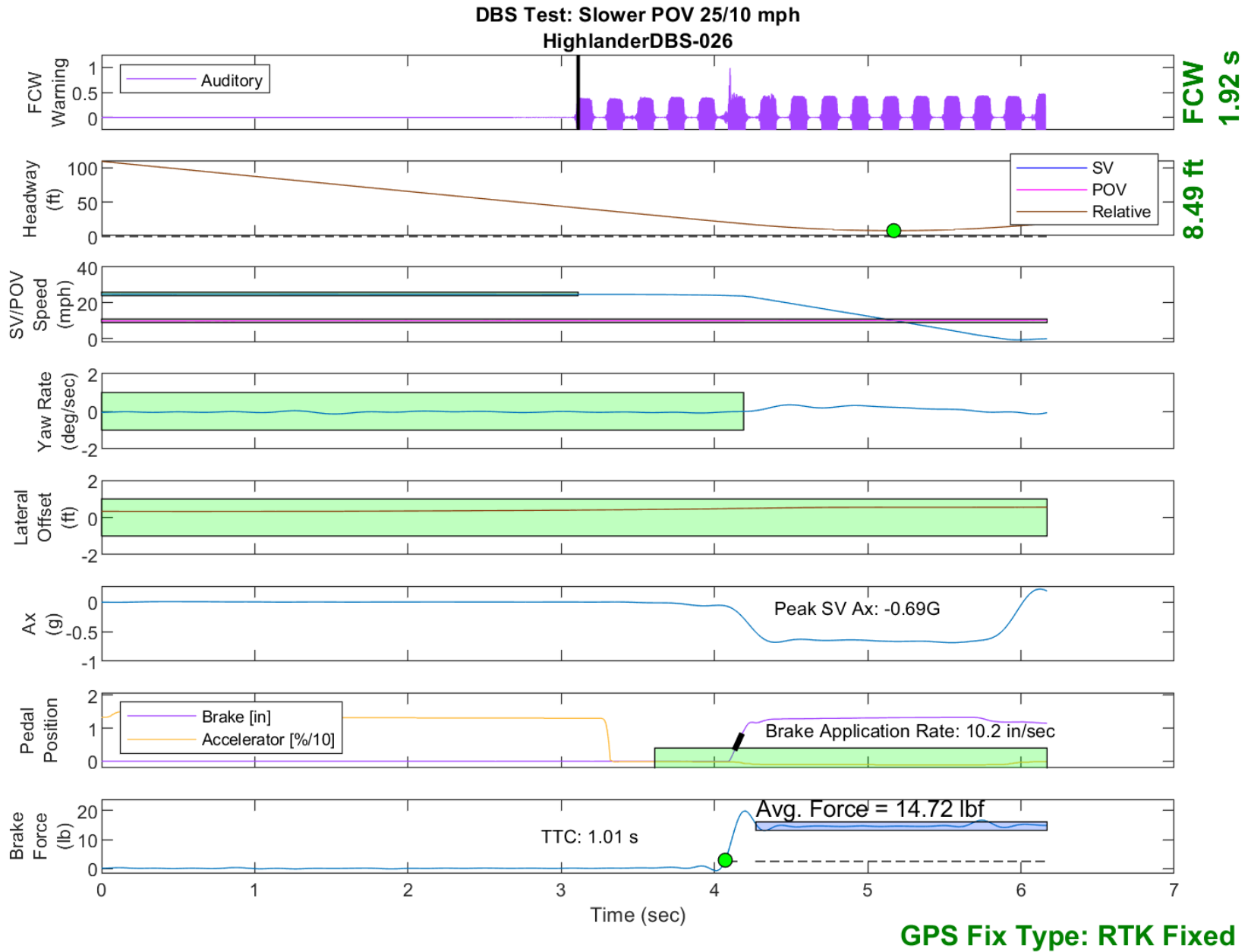


Figure E21. Time History for DBS Run 26, SV Encounters Slower POV, SV 25 mph, POV 10 mph



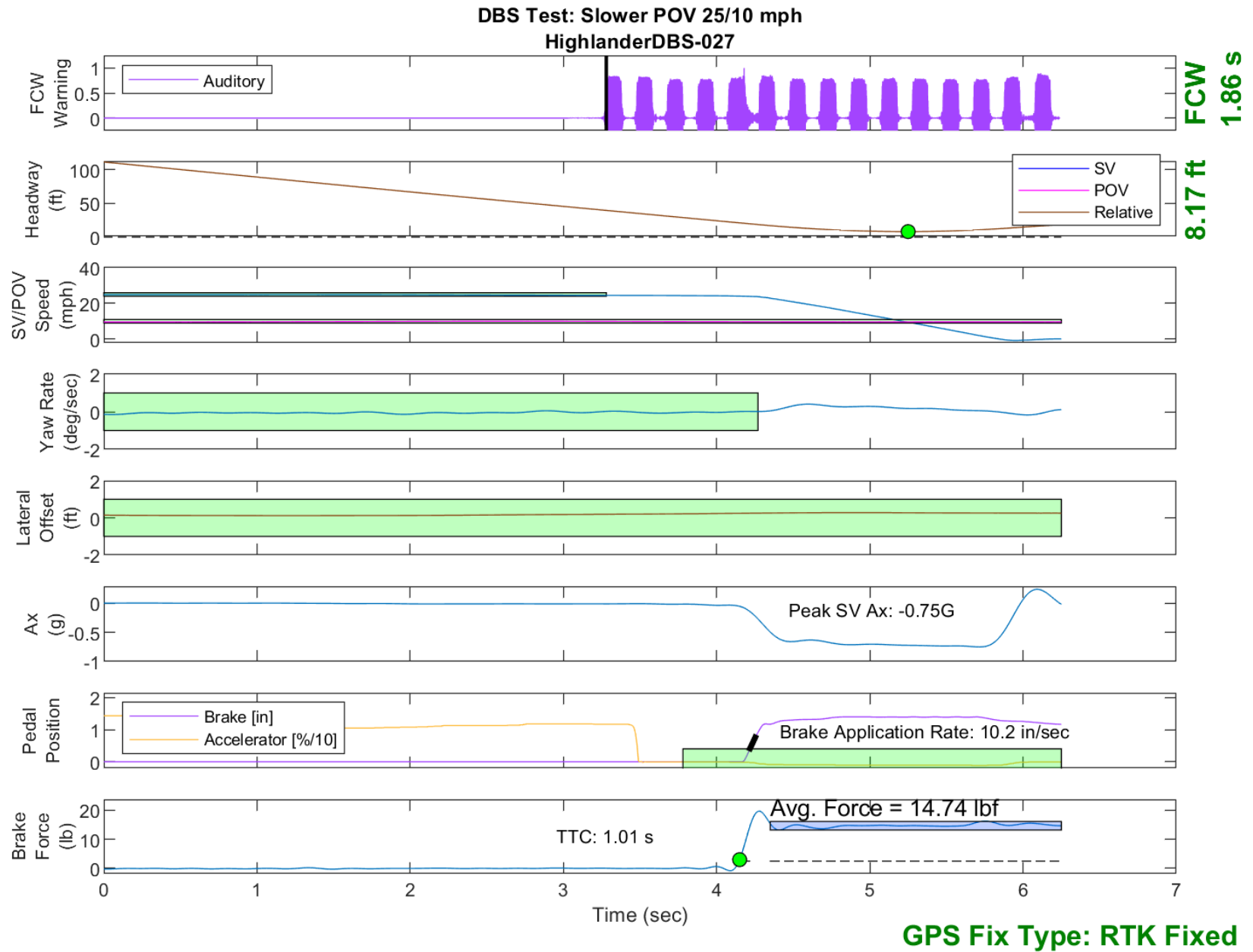


Figure E22. Time History for DBS Run 27, SV Encounters Slower POV, SV 25 mph, POV 10 mph

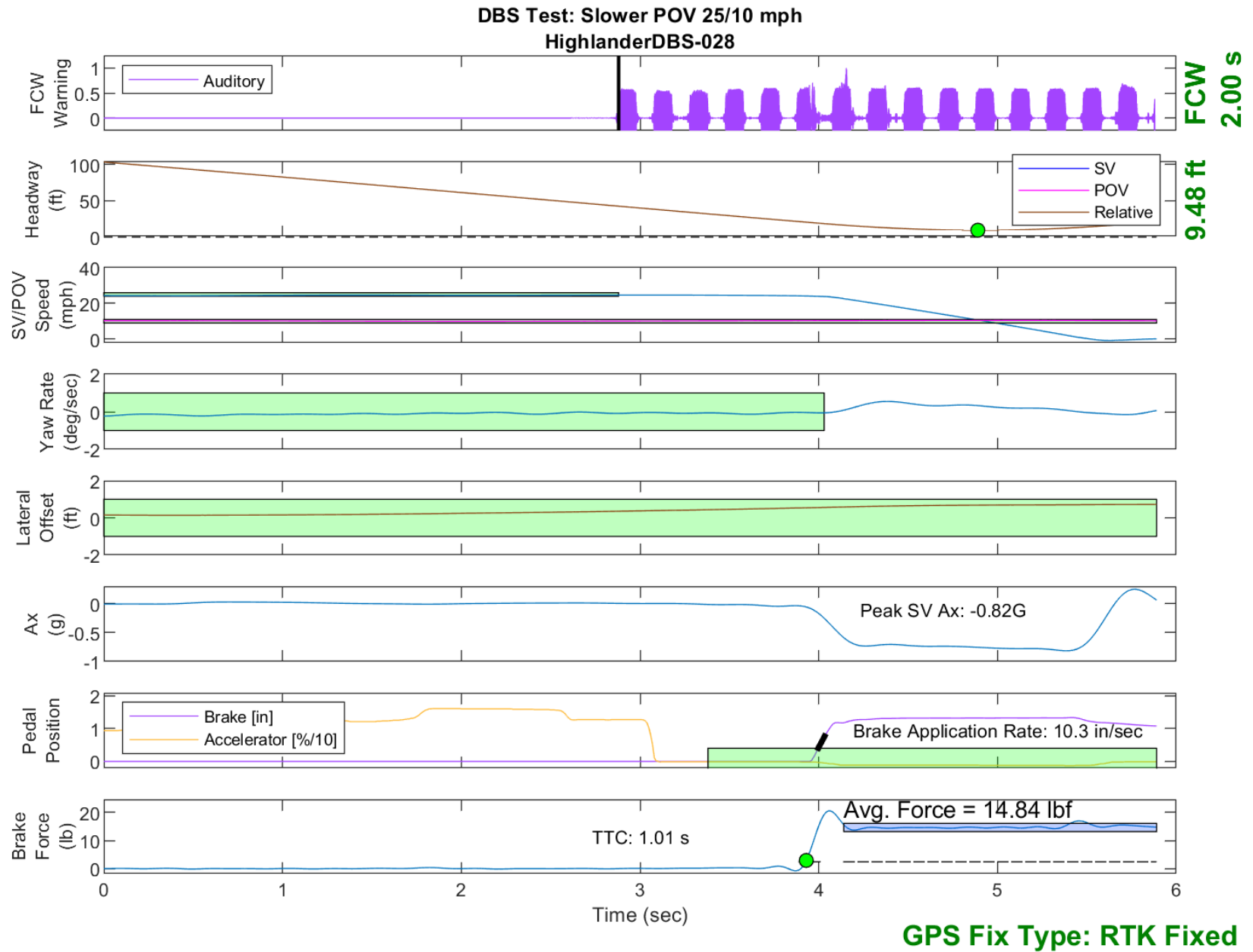


Figure E23. Time History for DBS Run 28, SV Encounters Slower POV, SV 25 mph, POV 10 mph

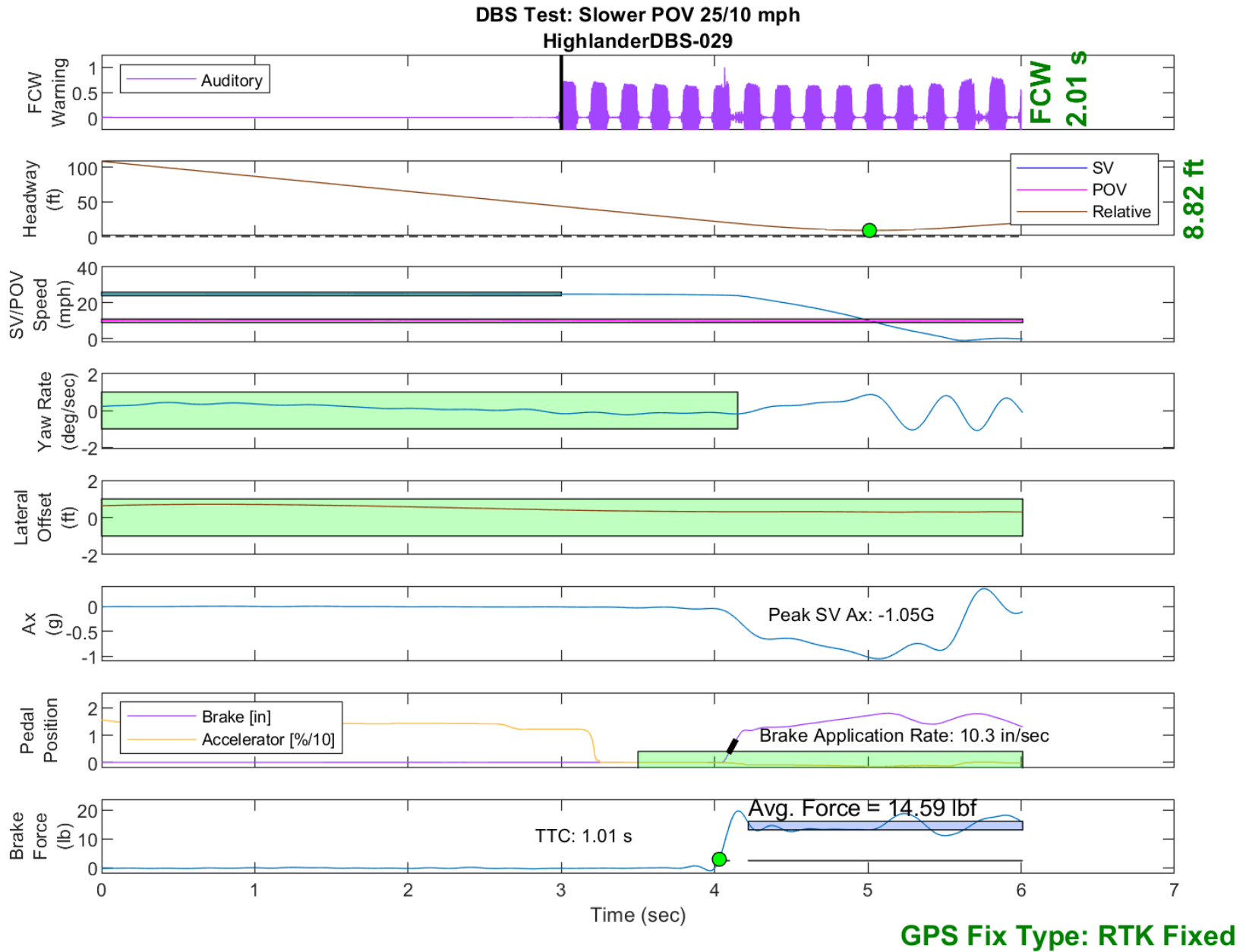


Figure E24. Time History for DBS Run 29, SV Encounters Slower POV, SV 25 mph, POV 10 mph

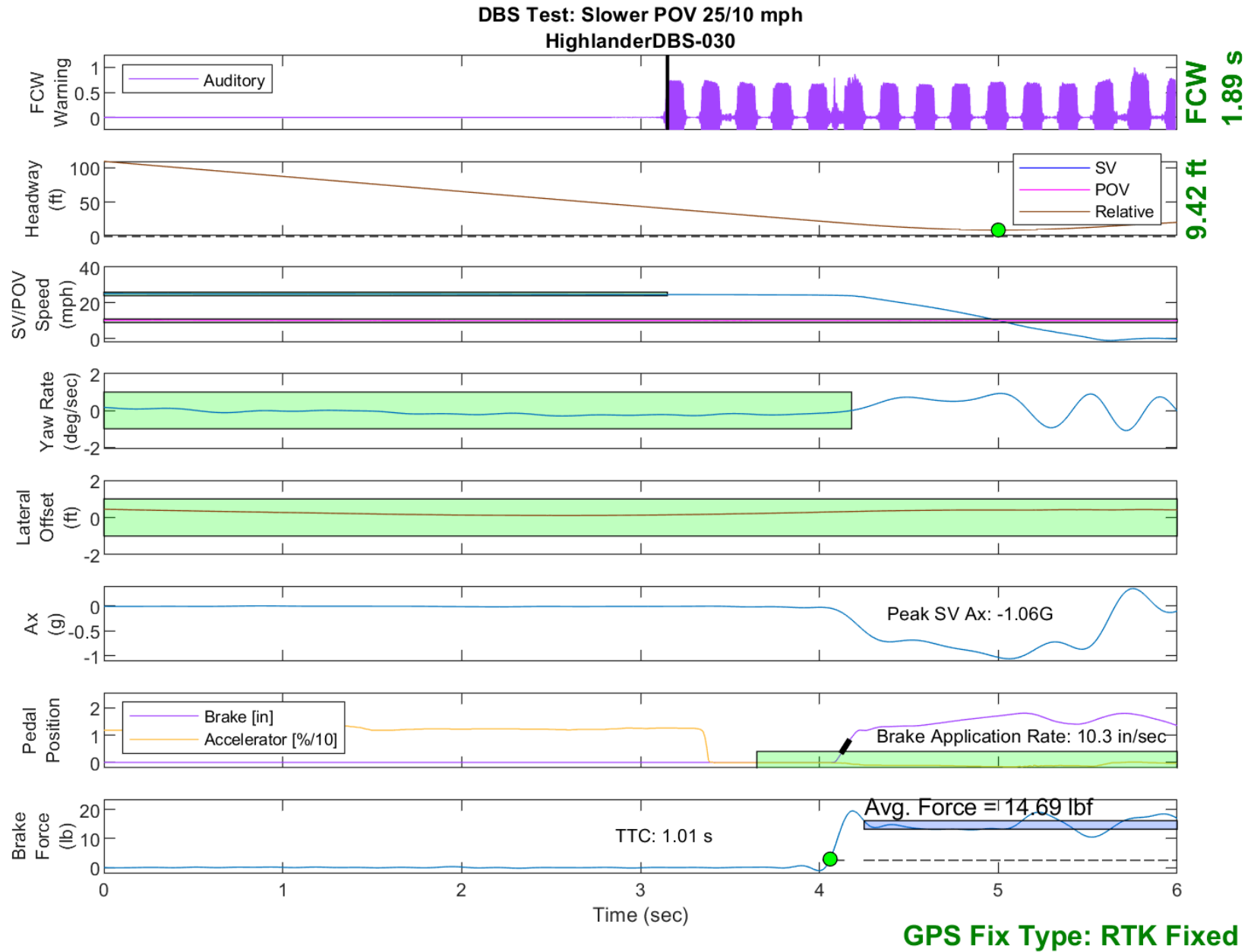


Figure E25. Time History for DBS Run 30, SV Encounters Slower POV, SV 25 mph, POV 10 mph

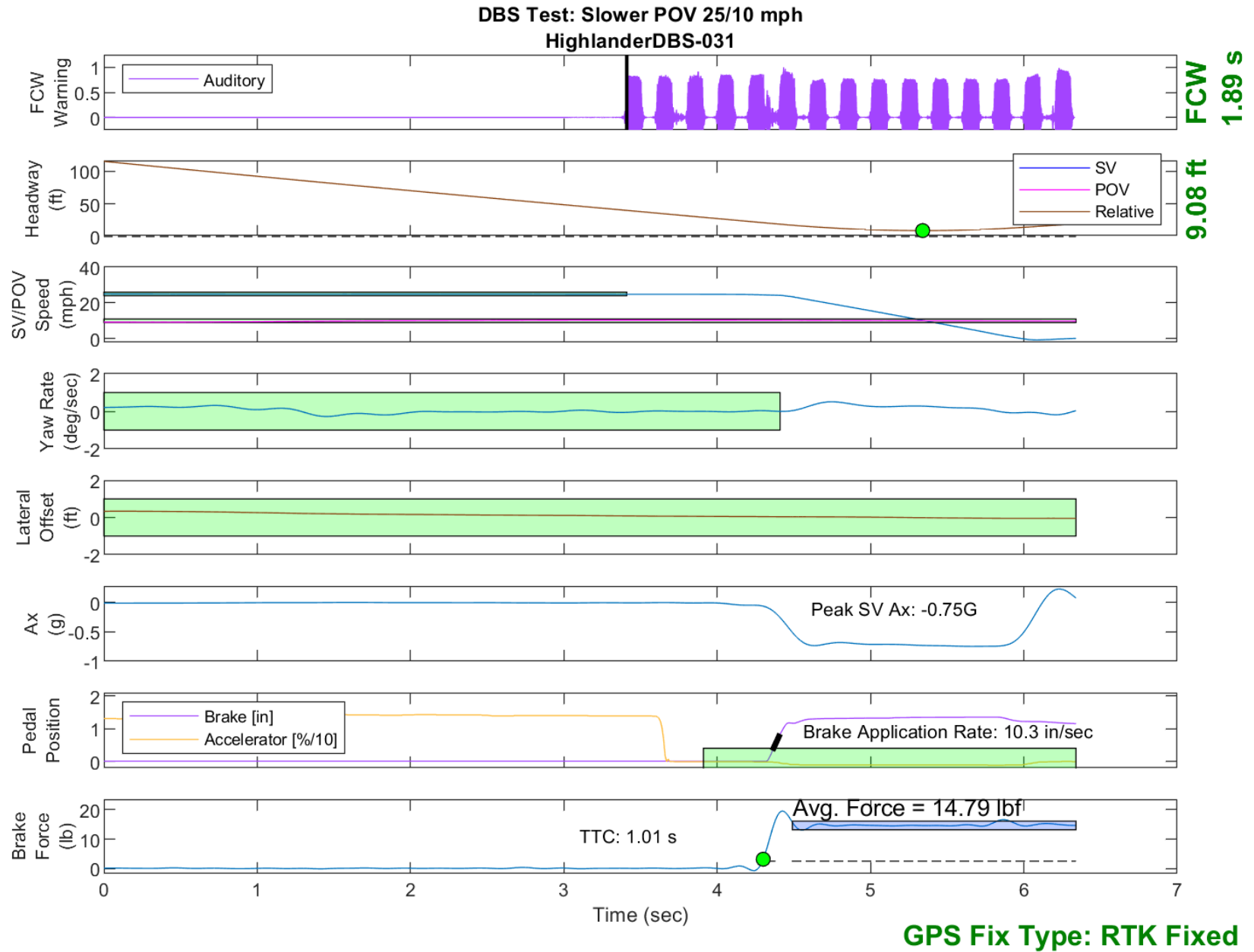


Figure E26. Time History for DBS Run 31, SV Encounters Slower POV, SV 25 mph, POV 10 mph

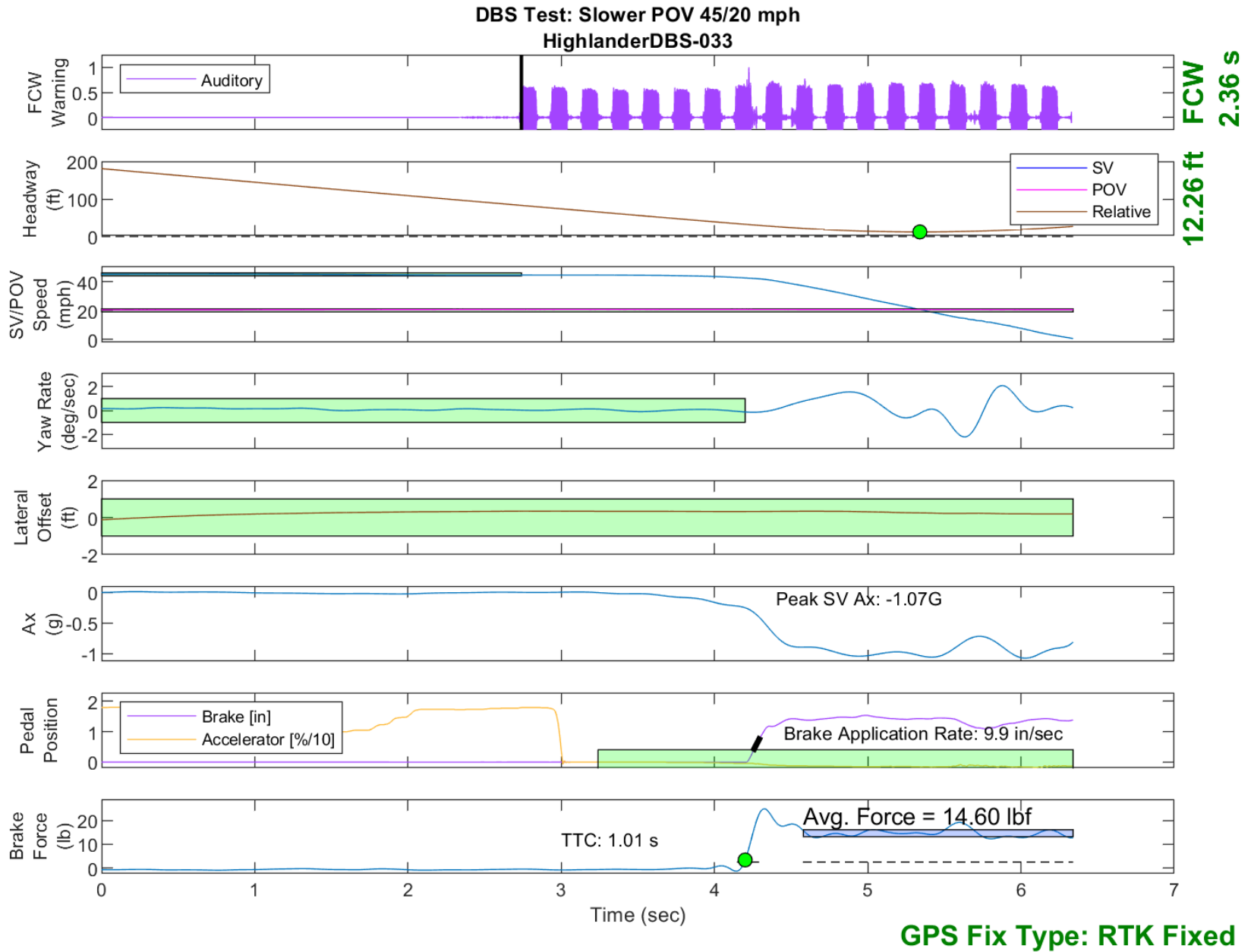


Figure E27. Time History for DBS Run 33, SV Encounters Slower POV, SV 45 mph, POV 20 mph

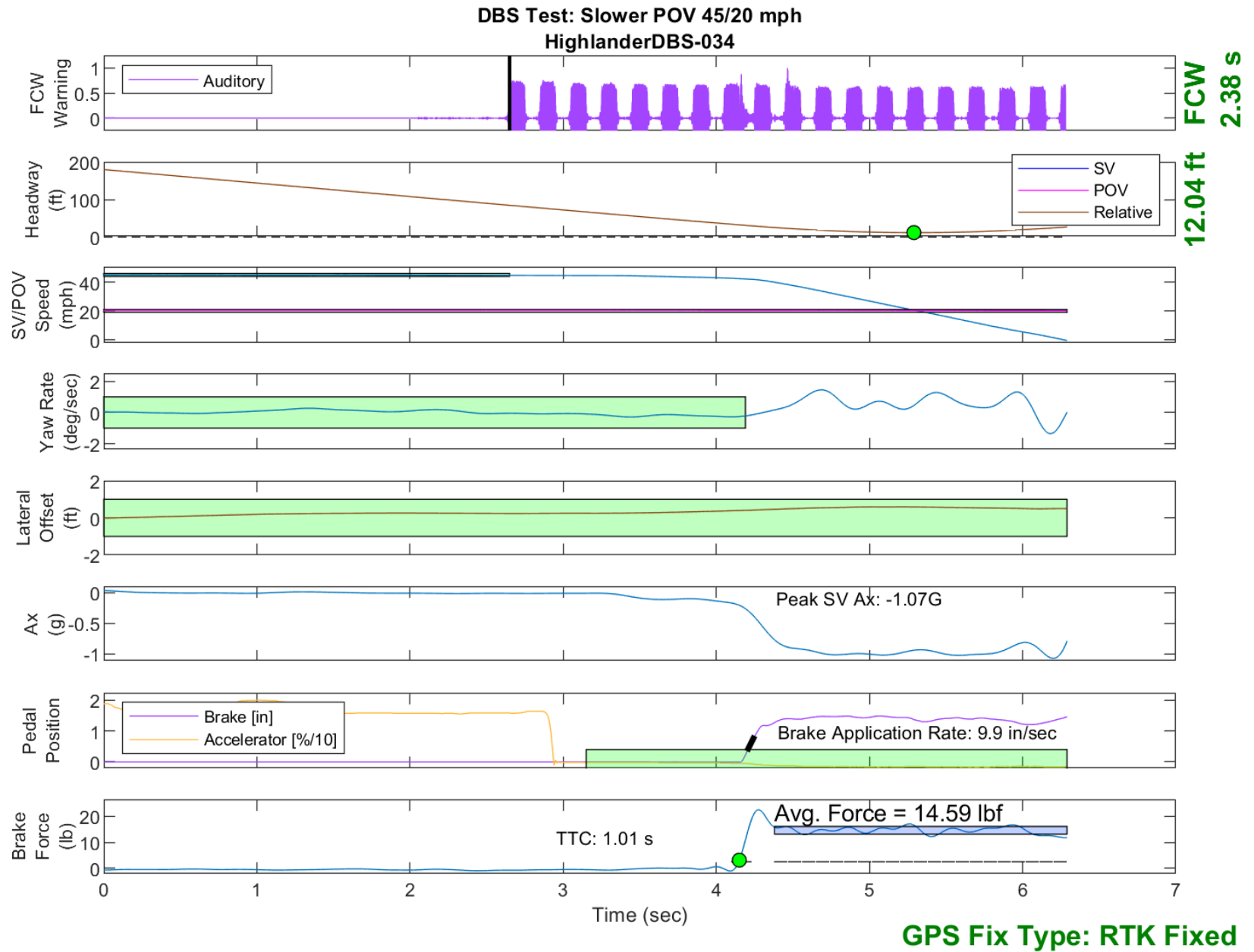


Figure E28. Time History for DBS Run 34, SV Encounters Slower POV, SV 45 mph, POV 20 mph

