NEW CAR ASSESSMENT PROGRAM
DYNAMIC BRAKE SUPPORT SYSTEM CONFIRMATION TEST
NCAP-DRI-DBS-22-05

2022 Ford Explorer RWD

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

5 July 2022

Final Report

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

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
New Car Assessment Program
1200 New Jersey Avenue, SE
West Building, 4th Floor (NRM-110)
Washington, DC 20590

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

Prepared By: Stephen Rhim and Anthony Saldana

Senior Engineer Staff Engineer

Date: 5 July 2022

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NCAP-DRI-DBS-22-05		

4. Title and Subtitle	5. Report Date
Final Report of Dynamic Brake Support System Confirmation Test of a 2022 Ford Explorer RWD.	5 July 2022
	6. Performing Organization Code DRI
7. Author(s) Stephen Rhim, Senior Engineer Anthony Saldana, Staff Engineer	8. Performing Organization Report No. DRI-TM-21-98
9. Performing Organization Name and Address Dynamic Research, Inc. 355 Van Ness Ave, STE 200 Torrance, CA 90501	10. Work Unit No. 11. Contract or Grant No. DTNH22-14-D-00333
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration New Car Assessment Program 1200 New Jersey Avenue, SE, West Building, 4th Floor (NRM-110) Washington, DC 20590	13. Type of Report and Period Covered Final Test Report July 2022 14. Sponsoring Agency Code NRM-110

15. Supplementary Notes

16. Abstract

These tests were conducted on the subject 2022 Ford Explorer RWD in accordance with the specifications of the New Car Assessment Program's (NCAP's) most current Test Procedure in docket NHTSA-2015-0006-0026; DYNAMIC BRAKE SUPPORT PERFORMANCE EVALUATION CONFIRMATION TEST FOR THE NEW CAR ASSESSMENT PROGRAM**,** October 2015. The vehicle passed the requirements of the test for all four DBS test scenarios.

17. Key Words	18. Distribution Statement
Dynamic Brake Support, DBS, AEB, New Car Assessment Program, NCAP	Copies of this report are available from the following: NHTSA Technical Reference Division National Highway Traffic Safety Administration 1200 New Jersey Avenue, SE Washington, DC 20590

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	146	

TABLE OF CONTENTS

Section I

INTRODUCTION

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

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

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

The purpose of the testing reported herein was to objectively quantify the performance of a Dynamic Brake Support system installed on a 2022 Ford Explorer RWD. 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)

2022 Ford Explorer RWD

VIN: *1FMSK7DH0NGB6xxxx*

Test start date: *6/28/2022* Test end date: *6/30/2022*

Dynamic Brake Support System settings: *High (FCW sensitivity only)*

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:

2022 Ford Explorer RWD

TEST VEHICLE INFORMATION

VIN: *1FMSK7DH0NGB6xxxx*

Body Style: *SUV* Color: *Carbonized Gray Metallic*

Date Received: *6/20/2022* Odometer Reading: *33 mi*

DATA FROM VEHICLE'S CERTIFICATON LABEL

Vehicle manufactured by: *Ford Motor Co.*

Date of manufacture: *05/22*

Vehicle Type: *MPV*

DATA FROM TIRE PLACARD

Tires size as stated on Tire Placard: Front: *255/65R18*

Rear: *255/65R18*

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

Rear: *230 kPa (33 psi)*

TIRES

Tire manufacturer and model: *Hankook Kinergy GT*

Front tire specification: *255/65R18 111H*

Rear tire specification: *255/65R18 111H*

Front tire DOT prefix: *00T68 2V HA*

Rear tire DOT prefix: *00T68 2V HA*

DYNAMIC BRAKE SUPPORT

DATA SHEET 3: TEST CONDITIONS

(Page 1 of 2)

2022 Ford Explorer RWD

GENERAL INFORMATION

Test start date: *6/28/2022* Test start date: *6/30/2022*

AMBIENT CONDITIONS

Air temperature: *39.4 C (103 F)*

Wind speed: *6.2 m/s (13.8 mph)*

X Wind speed ≤ 10 m/s (22 mph).

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

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

VEHICLE PREPARATION

Verify the following:

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

Fuel tank is full: **X**

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

Front: *230 kPa (33 psi)*

Rear: *230 kPa (33 psi)*

DYNAMIC BRAKE SUPPORT

DATA SHEET 3: TEST CONDITIONS

(Page 2 of 2)

2022 Ford Explorer RWD

WEIGHT

Weight of vehicle as tested including driver and instrumentation

Left Front:	*543.0 kg (1197 lb)*	Right Front:	*500.8 kg (1104 lb)*
Left Rear:	*506.2 kg (1116 lb)*	Right Rear:	*508.0 kg (1120 lb)*
		Total:	*2058.0 kg (4537 lb)*

DATA SHEET 4: DYNAMIC BRAKE SUPPORT SYSTEM OPERATION

2022 Ford Explorer RWD

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

Pre-Collision Assist with Automatic Emergency Braking comes standard on the vehicle model as part of the Ford Co-Pilot360 package.