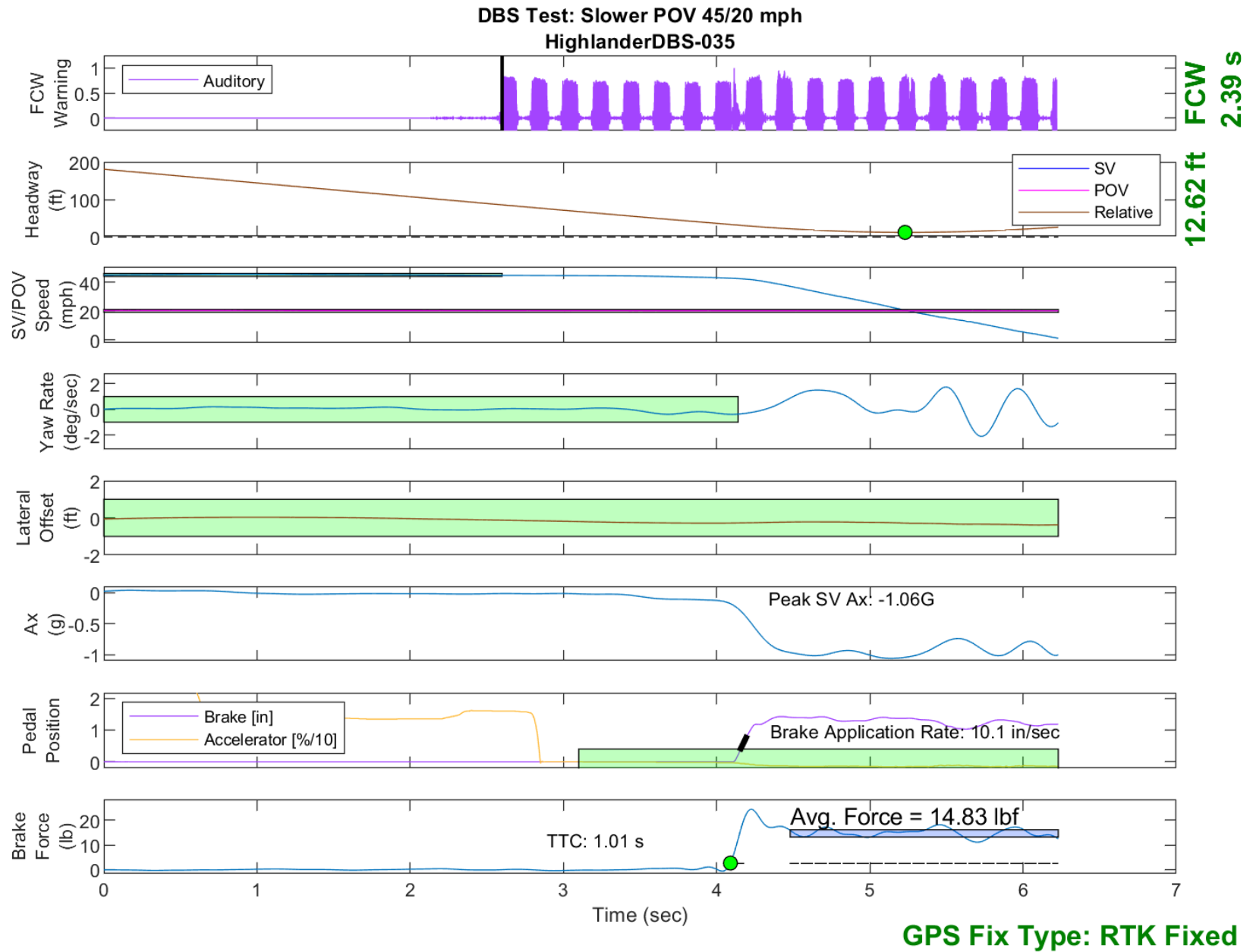


Figure E29. Time History for DBS Run 35, SV Encounters Slower POV, SV 45 mph, POV 20 mph



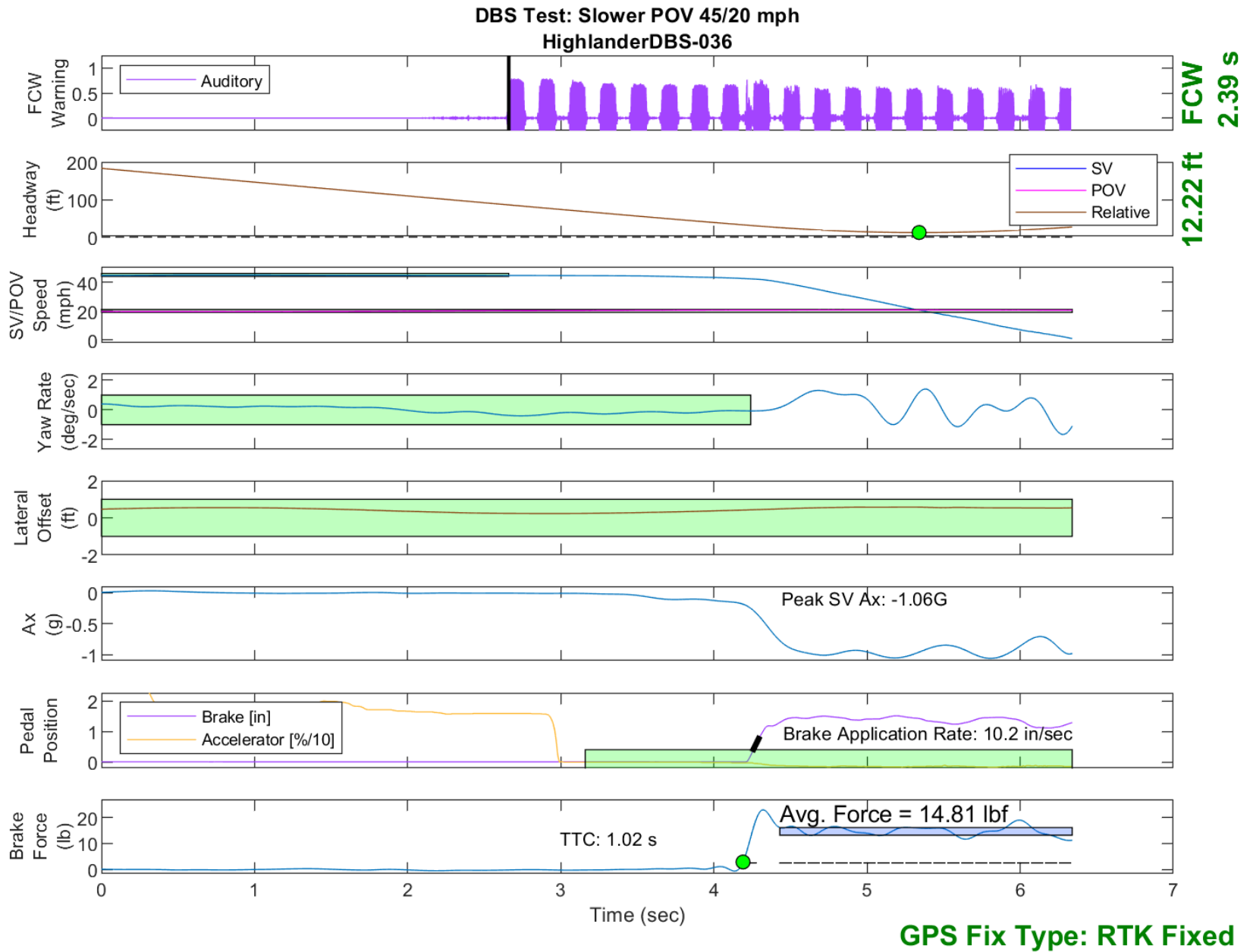


Figure E30. Time History for DBS Run 36, SV Encounters Slower POV, SV 45 mph, POV 20 mph

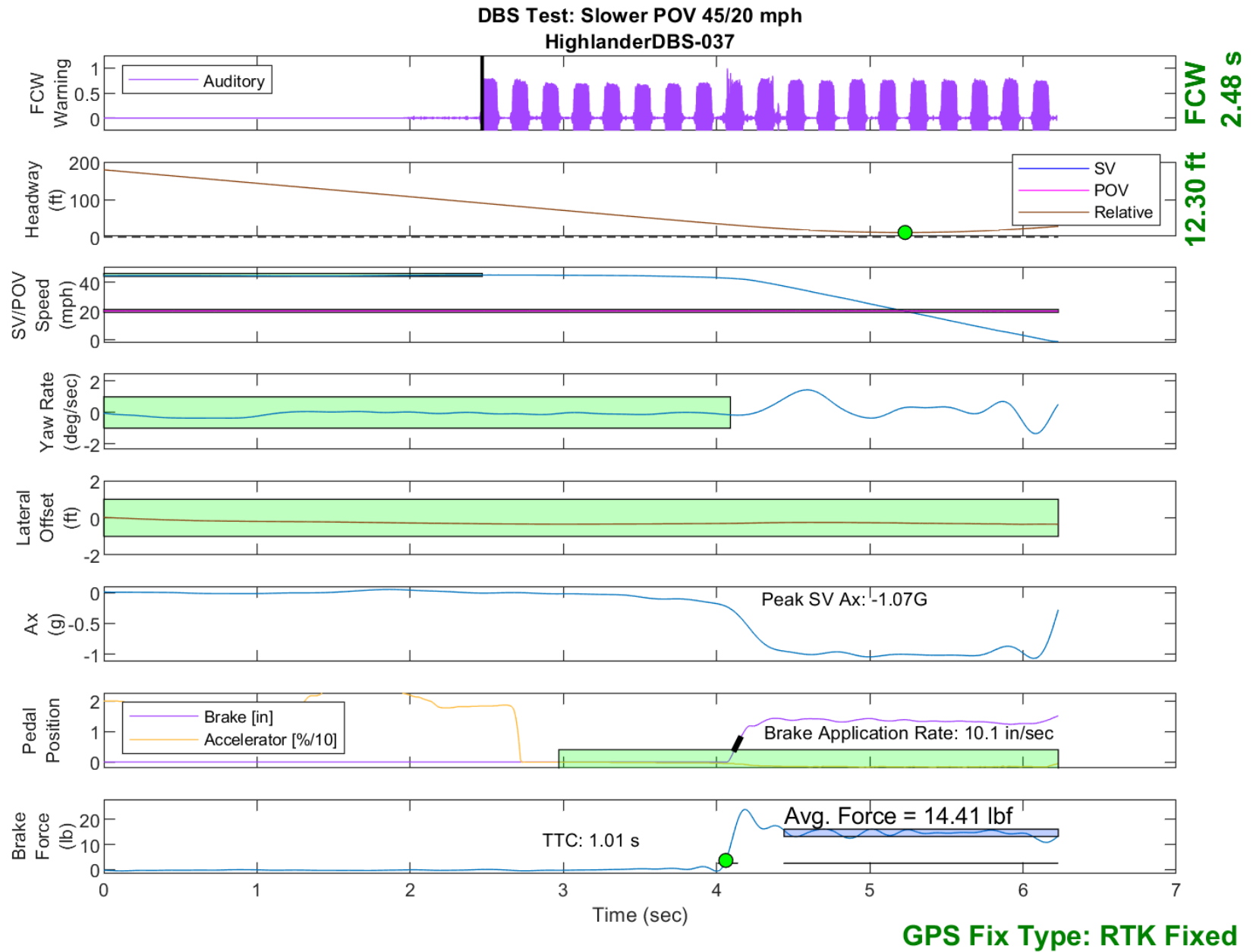


Figure E31. Time History for DBS Run 37, SV Encounters Slower POV, SV 45 mph, POV 20 mph

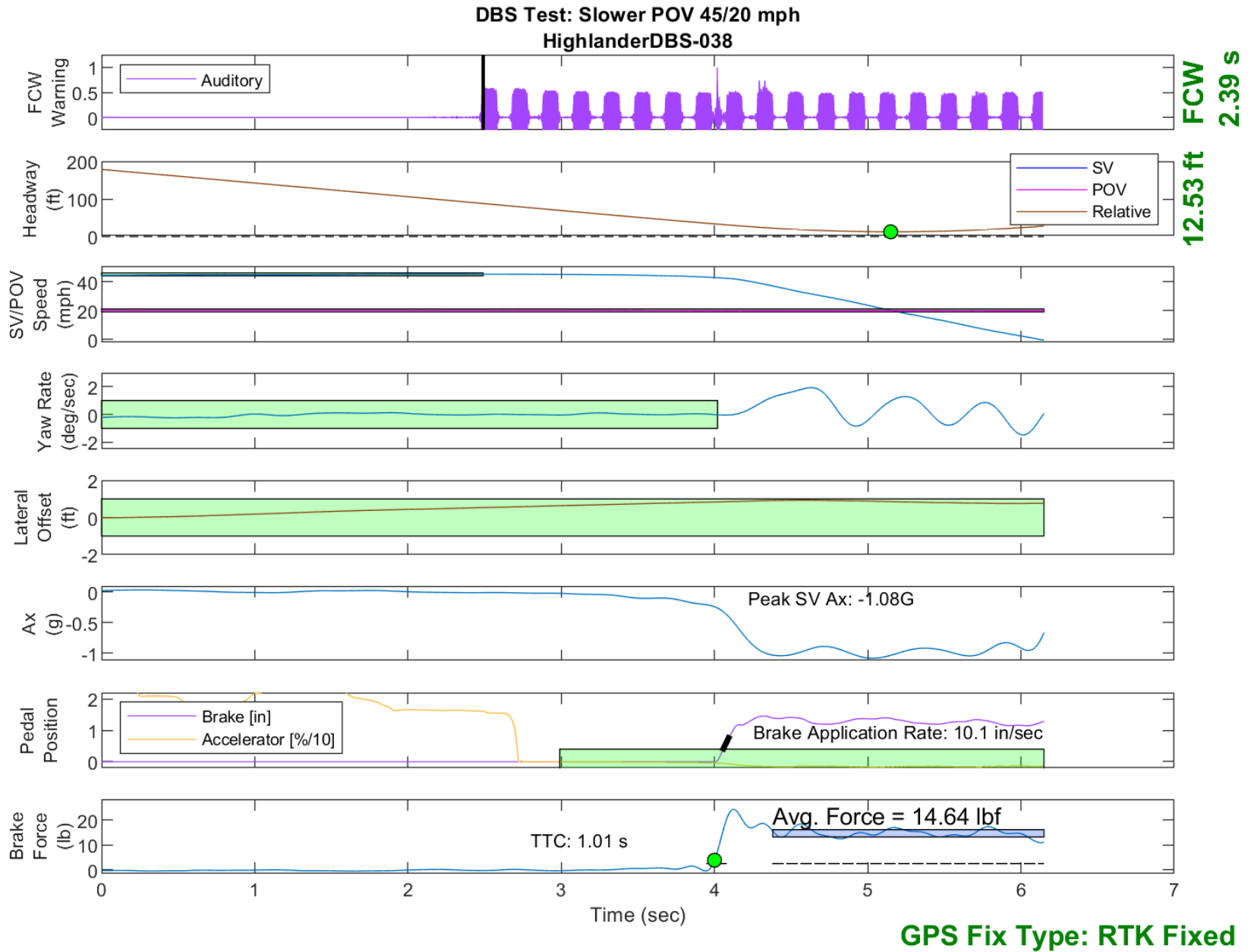


Figure E32. Time History for DBS Run 38, SV Encounters Slower POV, SV 45 mph, POV 20 mph

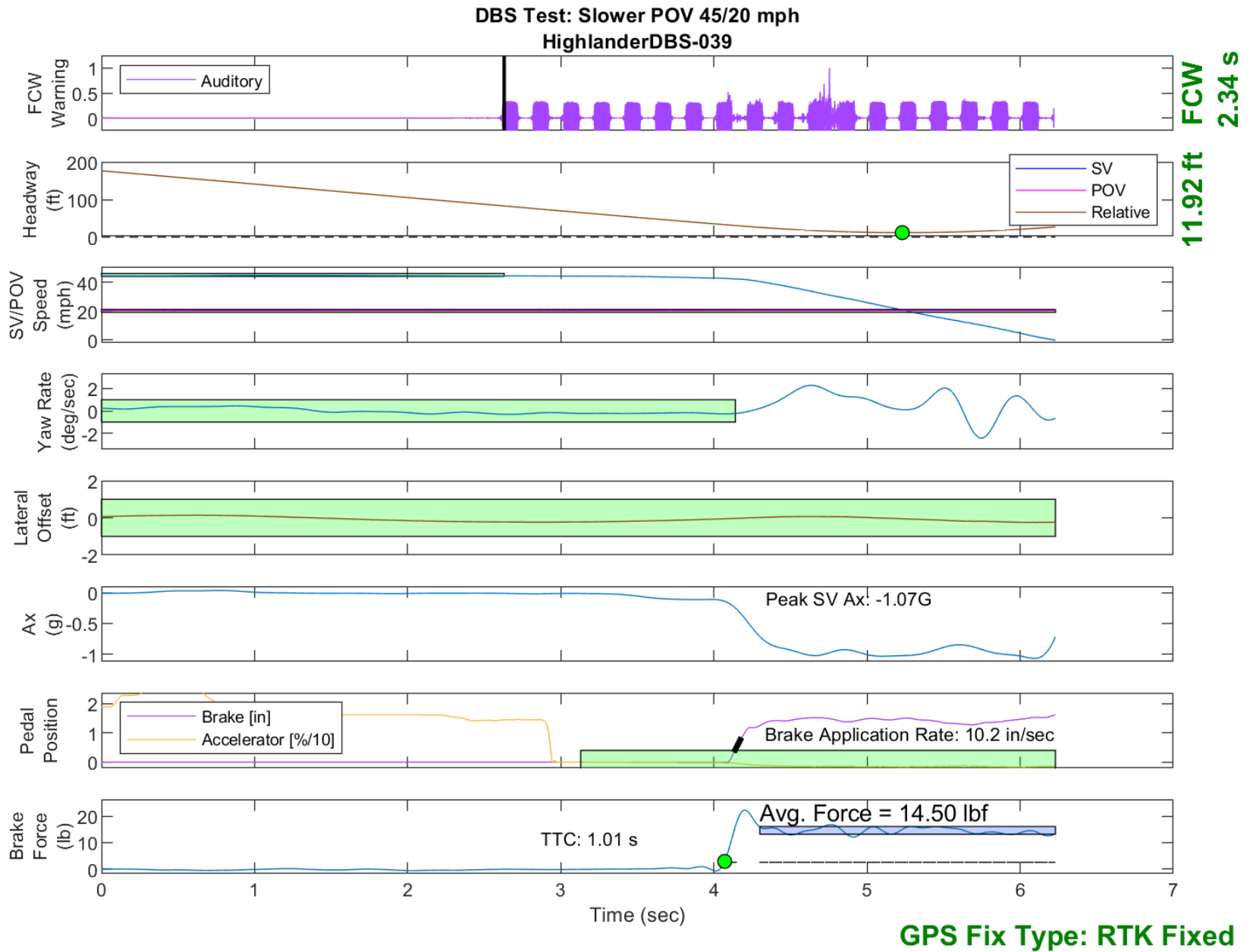


Figure E33. Time History for DBS Run 39, SV Encounters Slower POV, SV 45 mph, POV 20 mph

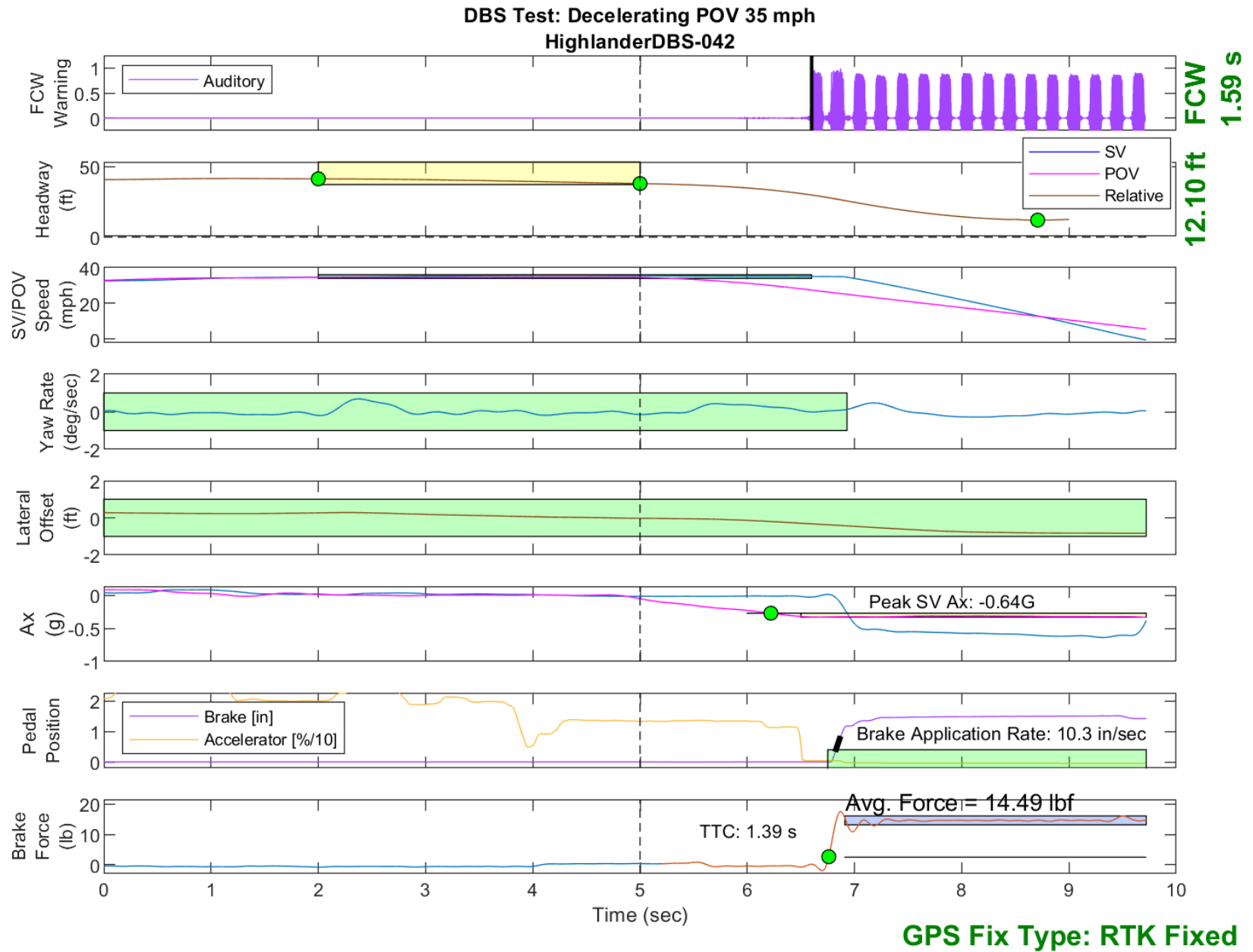


Figure E34. Time History for DBS Run 42, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

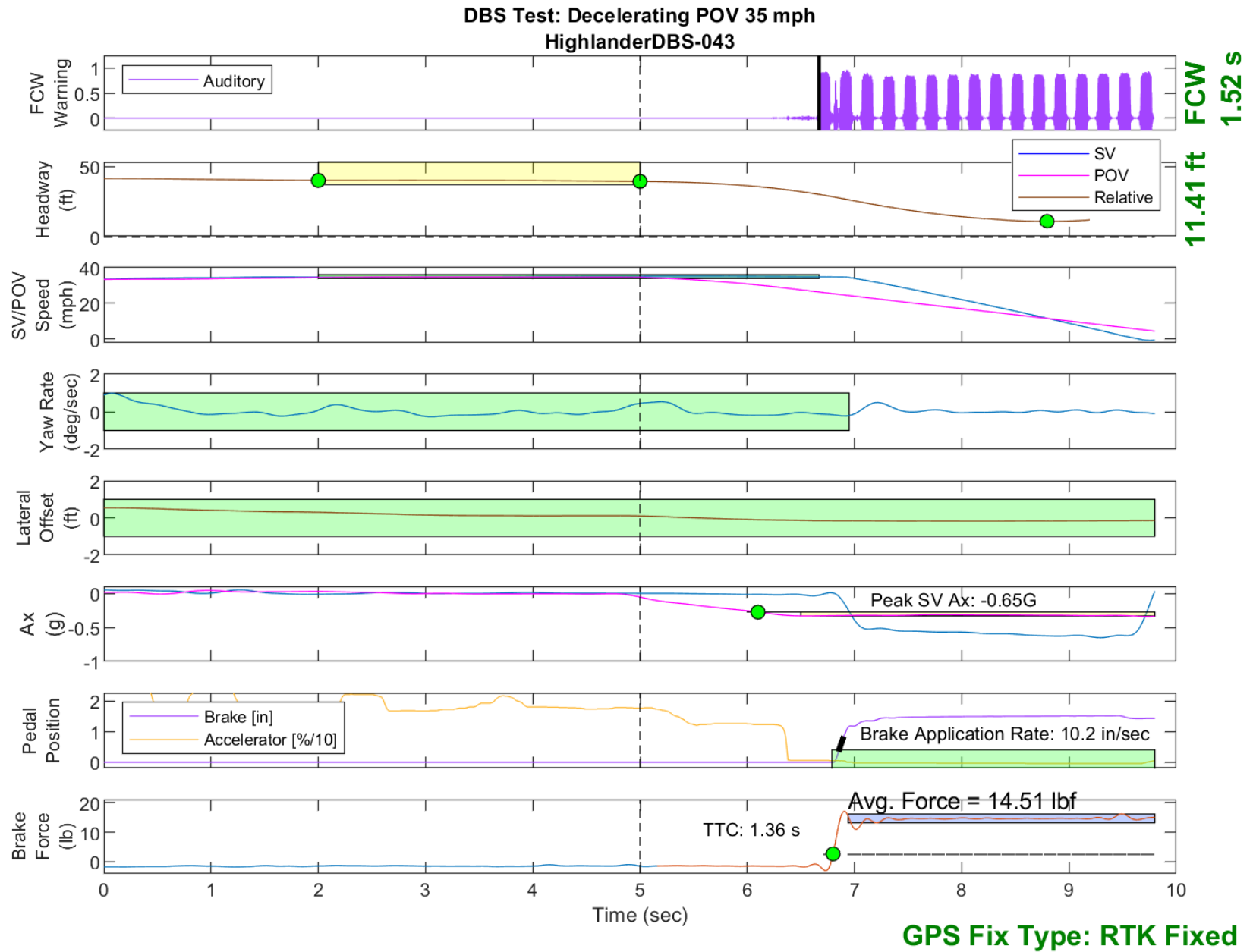


Figure E35. Time History for DBS Run 43, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

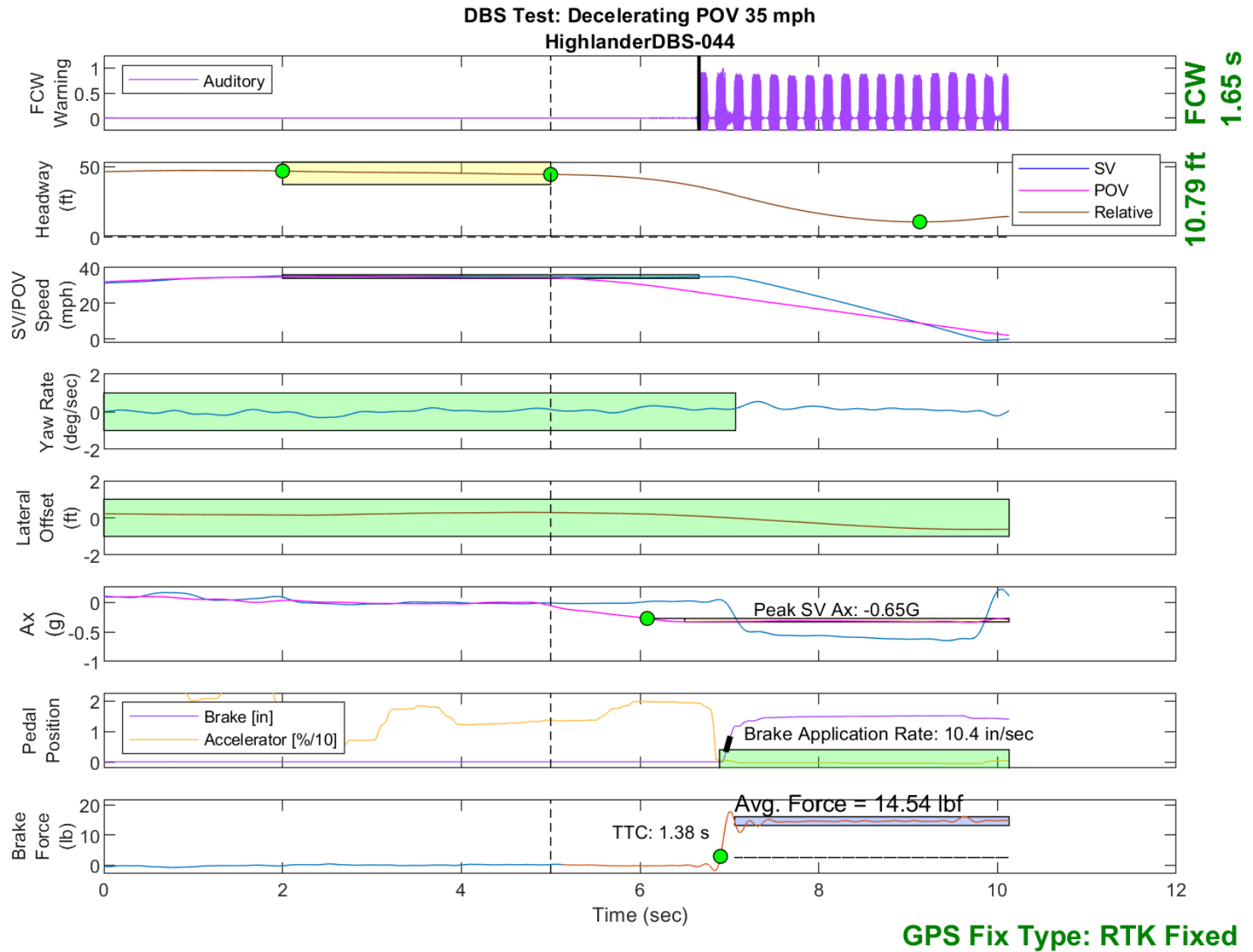


Figure E36. Time History for DBS Run 44, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

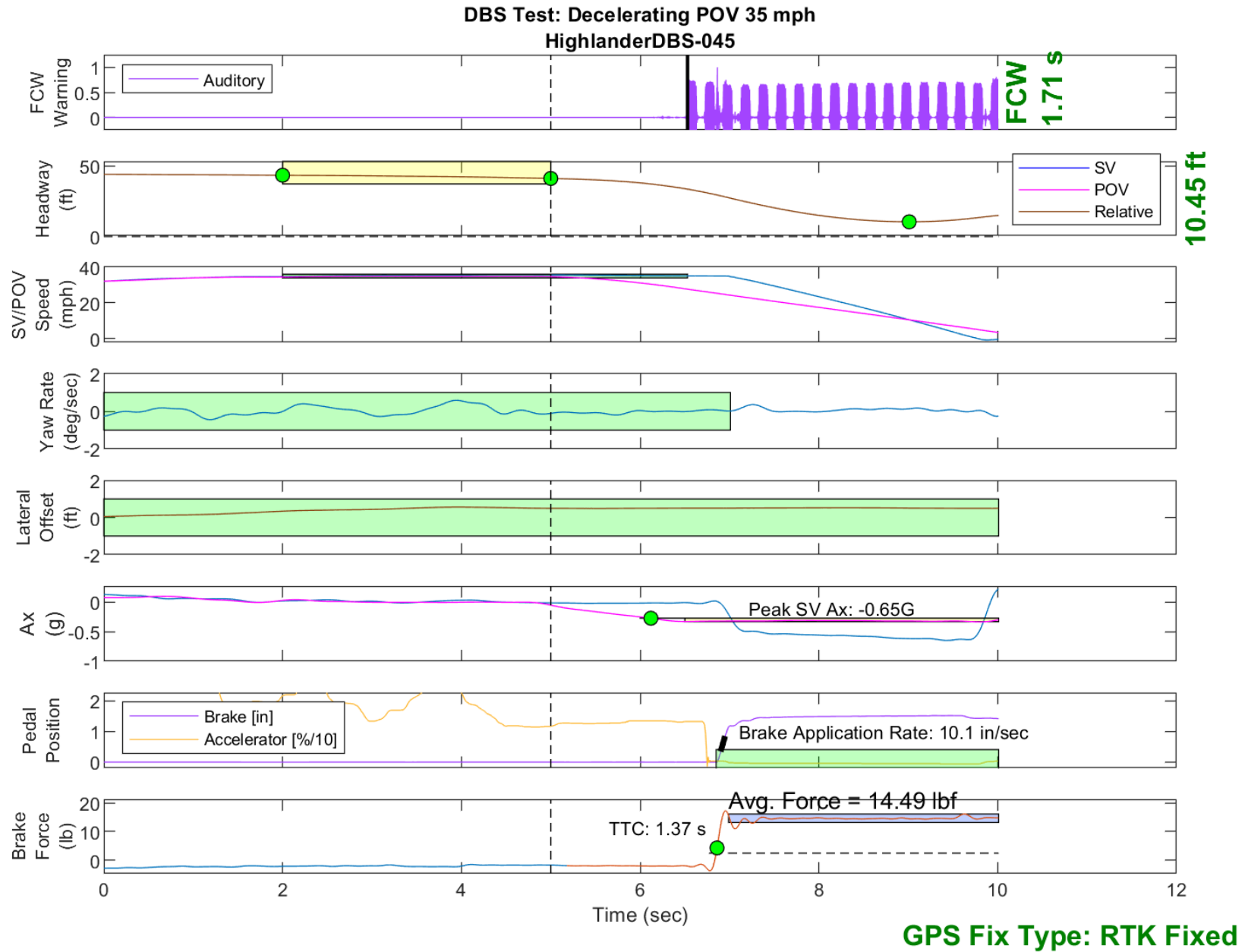


Figure E37. Time History for DBS Run 45, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph



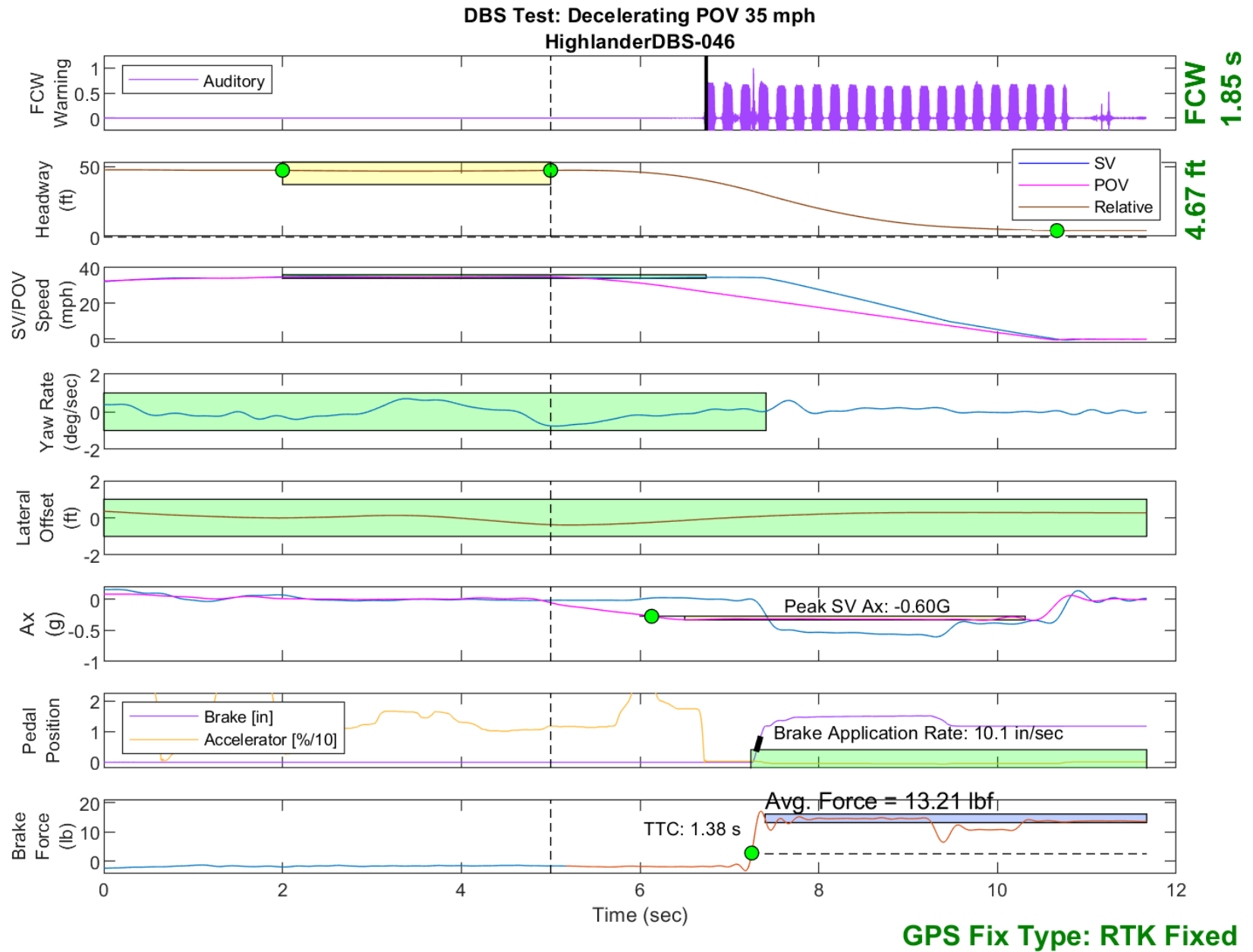


Figure E38. Time History for DBS Run 46, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

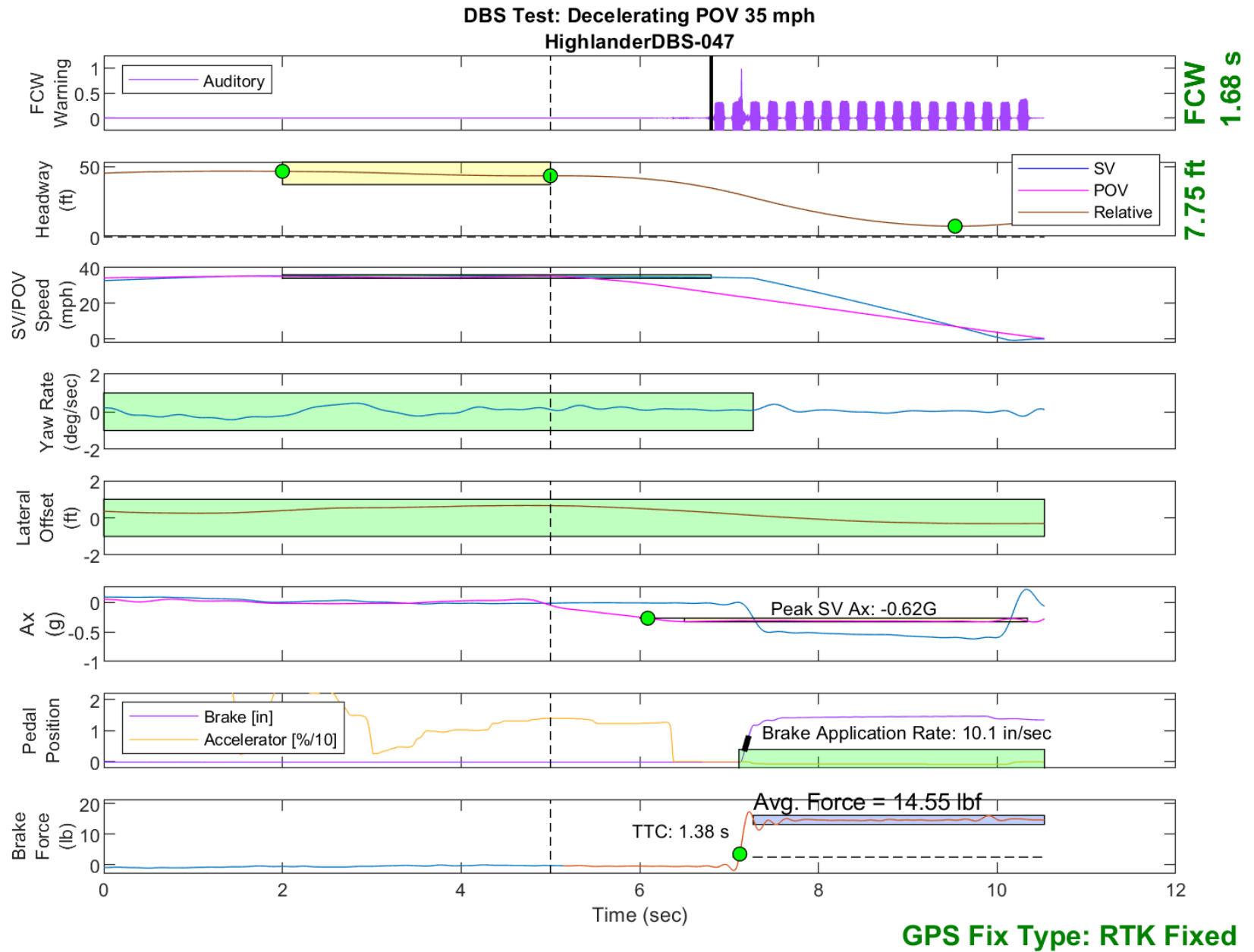


Figure E39. Time History for DBS Run 47, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph

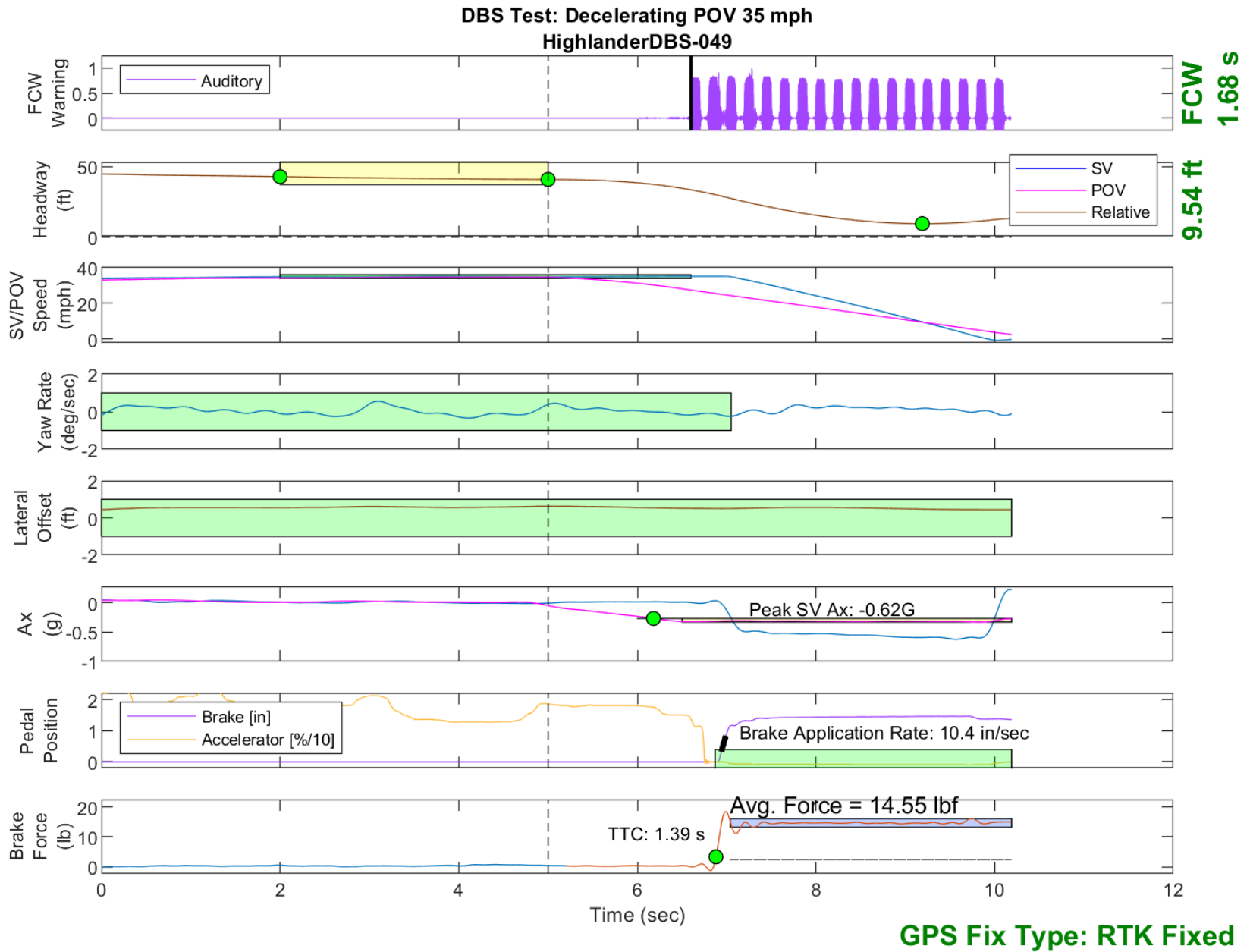
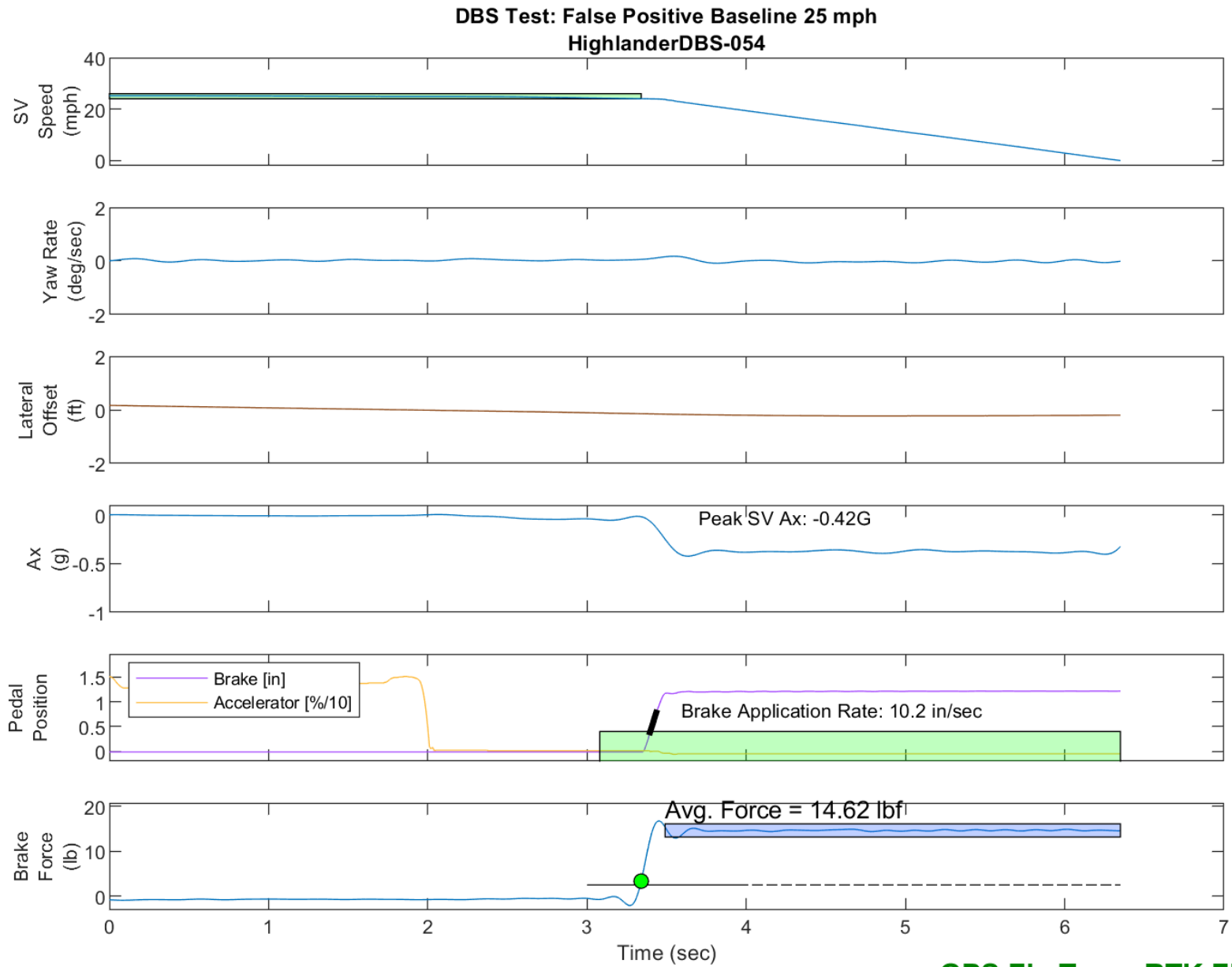
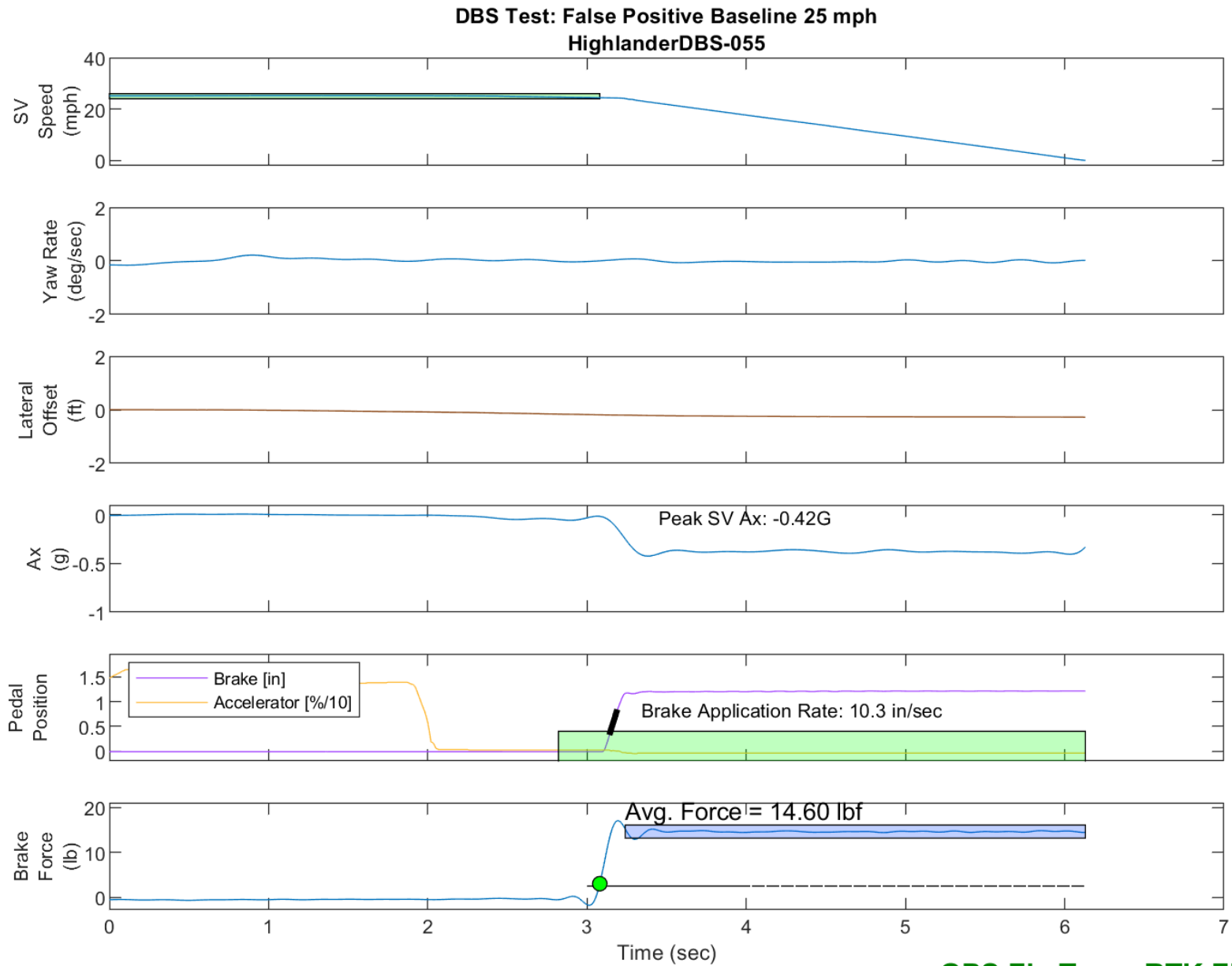


Figure E40. Time History for DBS Run 49, SV Encounters Decelerating POV, SV 35 mph, POV 35 mph



**GPS Fix Type: RTK Fixed**

Figure E41. Time History for DBS Run 54, False Positive Baseline, SV 25 mph



**GPS Fix Type: RTK Fixed**

Figure E42. Time History for DBS Run 55, False Positive Baseline, SV 25 mph

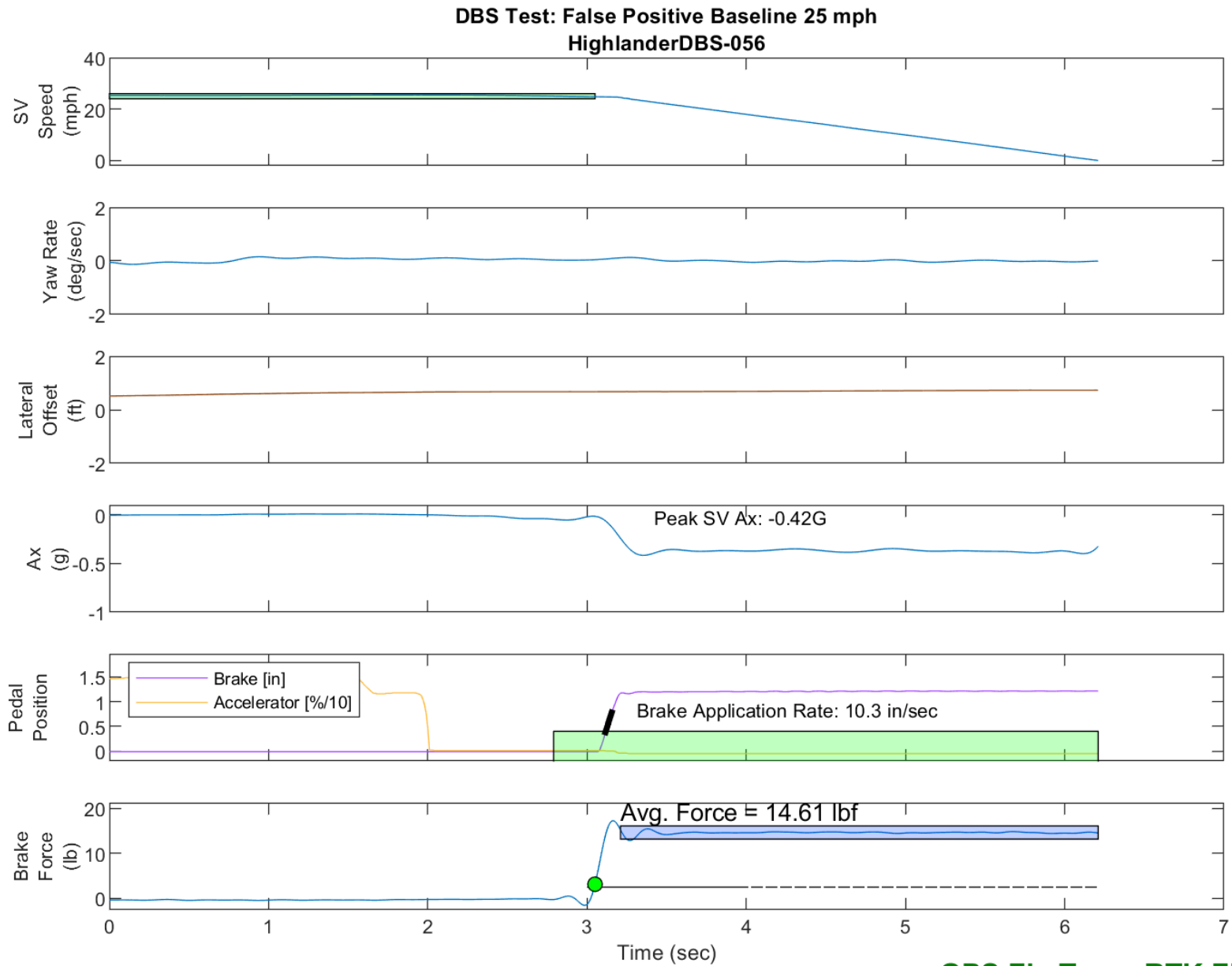
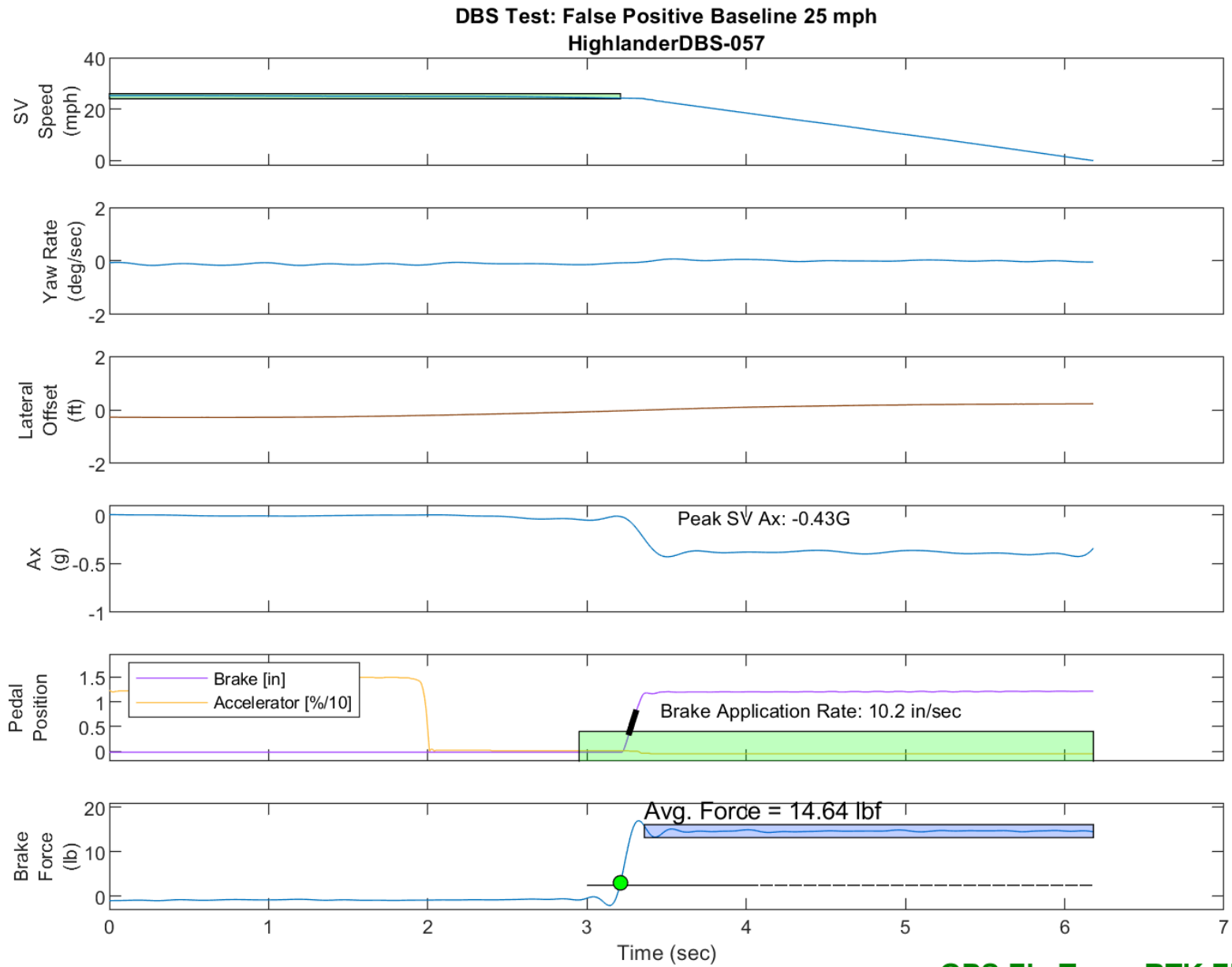


Figure E43. Time History for DBS Run 56, False Positive Baseline, SV 25 mph



**GPS Fix Type: RTK Fixed**

Figure E44. Time History for DBS Run 57, False Positive Baseline, SV 25 mph

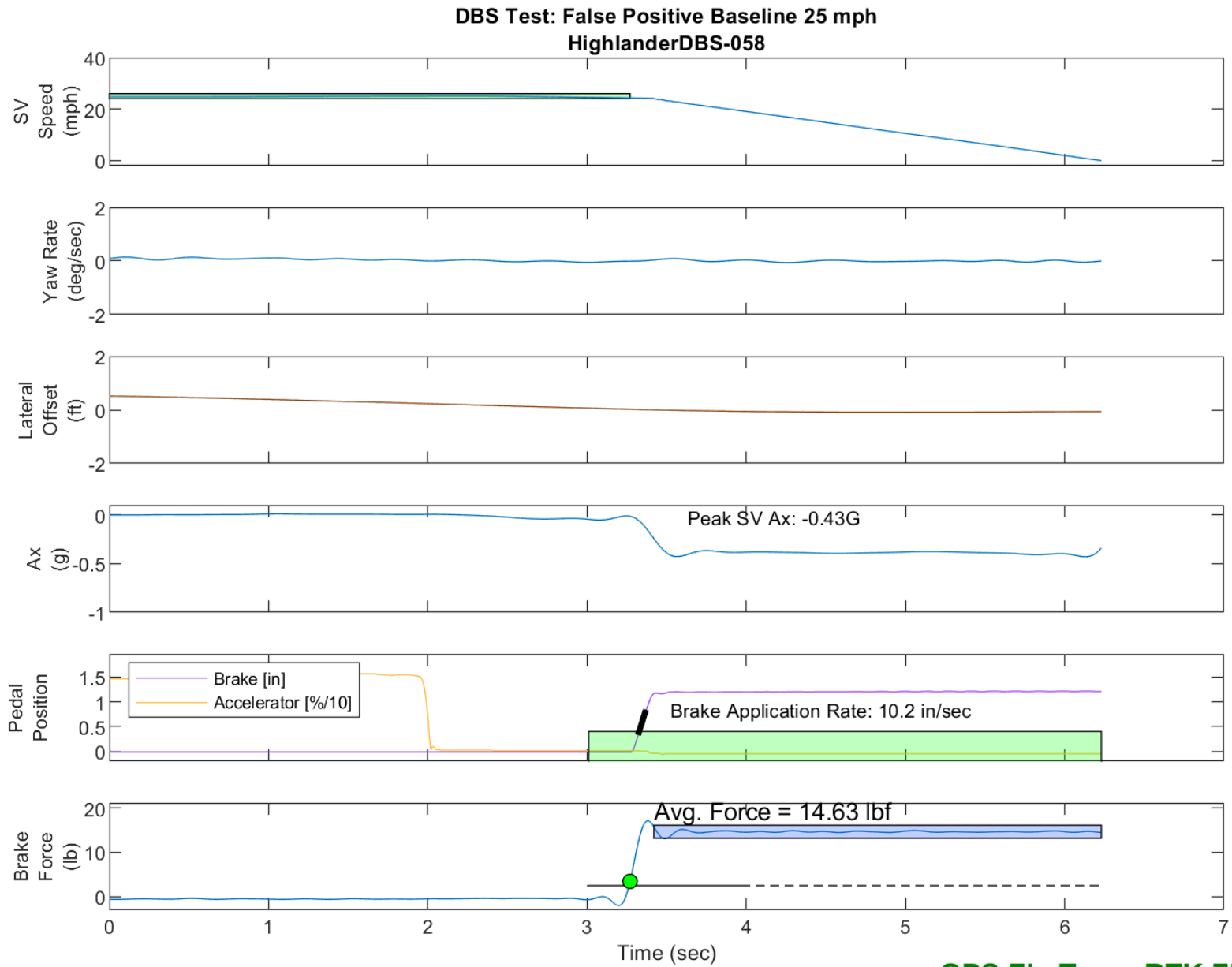
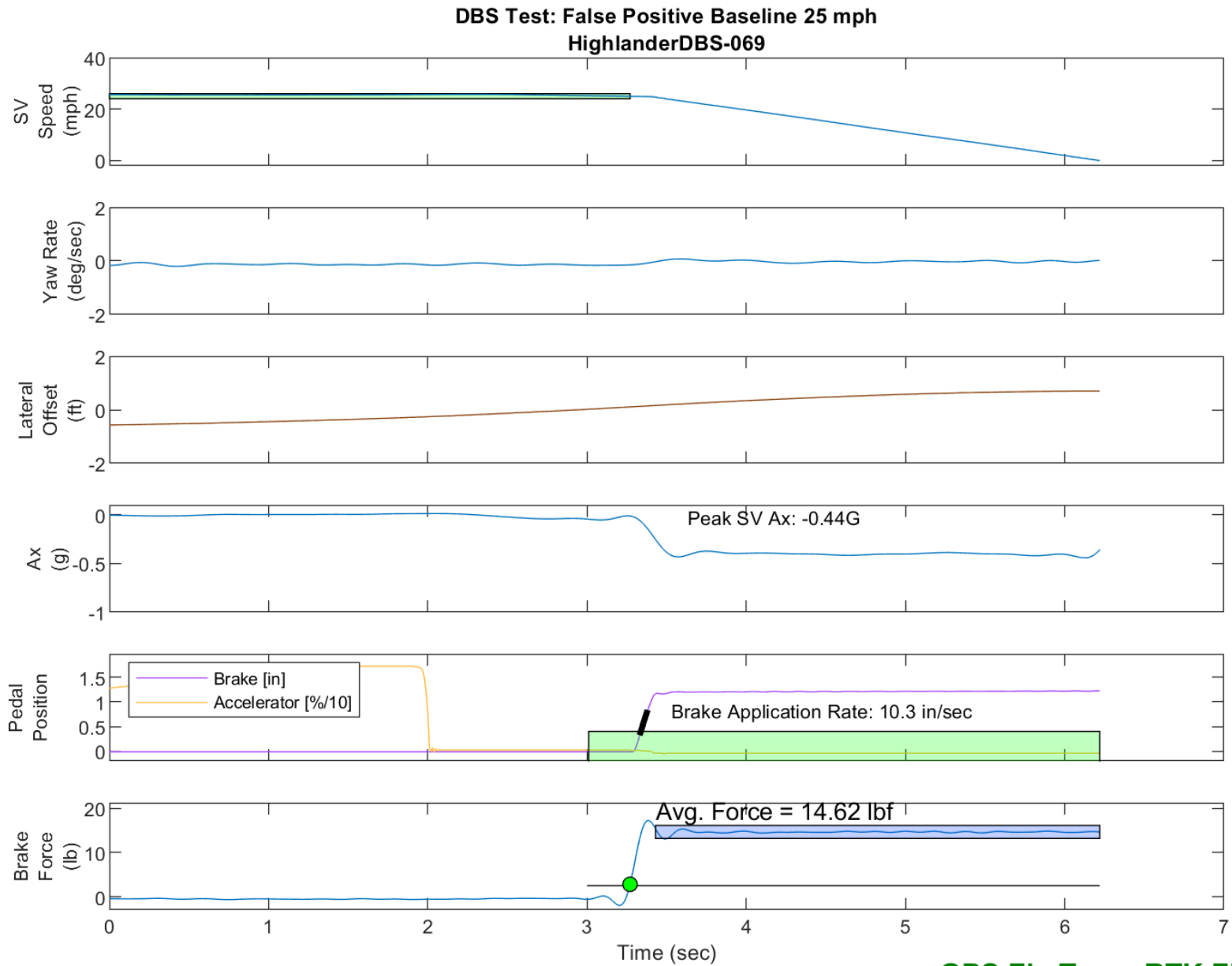


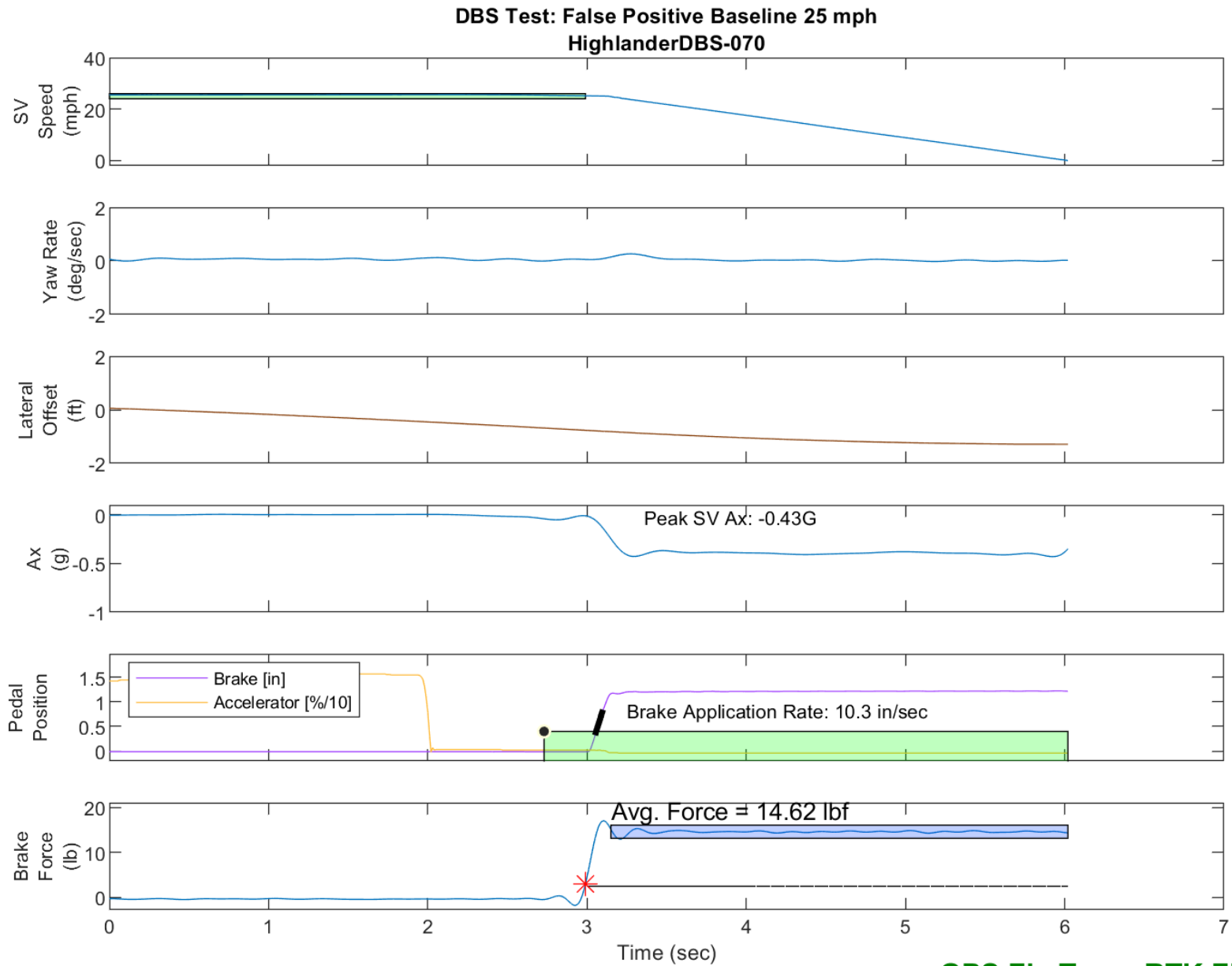
Figure E45. Time History for DBS Run 58, False Positive Baseline, SV 25 mph





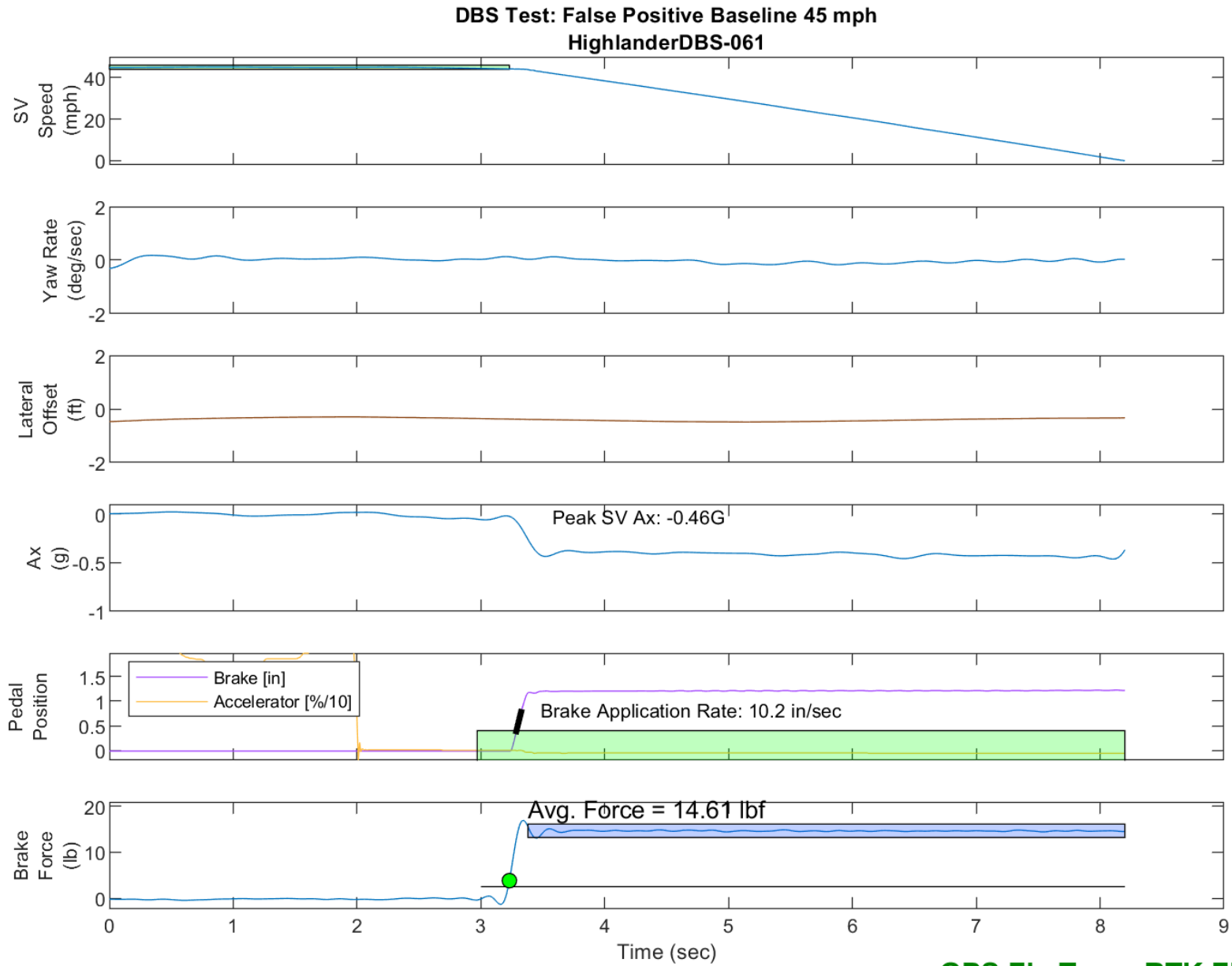
**GPS Fix Type: RTK Fixed**

Figure E46. Time History for DBS Run 69, False Positive Baseline, SV 25 mph



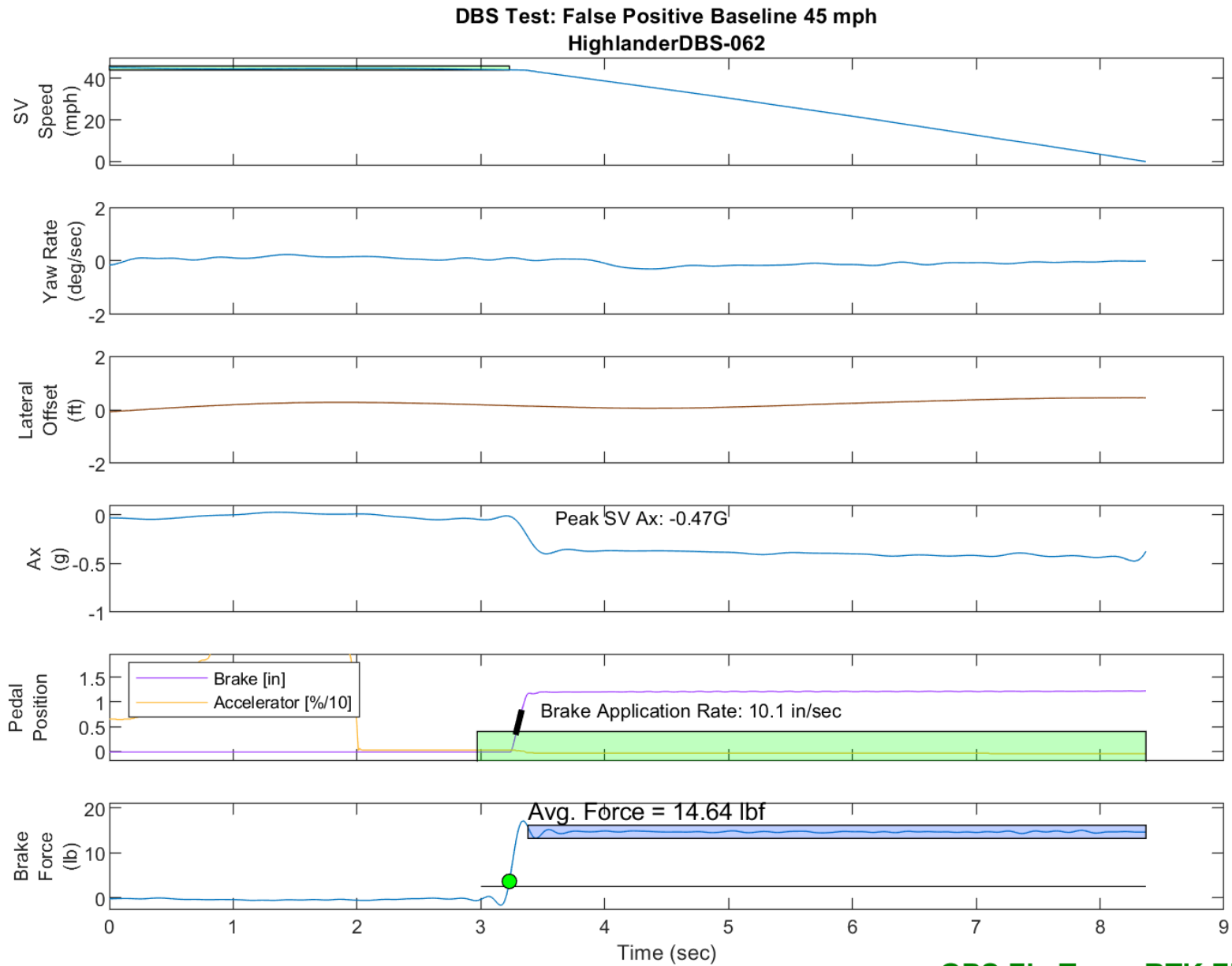
**GPS Fix Type: RTK Fixed**

Figure E47. Time History for DBS Run 70, False Positive Baseline, SV 25 mph



**GPS Fix Type: RTK Fixed**

Figure E48. Time History for DBS Run 61, False Positive Baseline, SV 45 mph



**GPS Fix Type: RTK Fixed**

Figure E49. Time History for DBS Run 62, False Positive Baseline, SV 45 mph

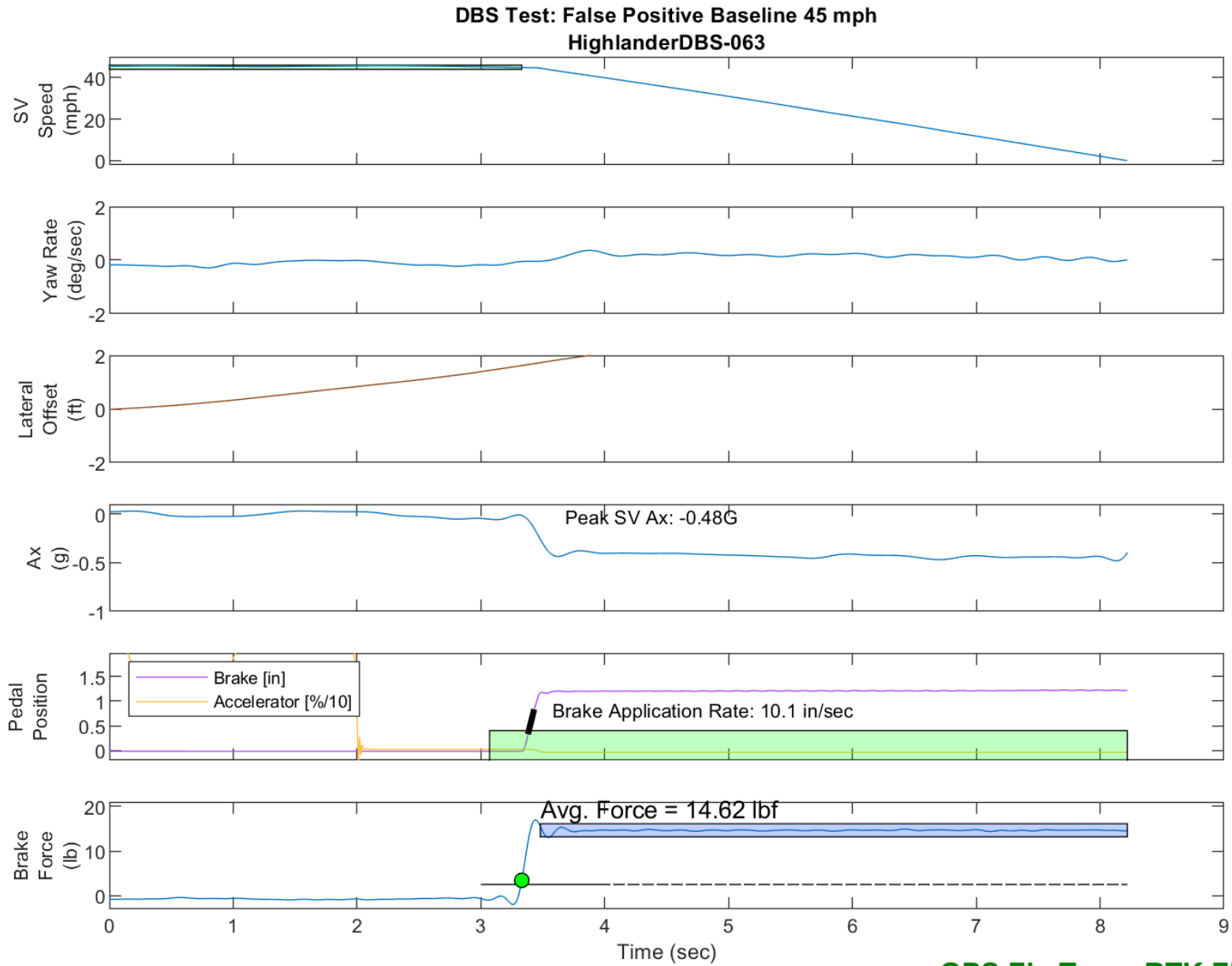
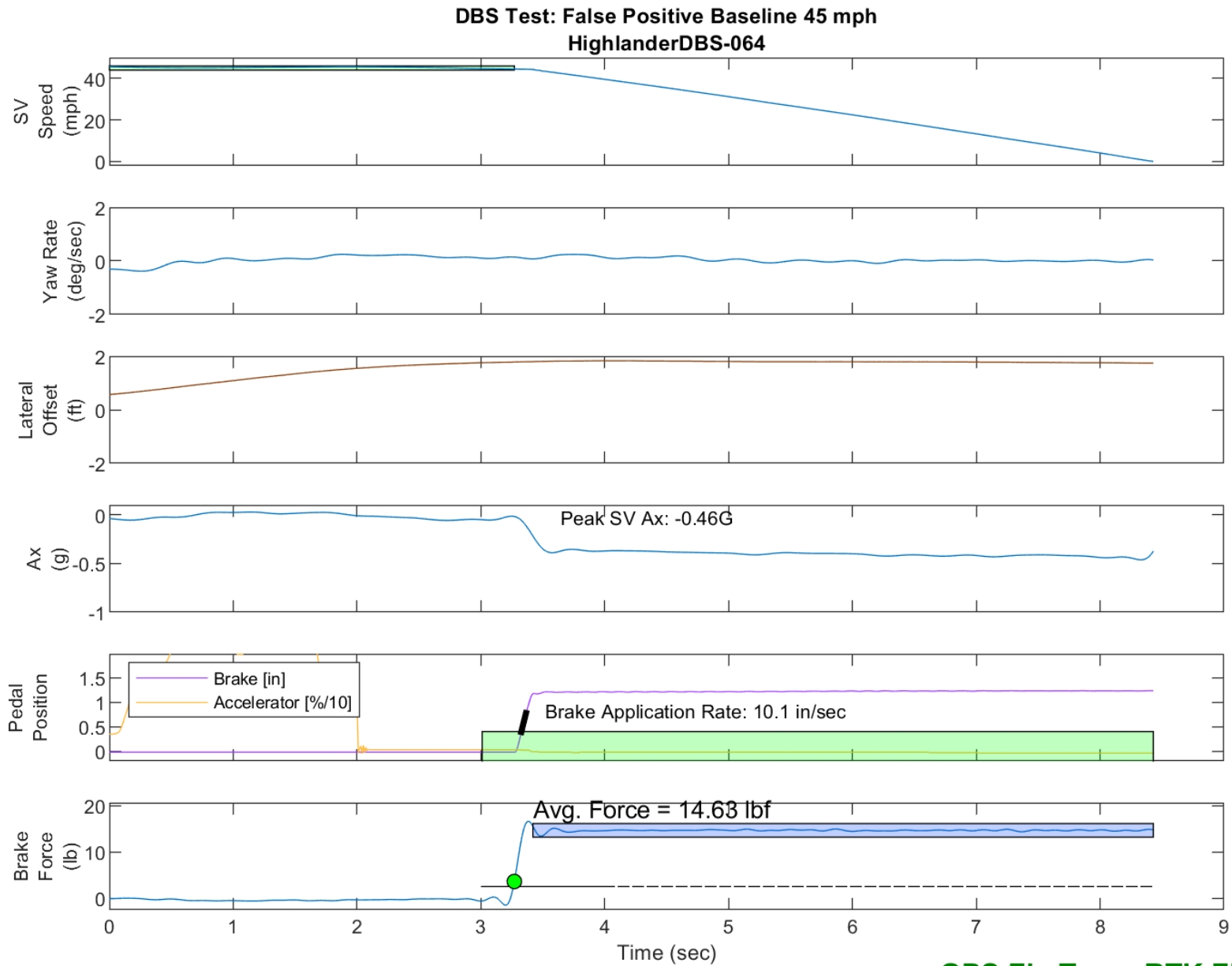
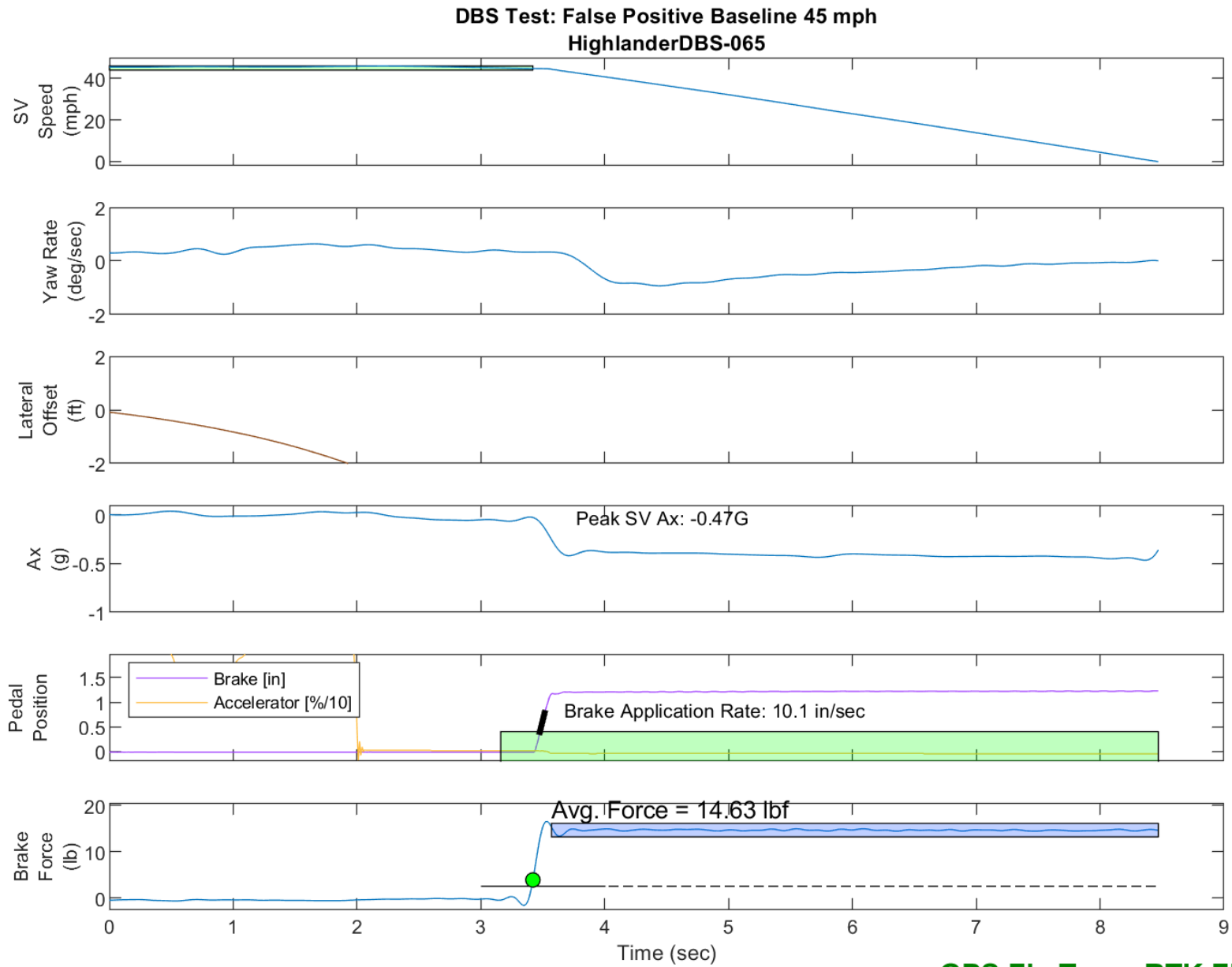


Figure E50. Time History for DBS Run 63, False Positive Baseline, SV 45 mph



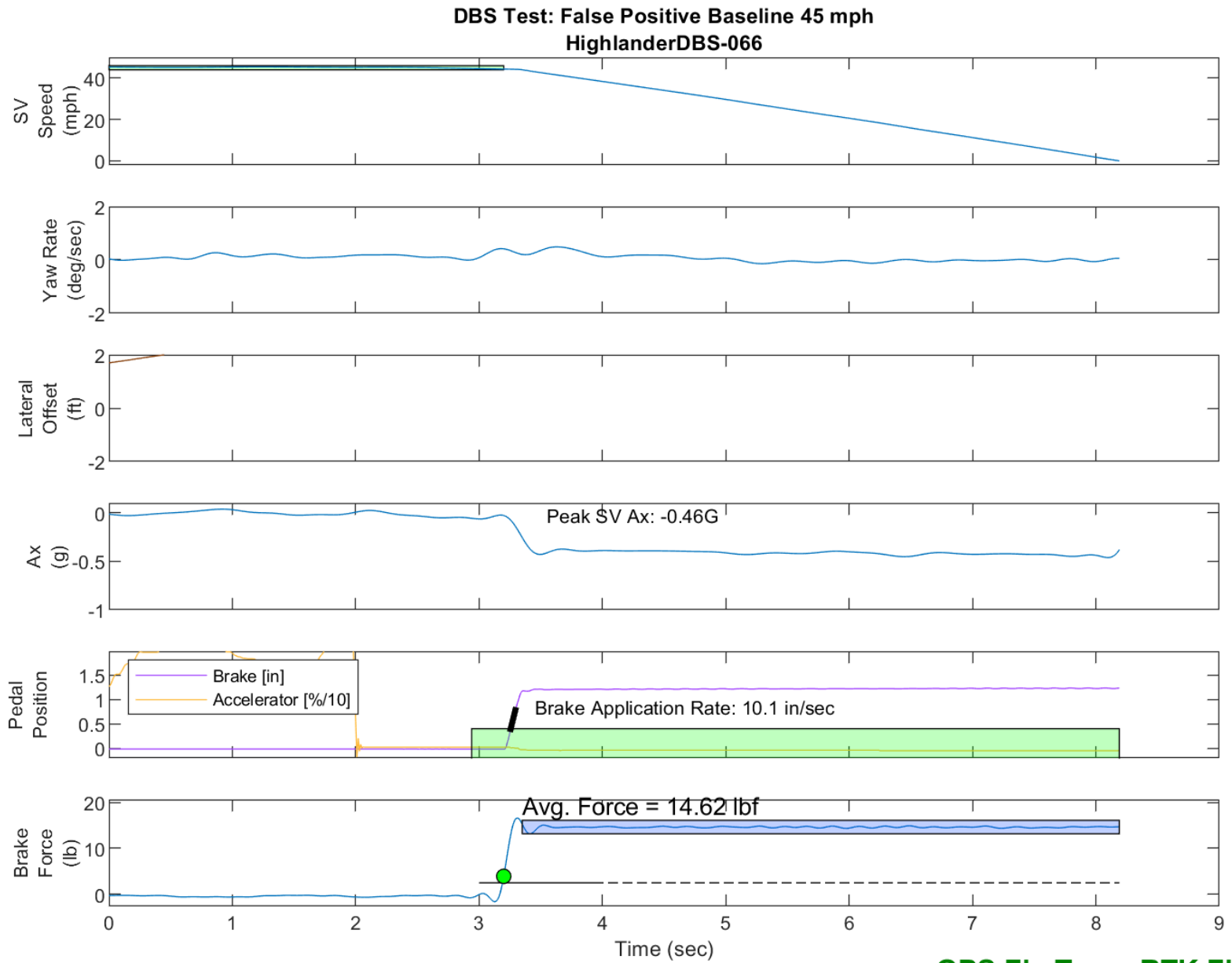
**GPS Fix Type: RTK Fixed**

Figure E51. Time History for DBS Run 64, False Positive Baseline, SV 45 mph



**GPS Fix Type: RTK Fixed**

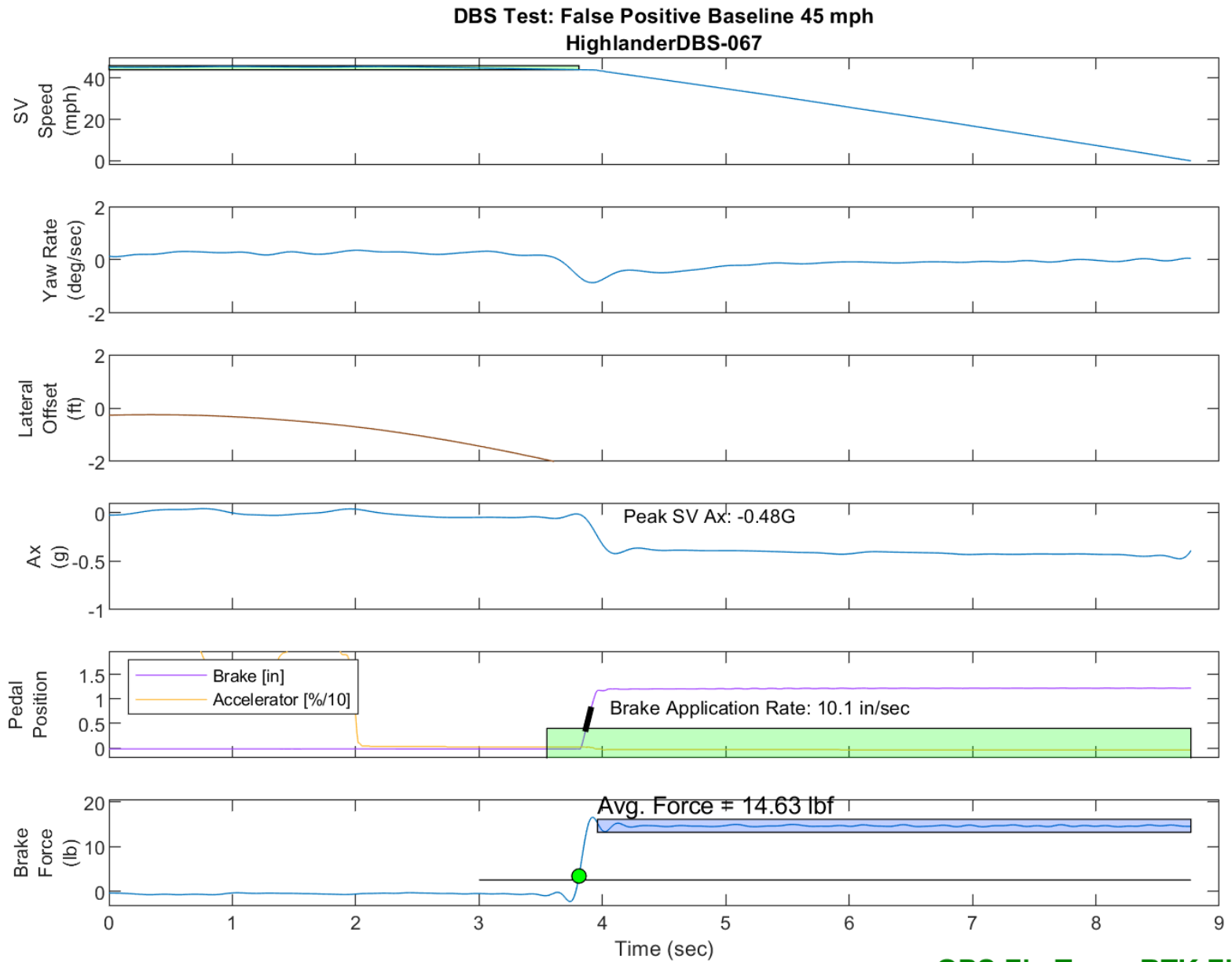
Figure E52. Time History for DBS Run 65, False Positive Baseline, SV 45 mph



**GPS Fix Type: RTK Fixed**

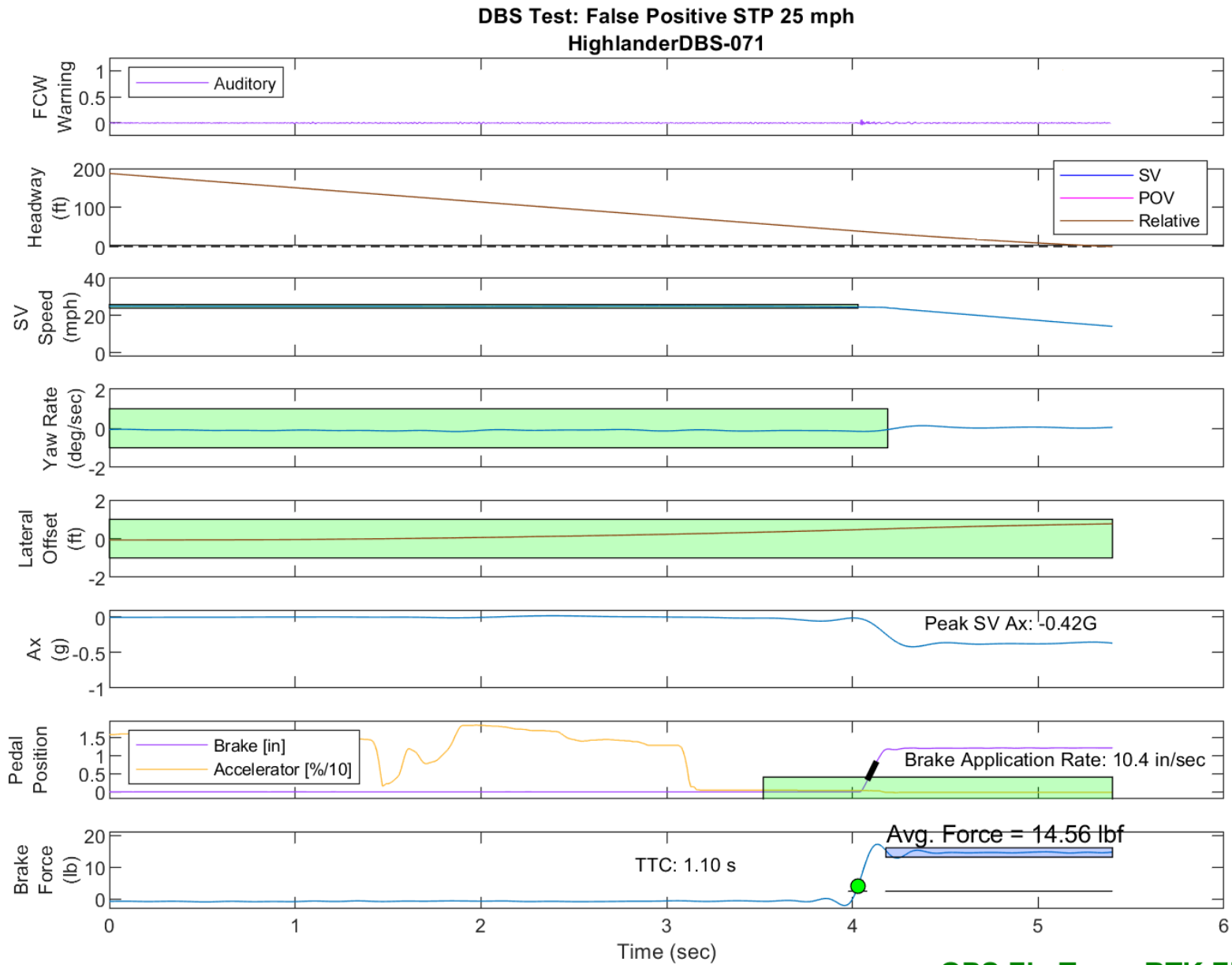
Figure E53. Time History for DBS Run 66, False Positive Baseline, SV 45 mph





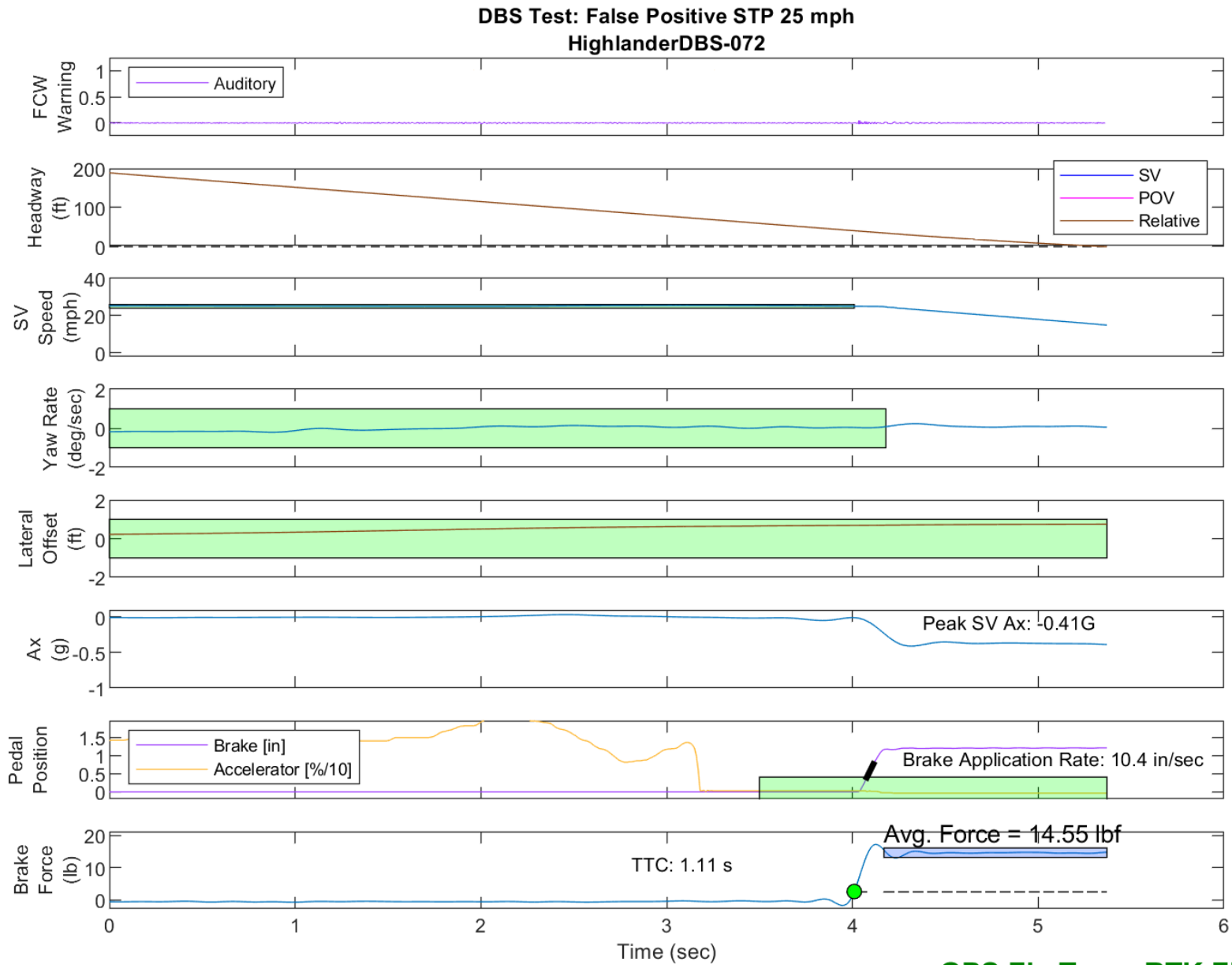
**GPS Fix Type: RTK Fixed**

Figure E54. Time History for DBS Run 67, False Positive Baseline, SV 45 mph



**GPS Fix Type: RTK Fixed**

Figure E55. Time History for DBS Run 71, SV Encounters Steel Trench Plate, SV 25 mph



**GPS Fix Type: RTK Fixed**

Figure E56. Time History for DBS Run 72, SV Encounters Steel Trench Plate, SV 25 mph

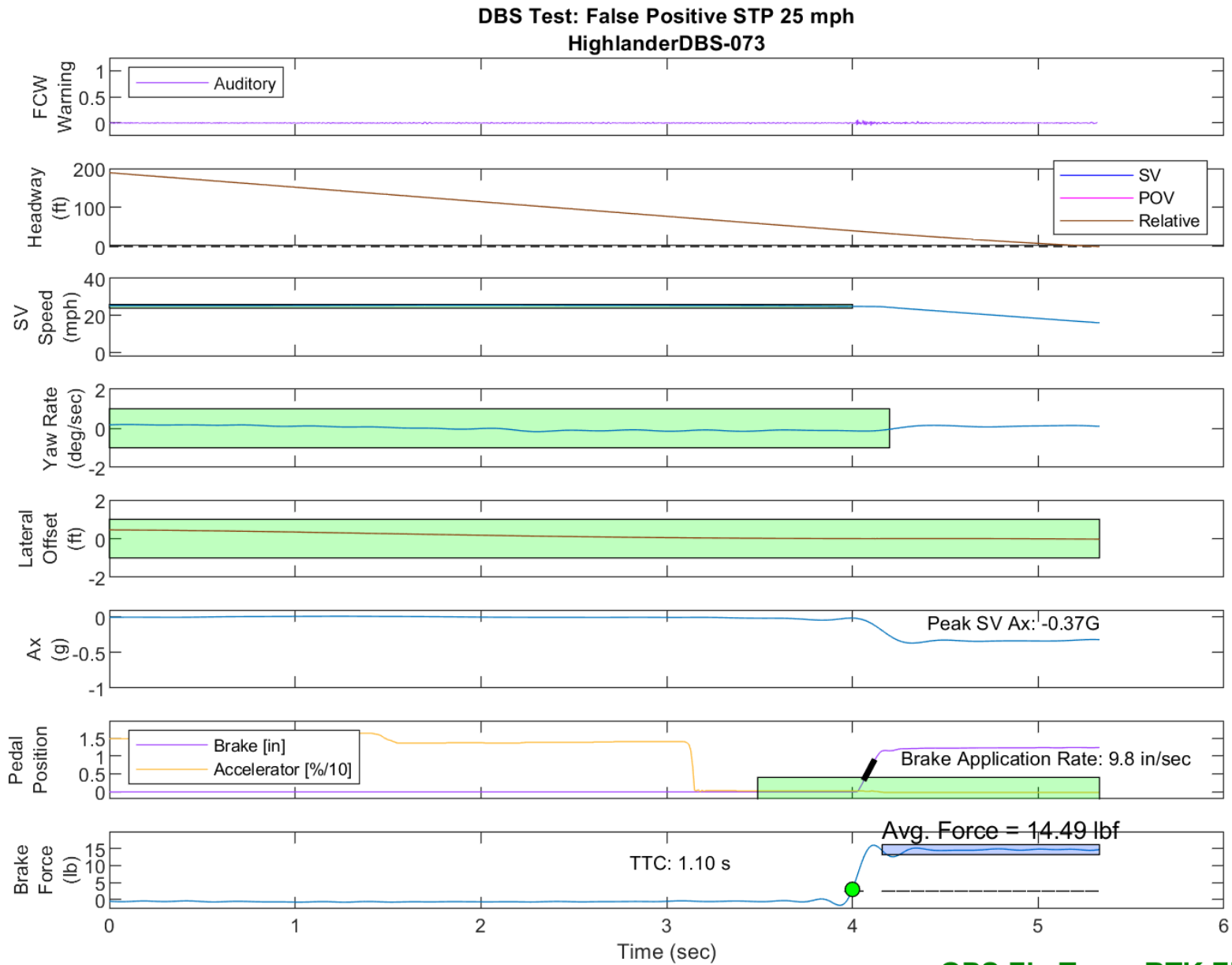
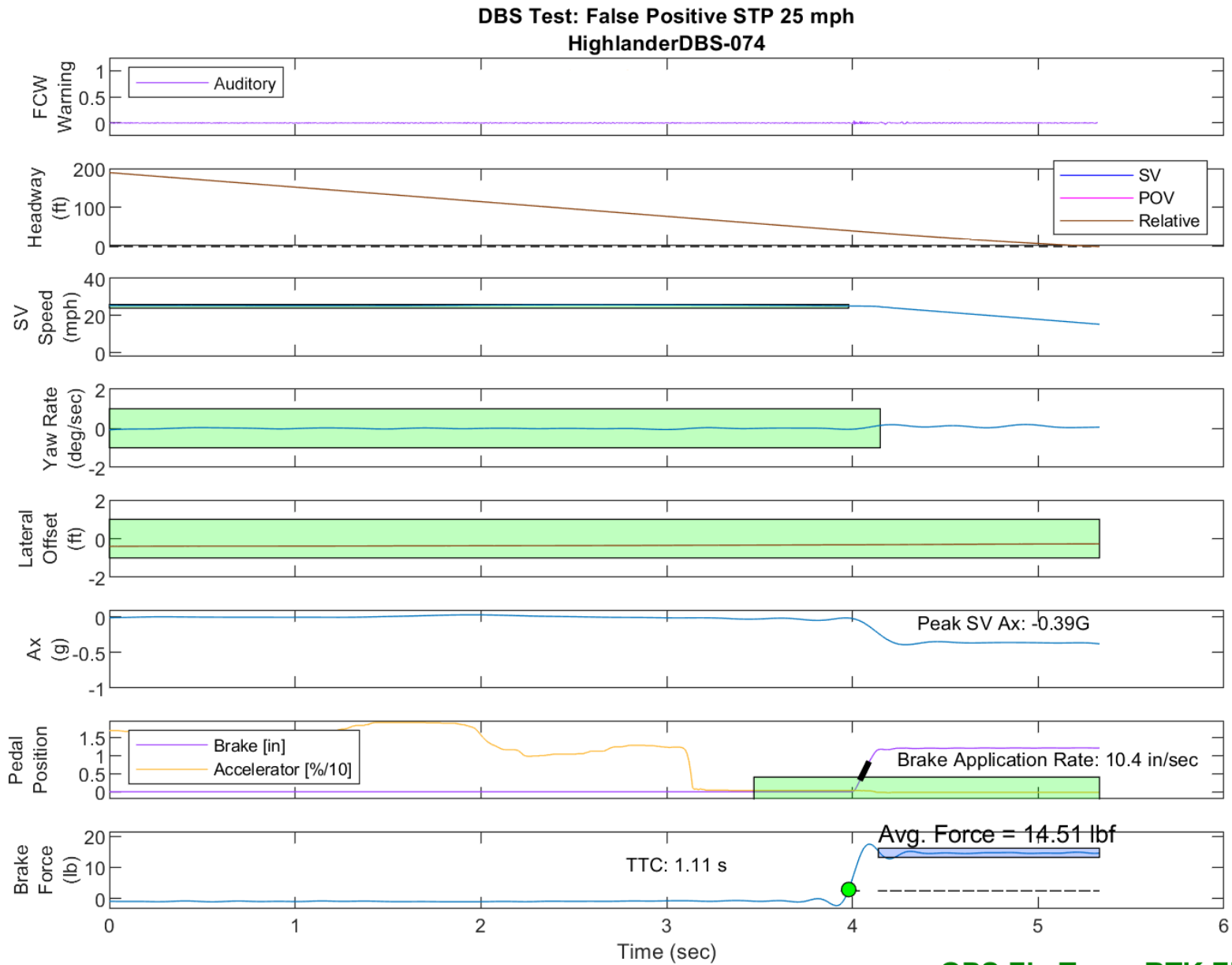
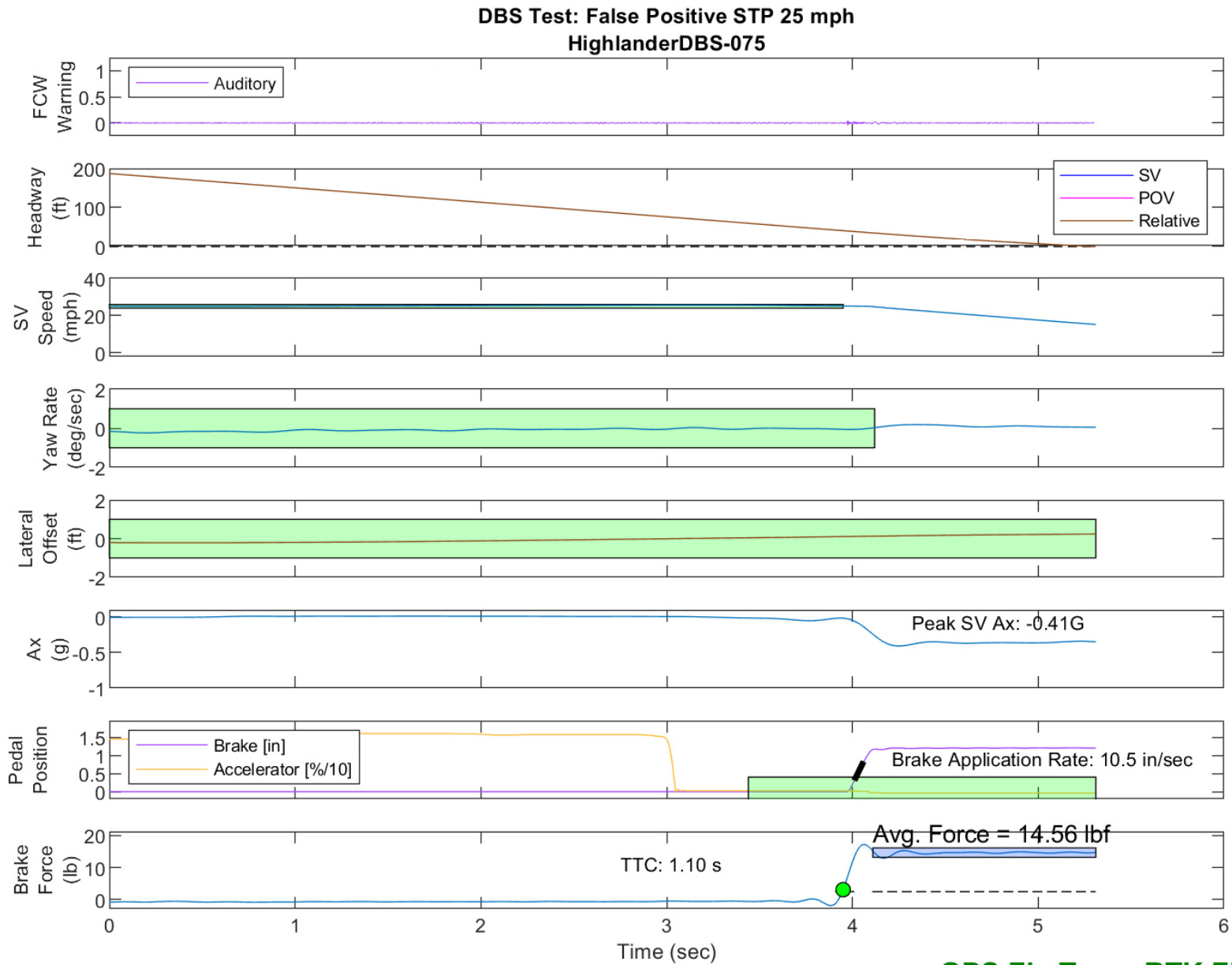


Figure E57. Time History for DBS Run 73, SV Encounters Steel Trench Plate, SV 25 mph



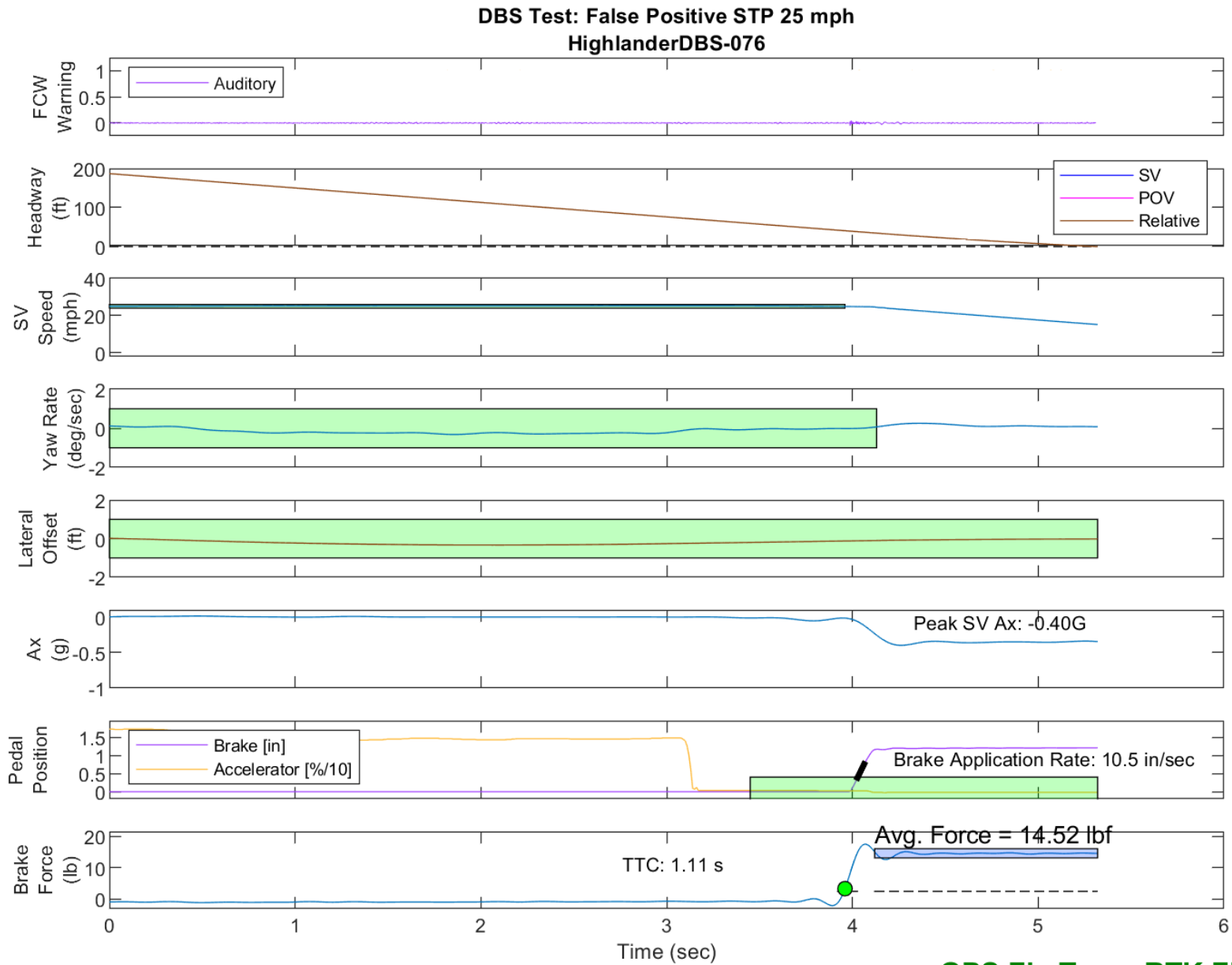
GPS Fix Type: RTK Fixed

Figure E58. Time History for DBS Run 74, SV Encounters Steel Trench Plate, SV 25 mph



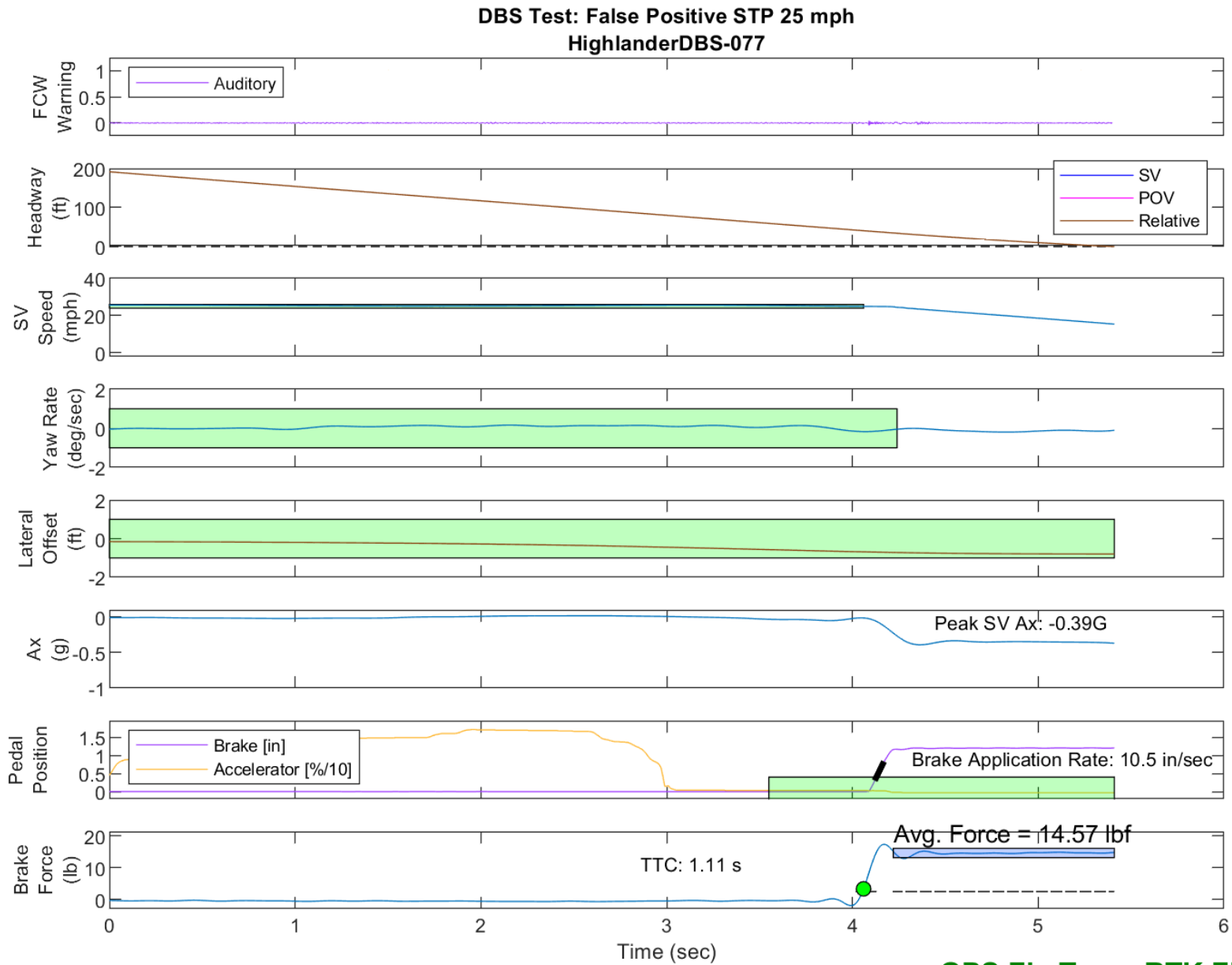
**GPS Fix Type: RTK Fixed**

Figure E59. Time History for DBS Run 75, SV Encounters Steel Trench Plate, SV 25 mph



GPS Fix Type: RTK Fixed

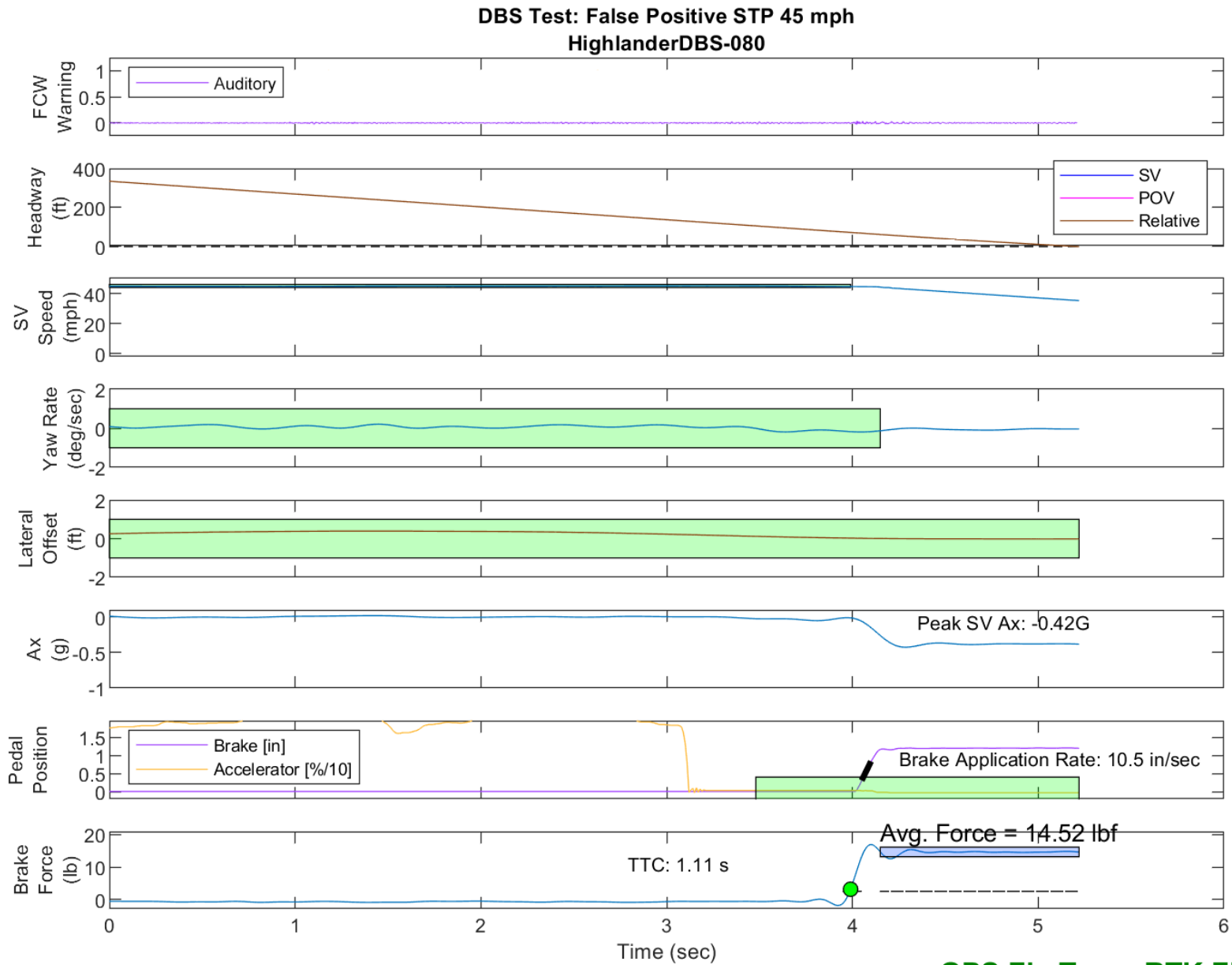
Figure E60. Time History for DBS Run 76, SV Encounters Steel Trench Plate, SV 25 mph



**GPS Fix Type: RTK Fixed**

Figure E61. Time History for DBS Run 77, SV Encounters Steel Trench Plate, SV 25 mph





**GPS Fix Type: RTK Fixed**

Figure E62. Time History for DBS Run 80, SV Encounters Steel Trench Plate, SV 45 mph

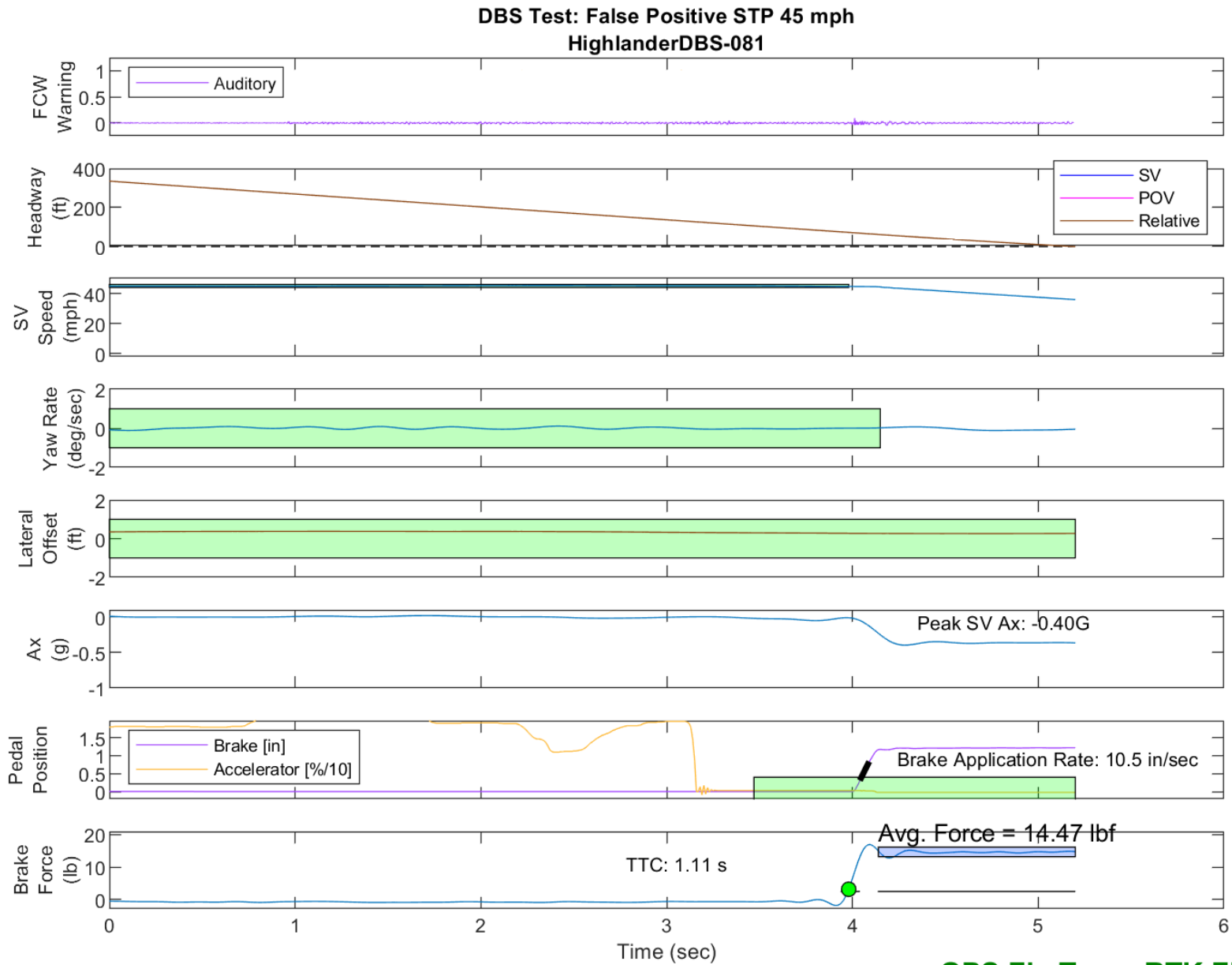
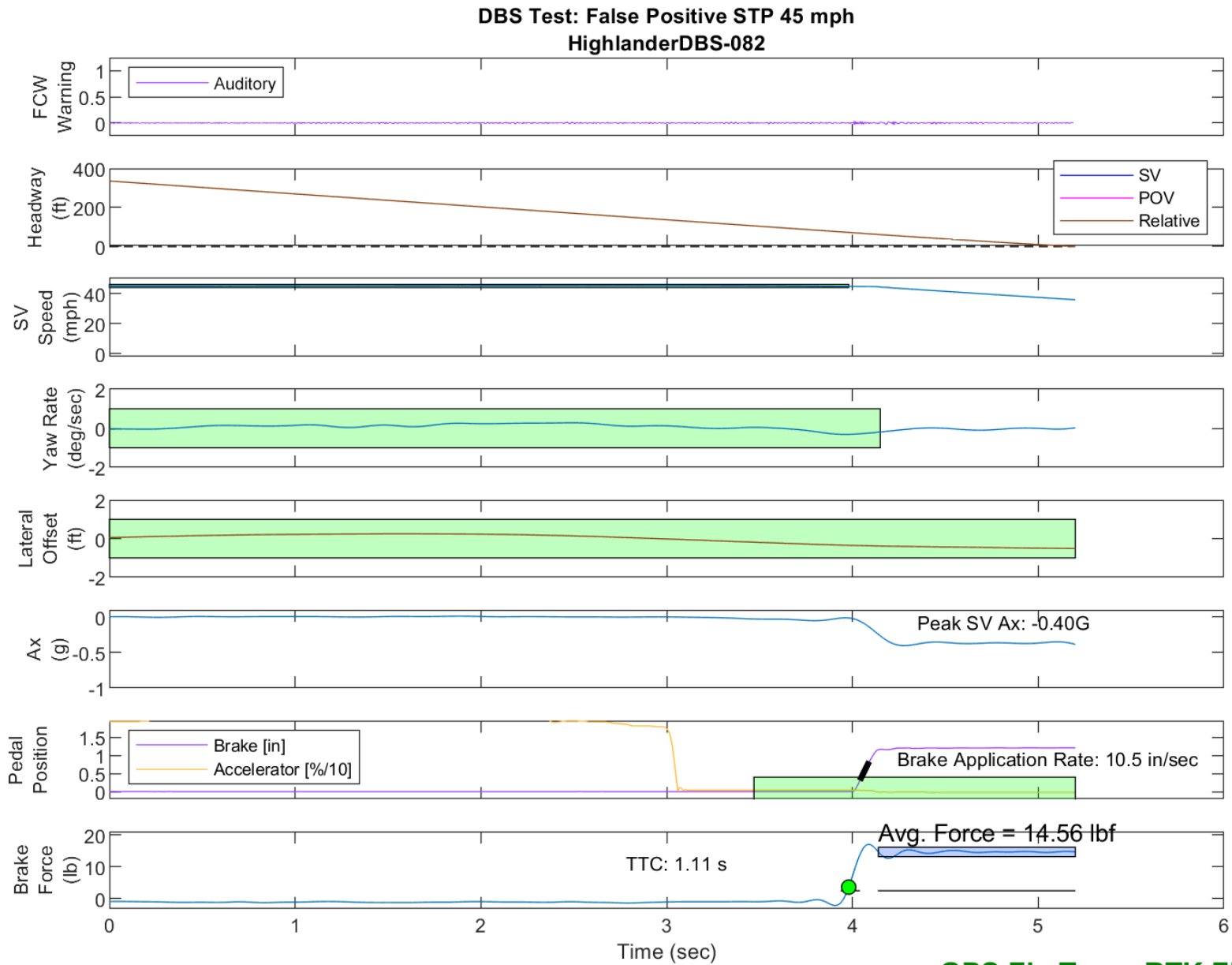
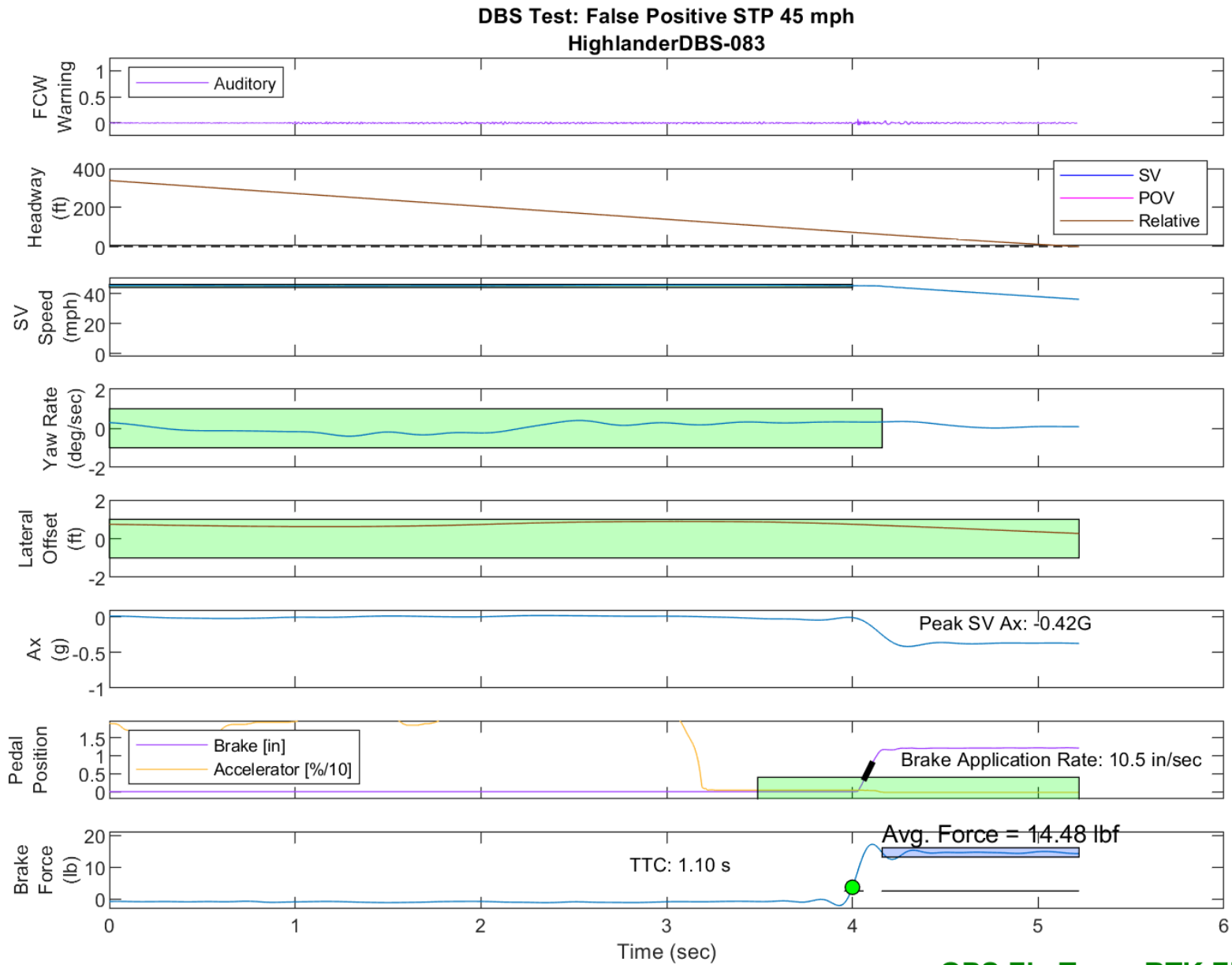


Figure E63. Time History for DBS Run 81, SV Encounters Steel Trench Plate, SV 45 mph



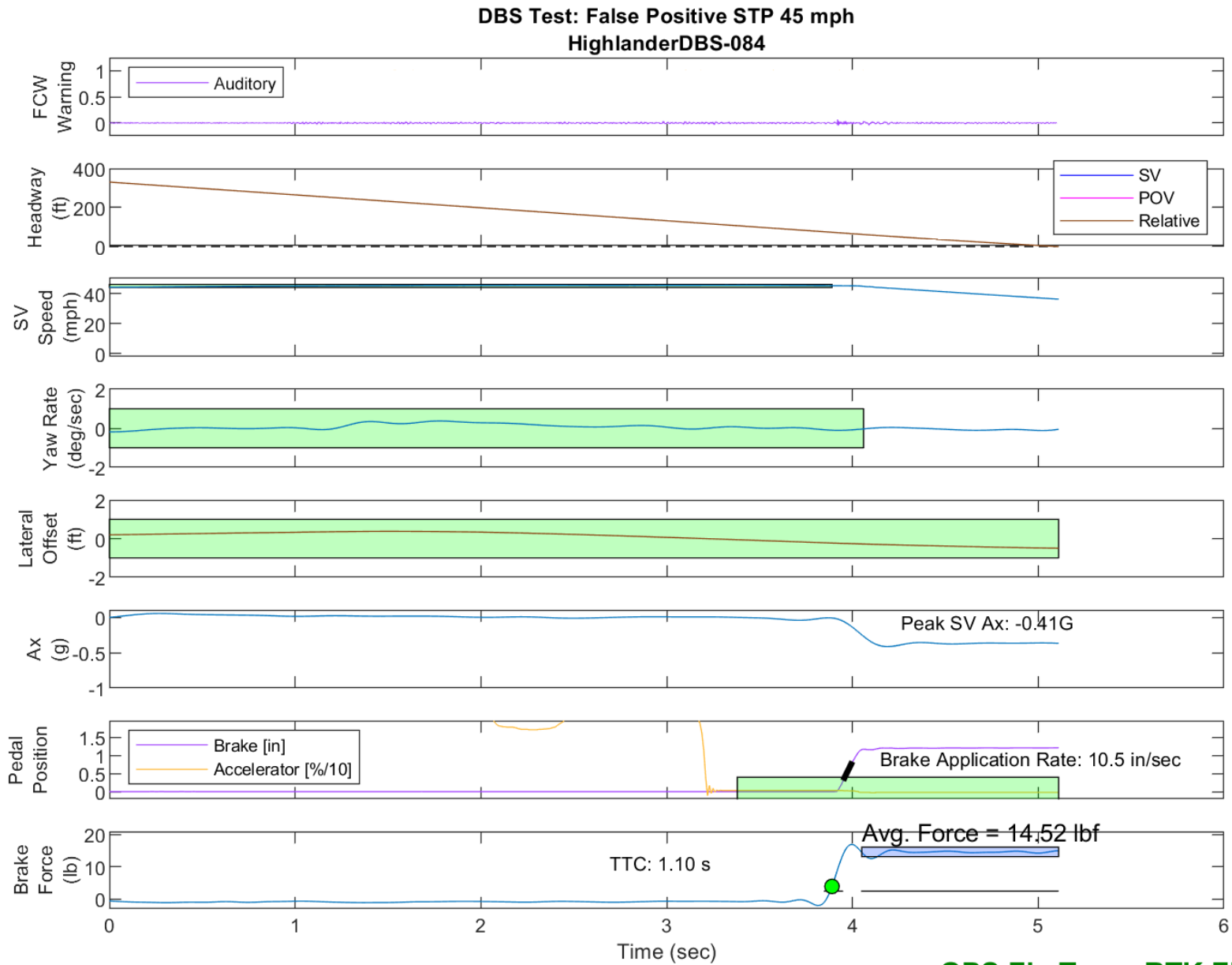
**GPS Fix Type: RTK Fixed**

Figure E64. Time History for DBS Run 82, SV Encounters Steel Trench Plate, SV 45 mph



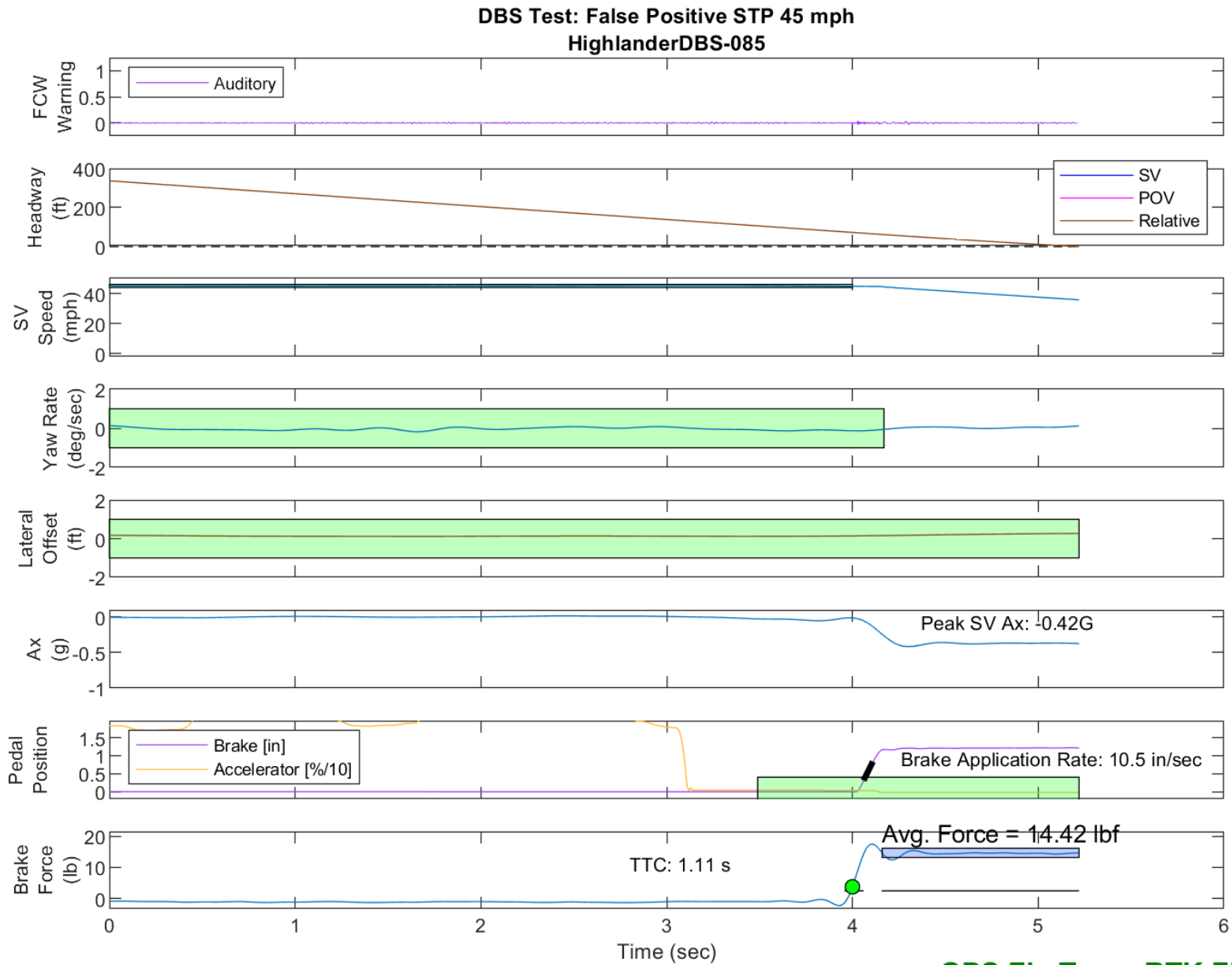
**GPS Fix Type: RTK Fixed**

Figure E65. Time History for DBS Run 83, SV Encounters Steel Trench Plate, SV 45 mph



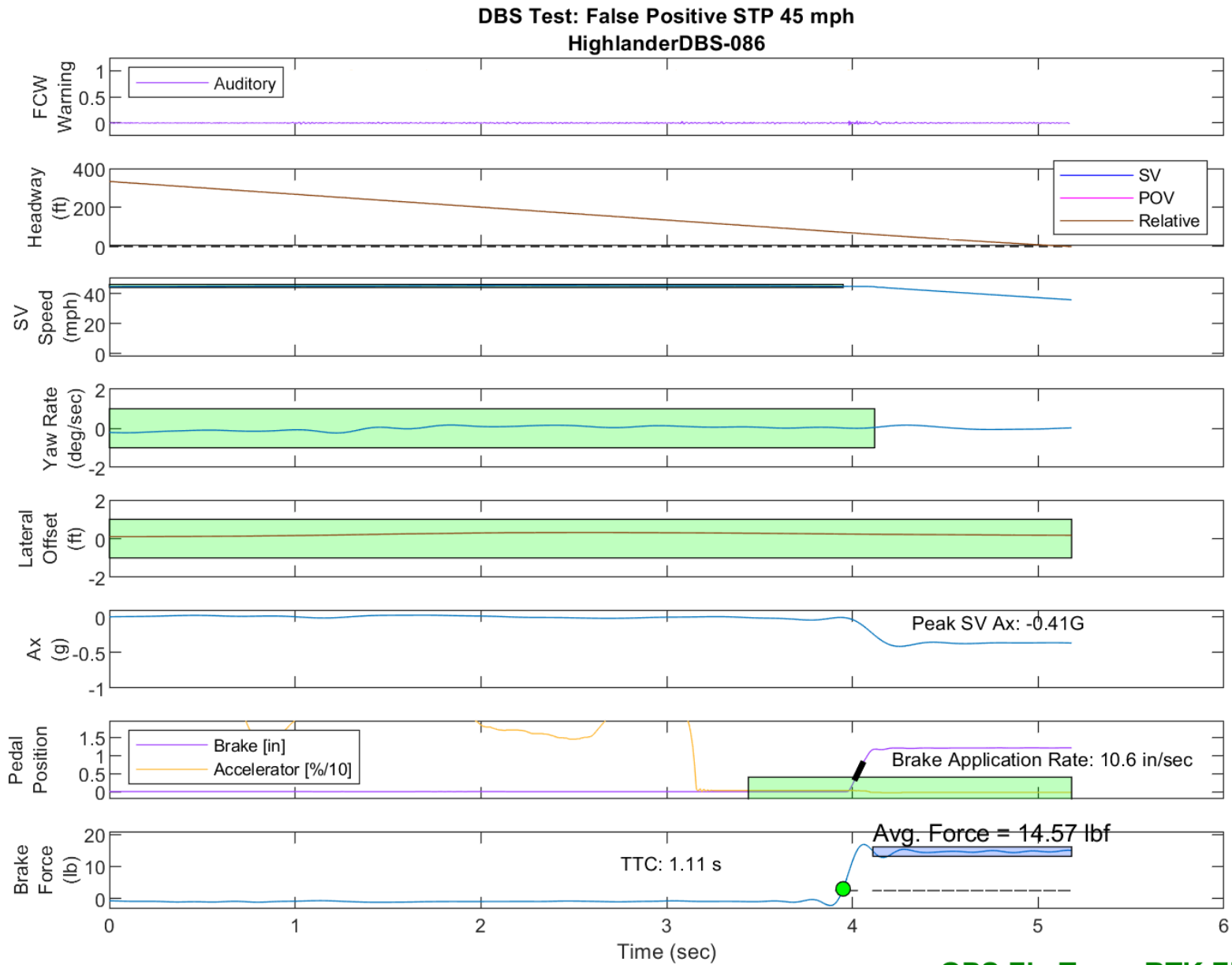
**GPS Fix Type: RTK Fixed**

Figure E66. Time History for DBS Run 84, SV Encounters Steel Trench Plate, SV 45 mph



GPS Fix Type: RTK Fixed

Figure E67. Time History for DBS Run 85, SV Encounters Steel Trench Plate, SV 45 mph



**GPS Fix Type: RTK Fixed**

Figure E68. Time History for DBS Run 86, SV Encounters Steel Trench Plate, SV 45 mph

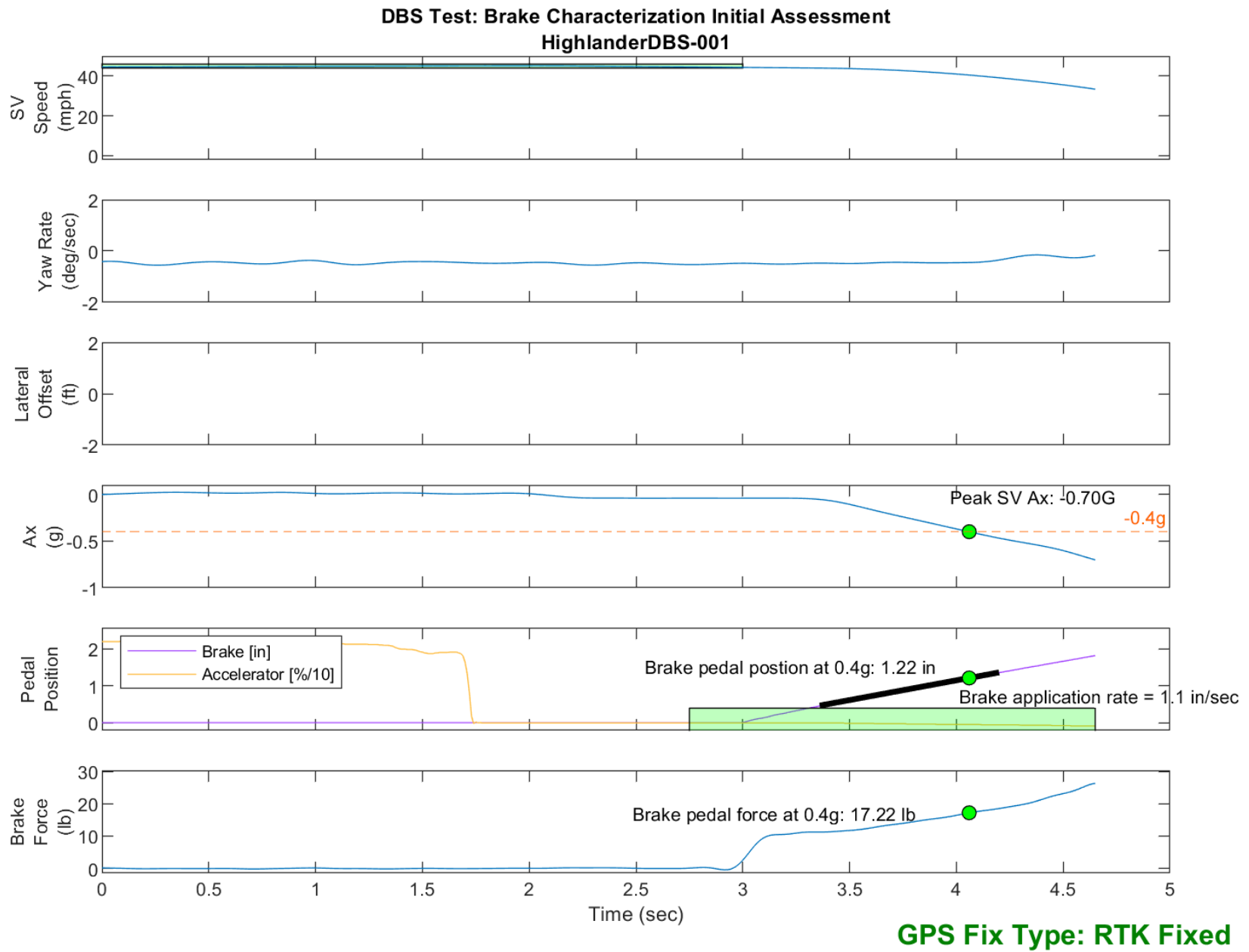


Figure E69. Time History for DBS Run 1, Brake Characterization Initial



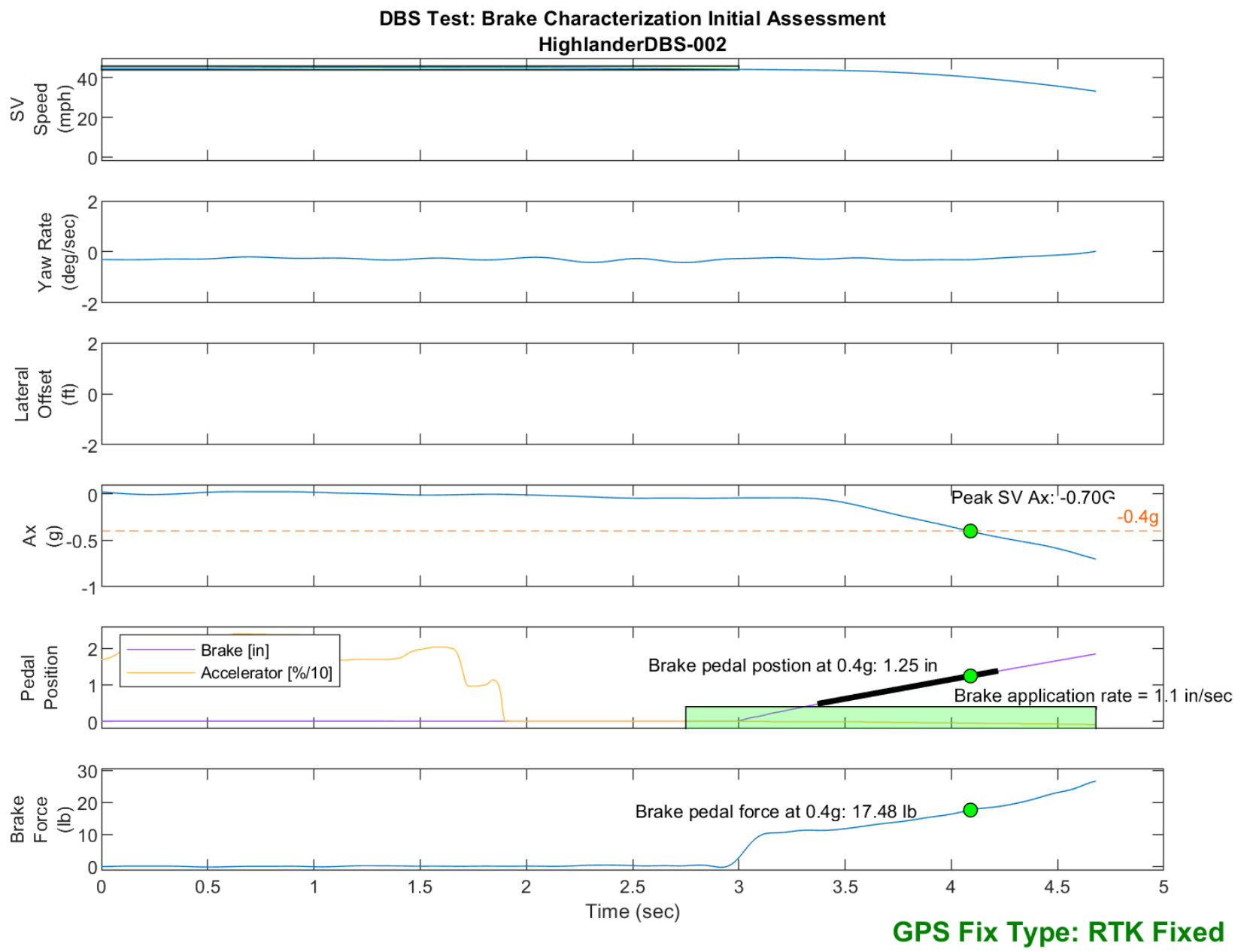


Figure E70. Time History for DBS Run 2, Brake Characterization Initial

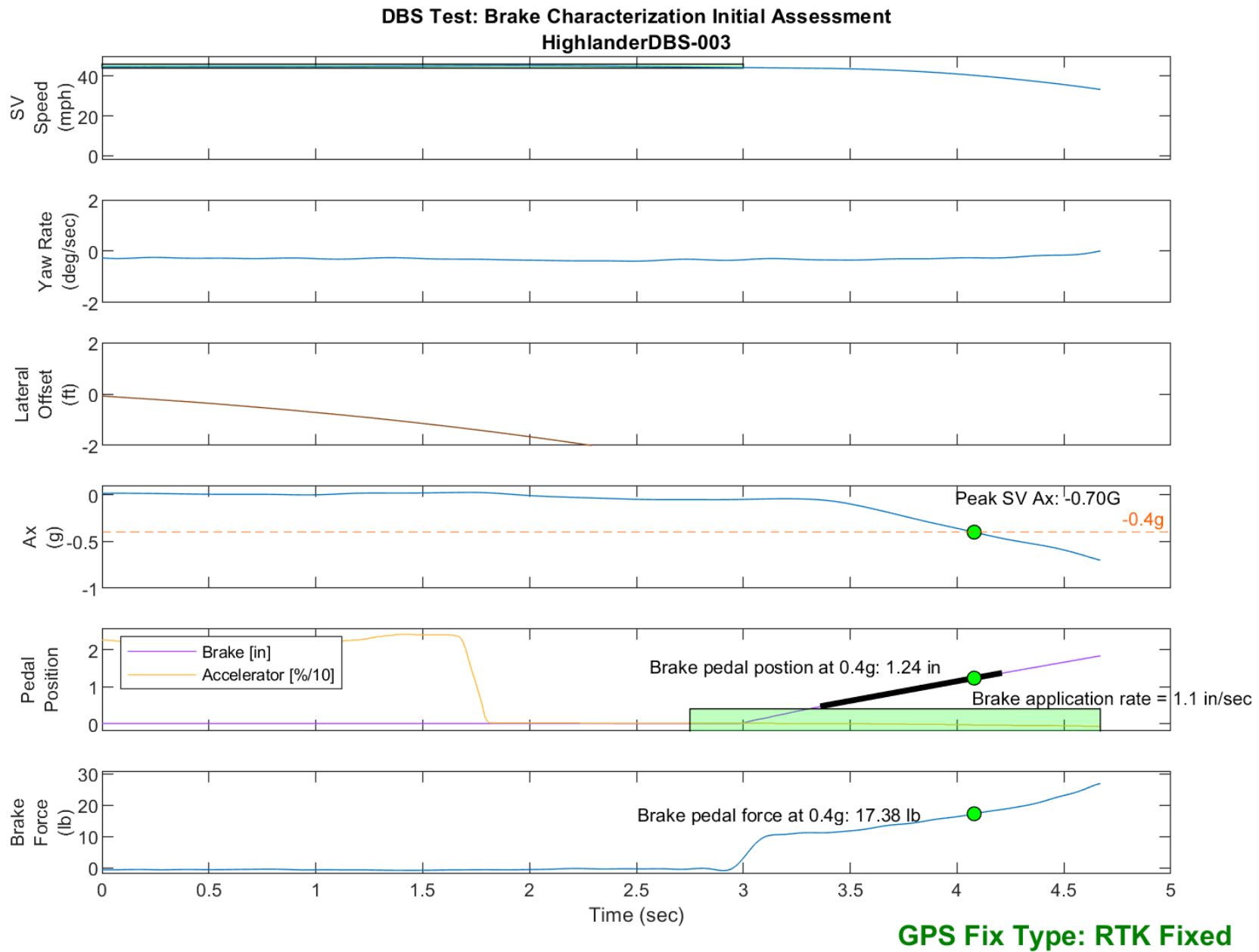


Figure E71. Time History for DBS Run 3, Brake Characterization Initial

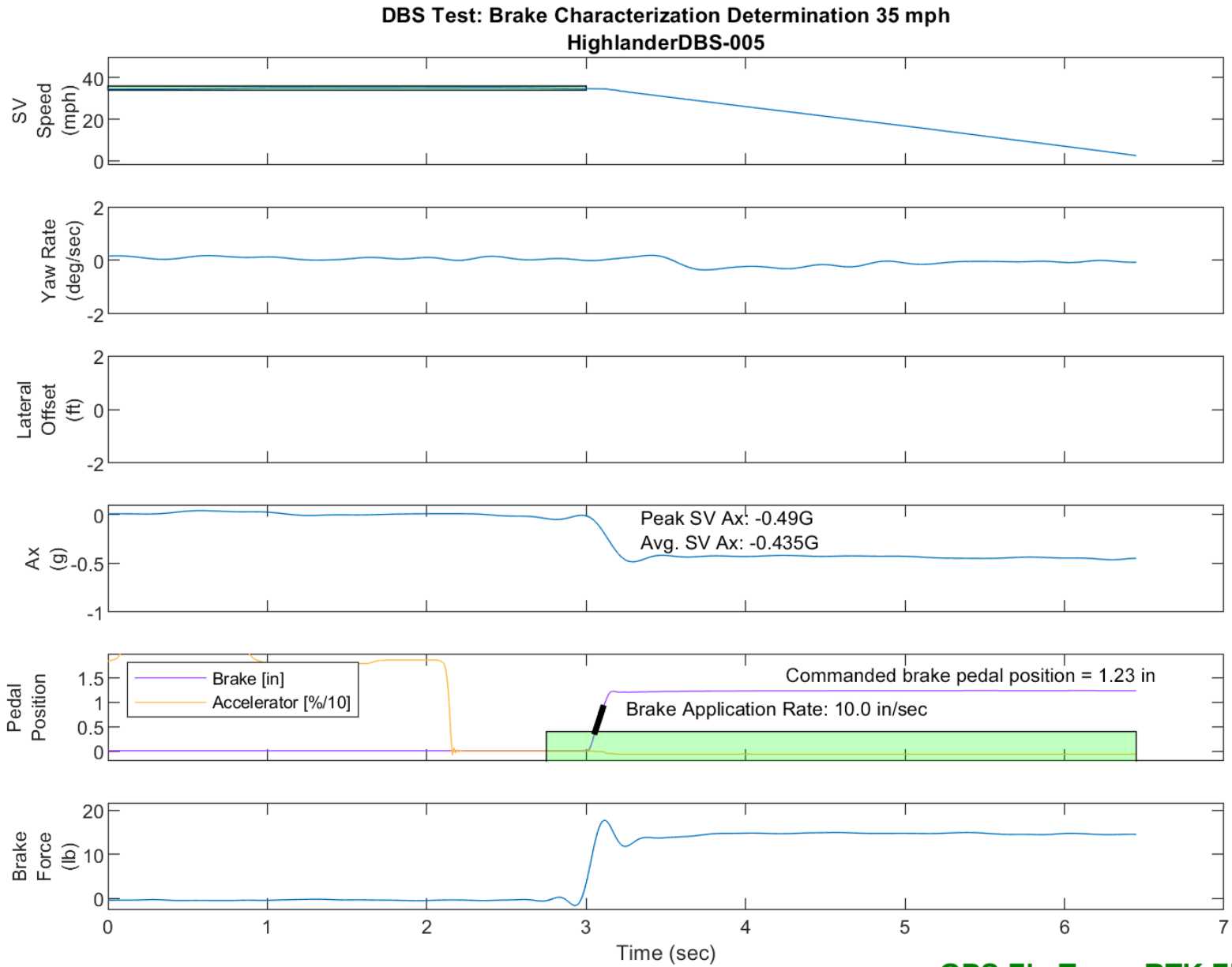
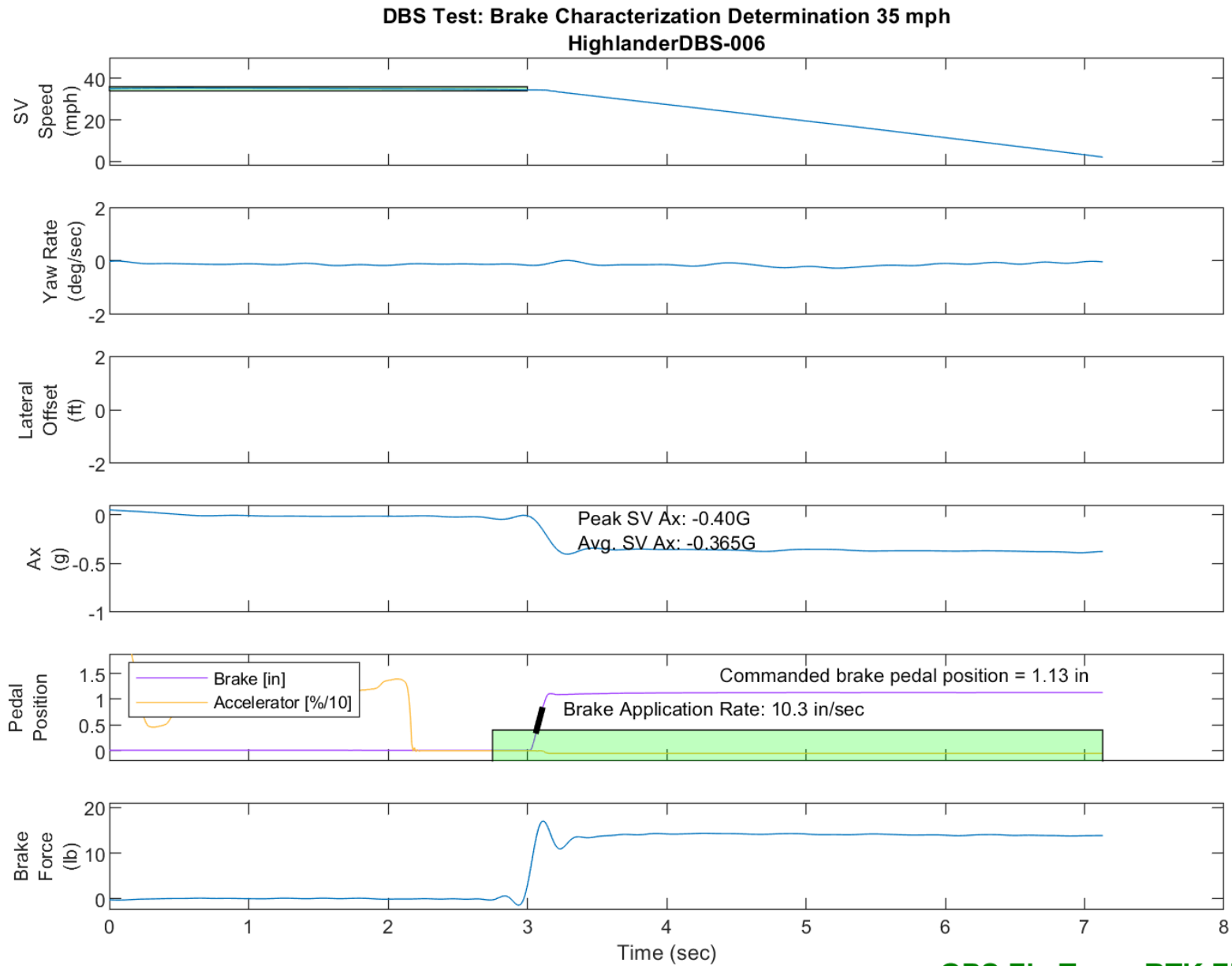


Figure E72. Time History for DBS Run 5, Brake Characterization Determination, Displacement Mode, 35 mph



**GPS Fix Type: RTK Fixed**

Figure E73. Time History for DBS Run 6, Brake Characterization Determination, Displacement Mode, 35 mph

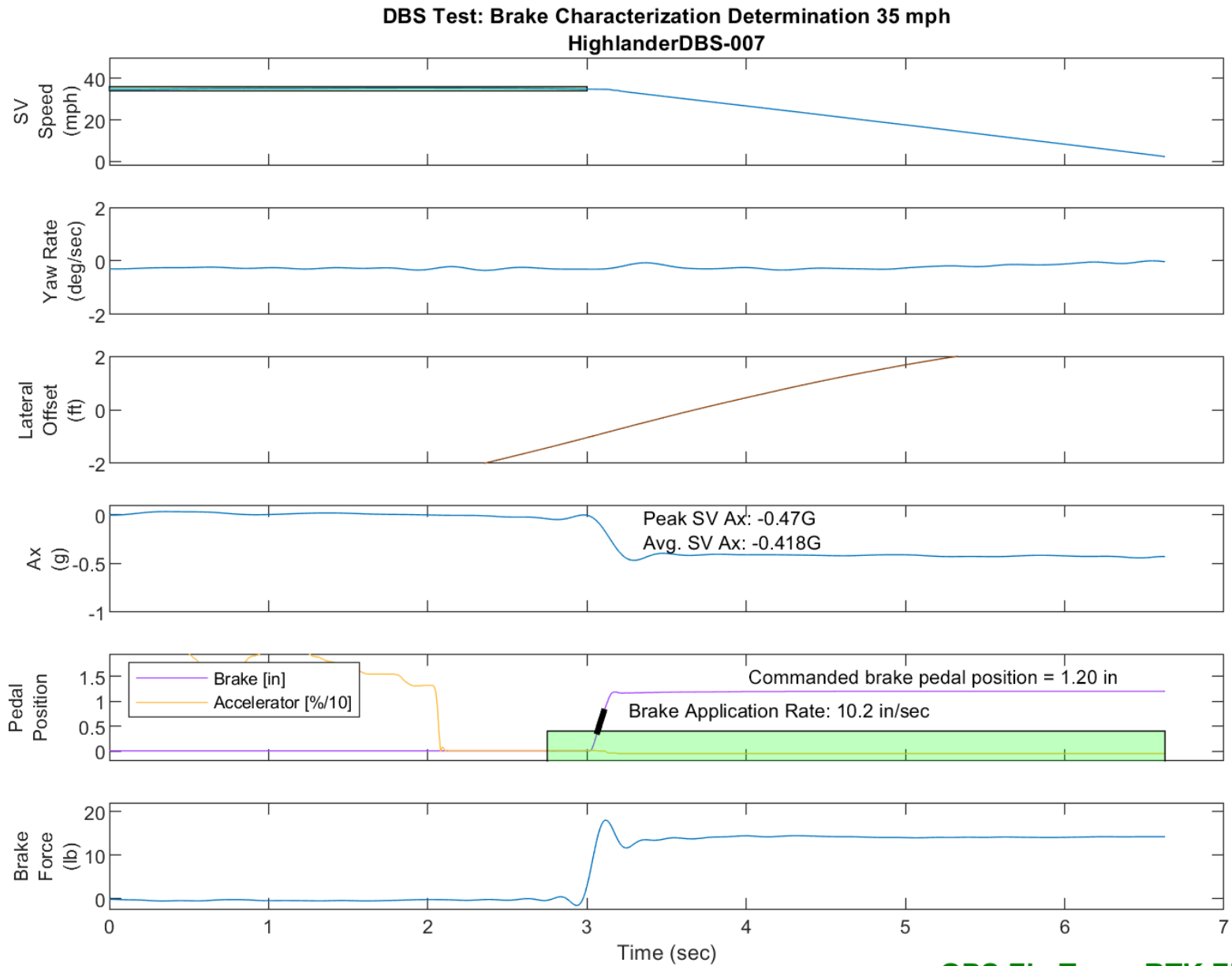
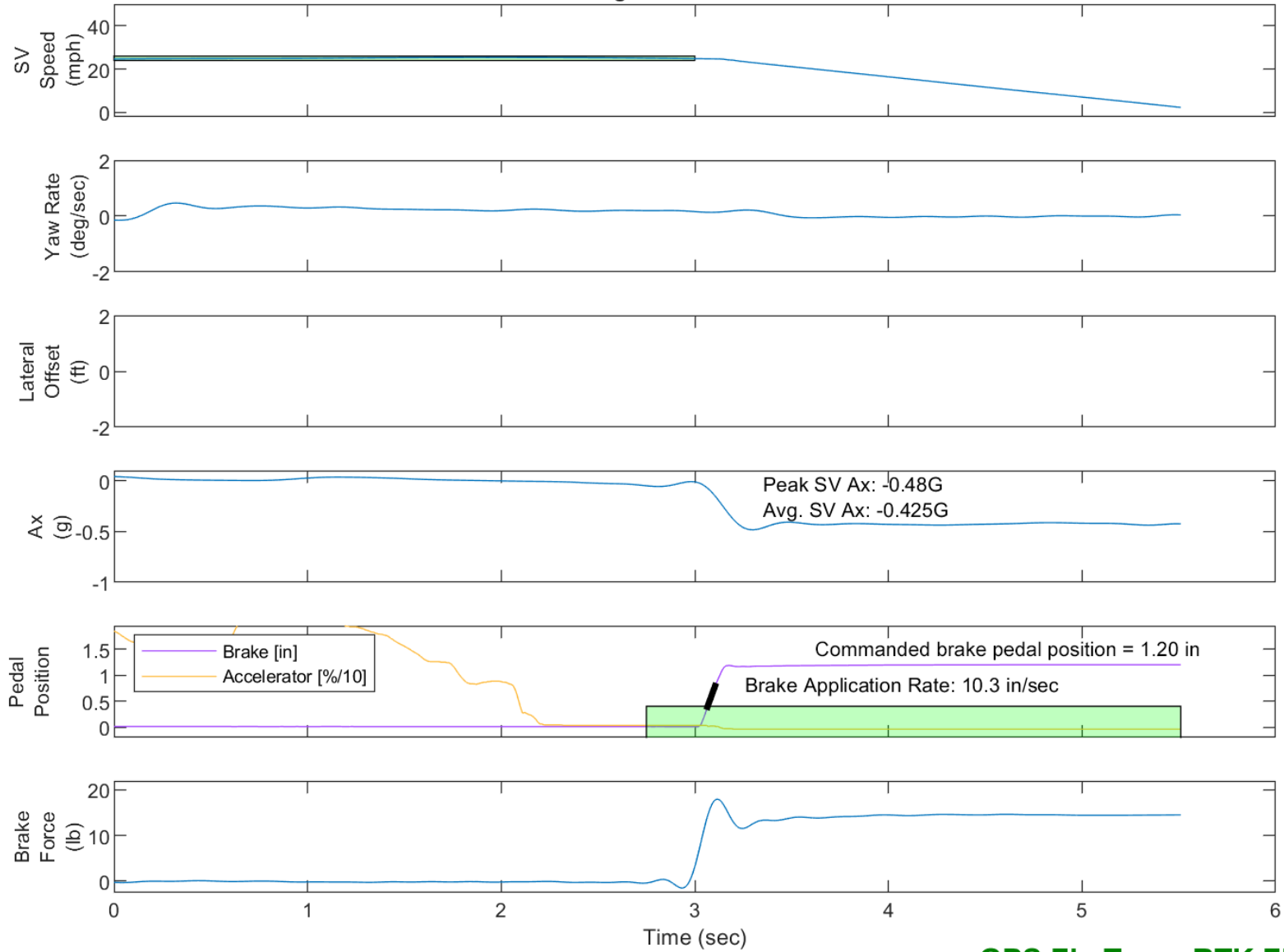


Figure E74. Time History for DBS Run 7, Brake Characterization Determination, Displacement Mode, 35 mph

### DBS Test: Brake Characterization Determination 25 mph HighlanderDBS-008



**GPS Fix Type: RTK Fixed**

Figure E75. Time History for DBS Run 8, Brake Characterization Determination, Displacement Mode, 25 mph

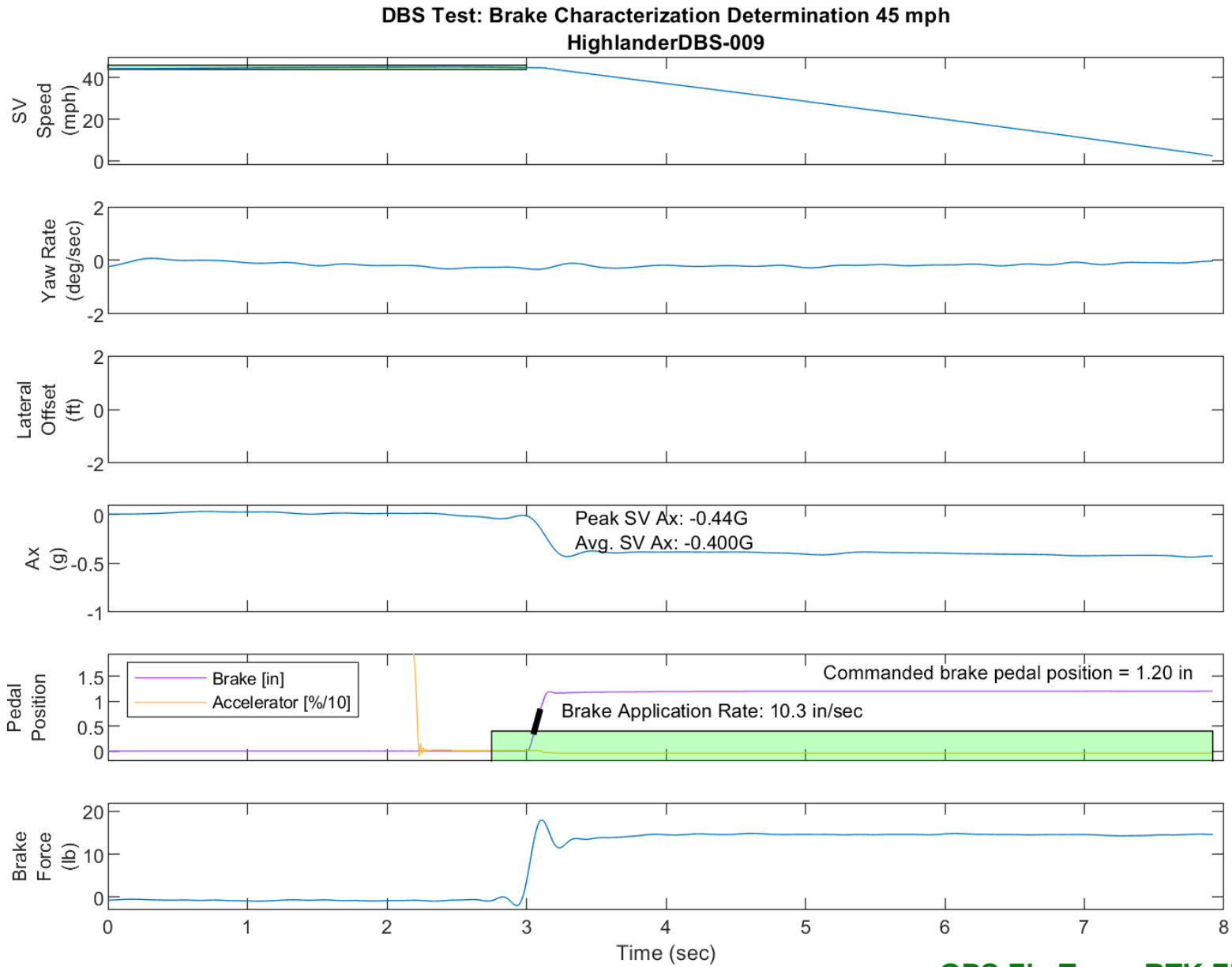


Figure E76. Time History for DBS Run 9, Brake Characterization Determination, Displacement Mode, 45 mph

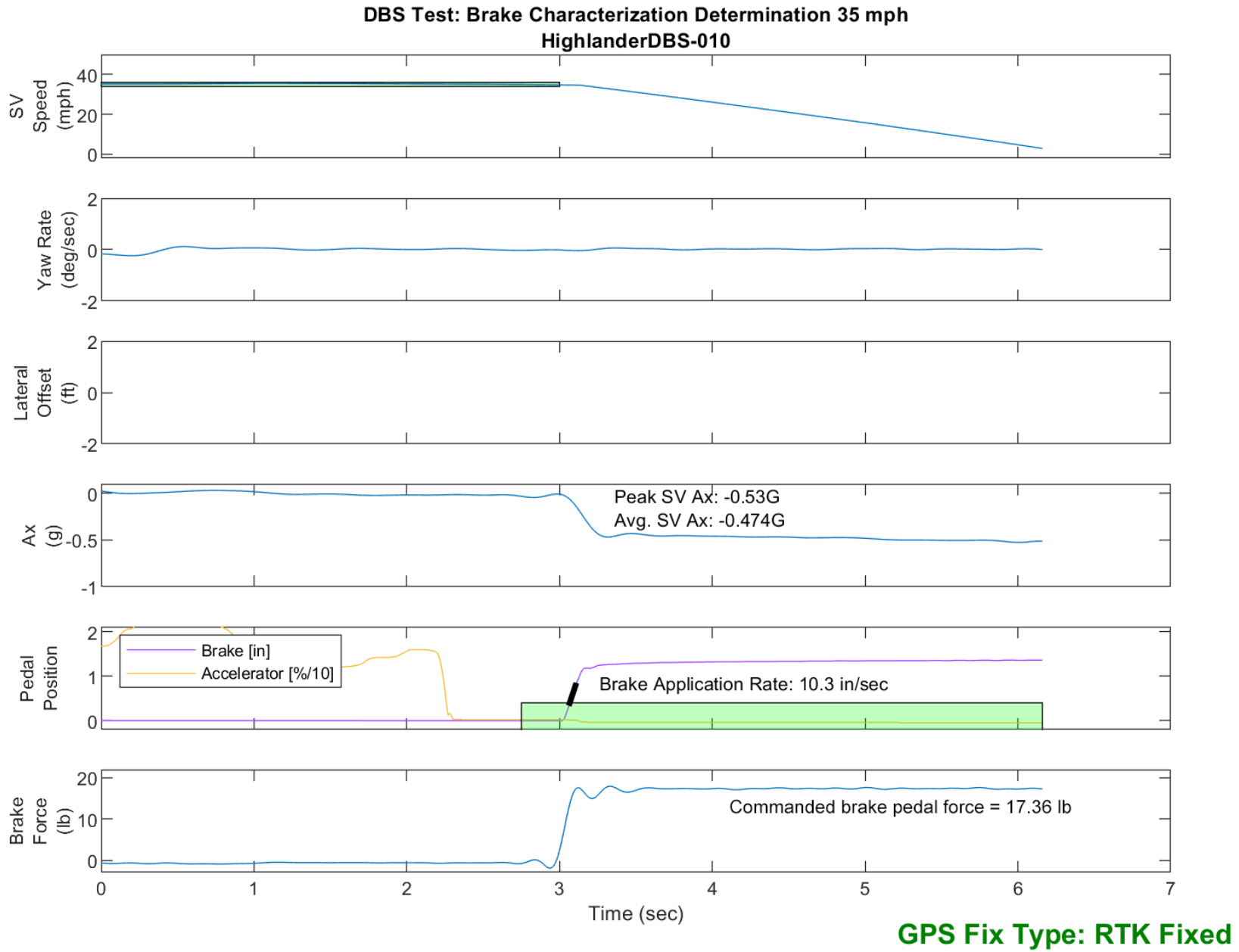
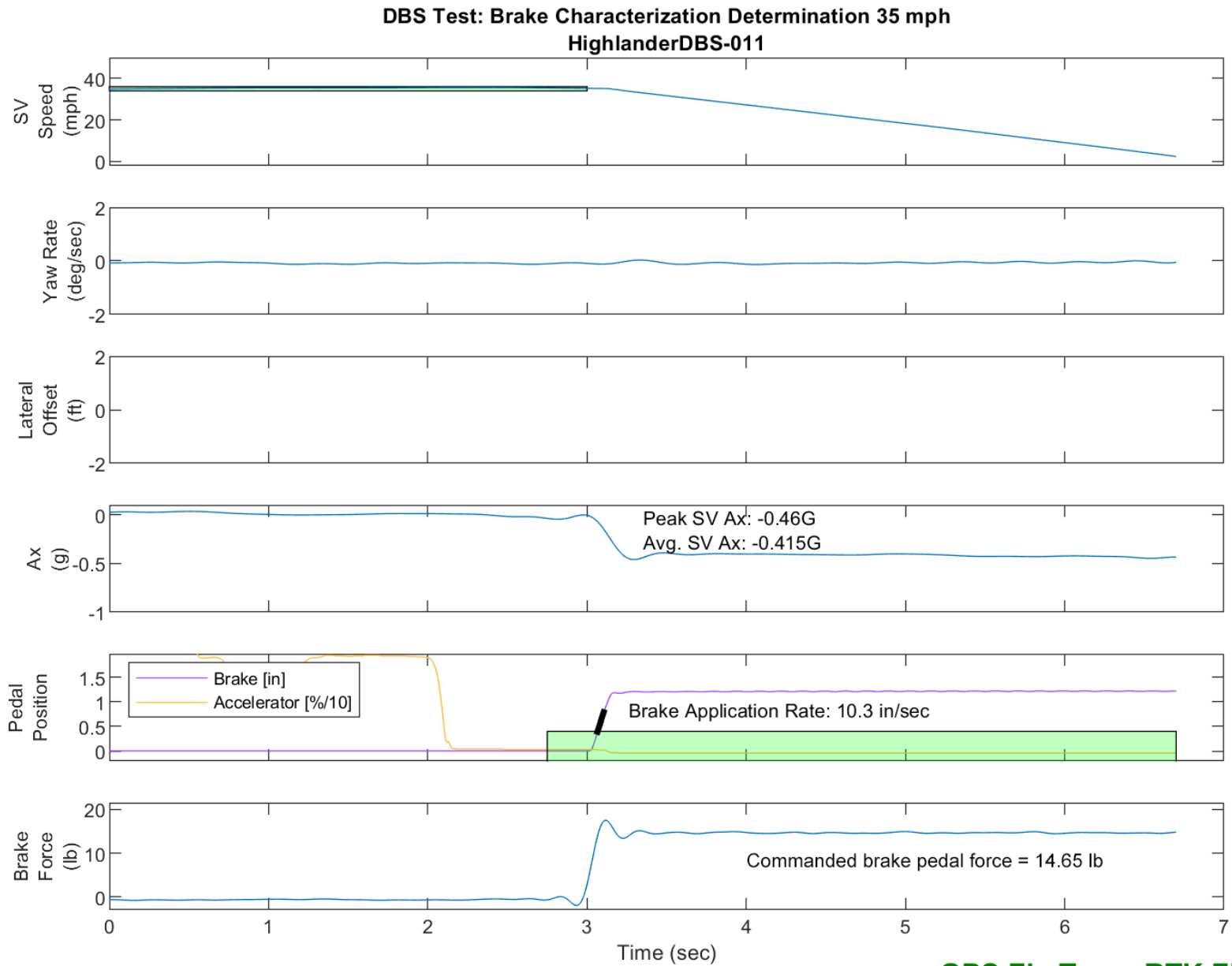


Figure E77. Time History for DBS Run 10, Brake Characterization Determination, Hybrid Mode, 35 mph

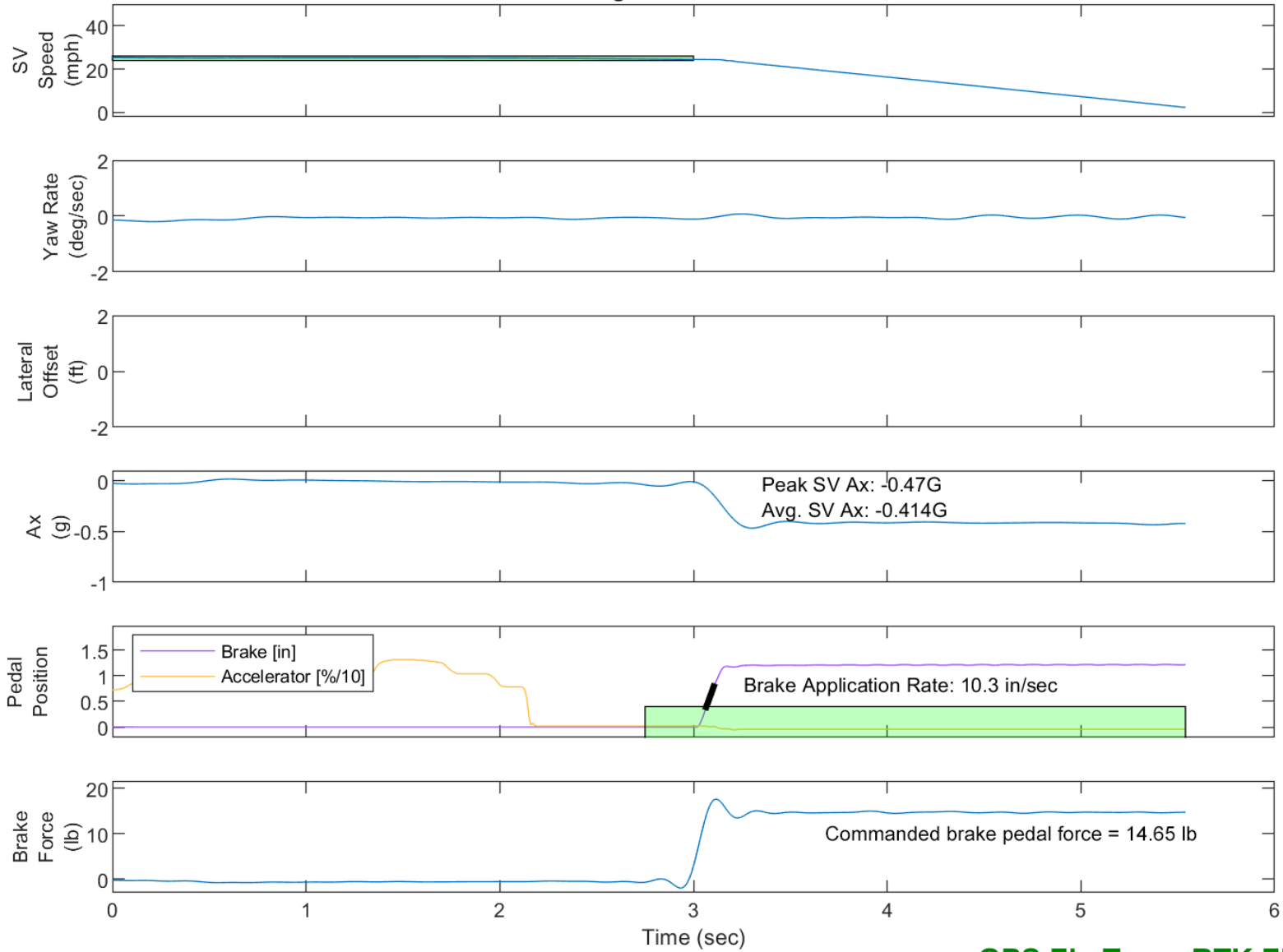




**GPS Fix Type: RTK Fixed**

Figure E78. Time History for DBS Run 11, Brake Characterization Determination, Hybrid Mode, 35 mph

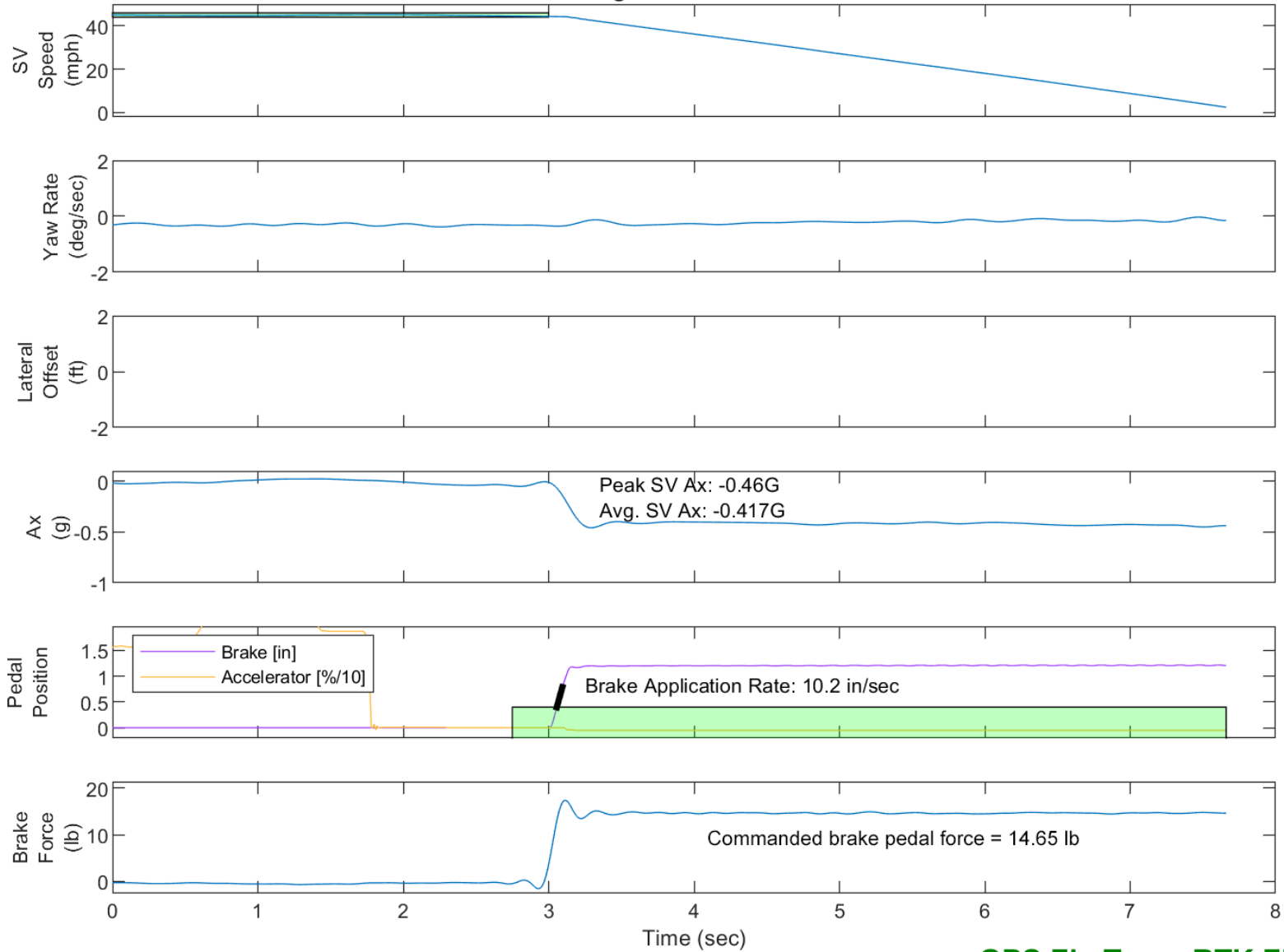
DBS Test: Brake Characterization Determination 25 mph  
HighlanderDBS-012



GPS Fix Type: RTK Fixed

Figure E79. Time History for DBS Run 12, Brake Characterization Determination, Hybrid Mode, 25 mph

DBS Test: Brake Characterization Determination 45 mph  
HighlanderDBS-013



GPS Fix Type: RTK Fixed

Figure E80. Time History for DBS Run 13, Brake Characterization Determination, Hybrid Mode, 45 mph