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

The AEB system uses a mono-camera system which is located in the upper center windshield.

System settings used for test (if applicable):

High (FCW sensitivity only)

Brake application mode used for test: *Constant pedal displacement*

Over what speed range is the system operational?

The AEB system is operational from 5-120 km/h (3-75 mph) per the owner's manual.

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

___ No

If yes, please provide a full description.

The vehicle must be driven above 35 mph for 40 to 50 miles on a roadway with moving and stationary targets to confirm the sensors are fully aligned.

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

X Yes

___ No

If yes, please provide a full description.

The system will deactivate due to three consecutive AEB activations within a short (approximately 1 minute) timeframe. This is indicated to the driver via a visual message that reads "Pre-Collision Assist Not Available" displayed in yellow text within the instrument panel cluster. If the system is deactivated due to consecutive activations within the short timeframe, it can be reactivated via an ignition cycle.

How is the Forward Collision Warning presented to the driver?

(Check all that apply)

X Warning light

X Buzzer or auditory alarm

___ Vibration

___ Other ______________

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

The AEB system alerts the driver with a visual and auditory alert. The visual alert is displayed in the instrument panel and consists of a red flashing box with the words "Pre-Collision Assist" and an image of two vehicles. The auditory alert consists of repeated beeps with a primary frequency of 1800 Hz.

Is there a way to deactivate the system? **X** Yes / ___ No

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

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

1. Select "Settings" -> "Driver Assistance Settings" -> "Pre-Collision Assist".

2. Select "Active Braking" to turn the AEB system on/off.

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

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

If yes, please provide a full description.

The vehicle offers three FCW sensitivity settings (High, Normal, Low) using the touch screen display, however this does not affect the performance of the AEB system.

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

If yes, please provide a full description.

For low-visibility conditions (e.g., fog, rain, snow, etc.), the sensing system's effectiveness will likely be degraded or potentially inoperable (particularly for the camera-only sensing variant). For low-friction conditions (e.g., icy or wet pavement), stopping distance may be adversely affected. Refer to the owner's manual pages 273 to 274 shown in Appendix B pages B-2 to B-3 for additional information.

Notes:

Section III

TEST PROCEDURES

A. Test Procedure Overview

Four test scenarios were used, as follows:

Test 1. Subject Vehicle (SV) Encounters Stopped Principal Other Vehicle (POV)

Test 2. Subject Vehicle Encounters Slower Principal Other Vehicle

Test 3. Subject Vehicle Encounters Decelerating Principal Other Vehicle

Test 4. Subject Vehicle Encounters Steel Trench Plate

An overview of each of the test procedures follows.

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

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

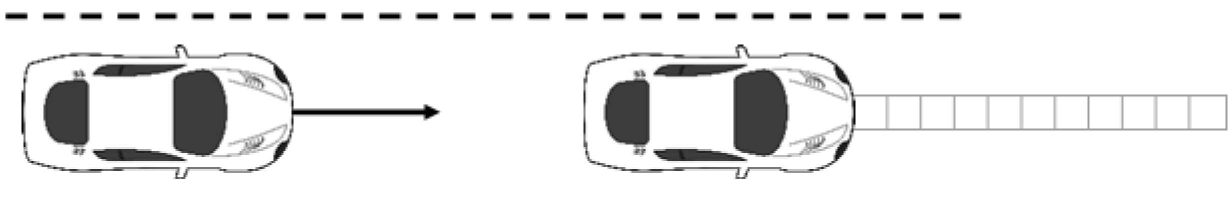


Figure 1. Depiction of Test 1

a. Procedure

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

The SV ignition was cycled prior to each test run. The SV was driven at a nominal speed of 25 mph (40.2 km/h) in the center of the lane of travel, toward the parked POV. The SV throttle pedal was released within 500 ms after t_{FCW}, i.e., within 500 ms of the FCW alert or SV brake application if no FCW alert was given. The SV brakes were applied at TTC = 1.1 seconds (SV-to-POV distance of 40 ft (12 m)). The test concluded when either:

- The SV came into contact with the POV or

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

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

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

Table 1. Nominal Stopped POV DBS Test Choreography

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

b. Criteria

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

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

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

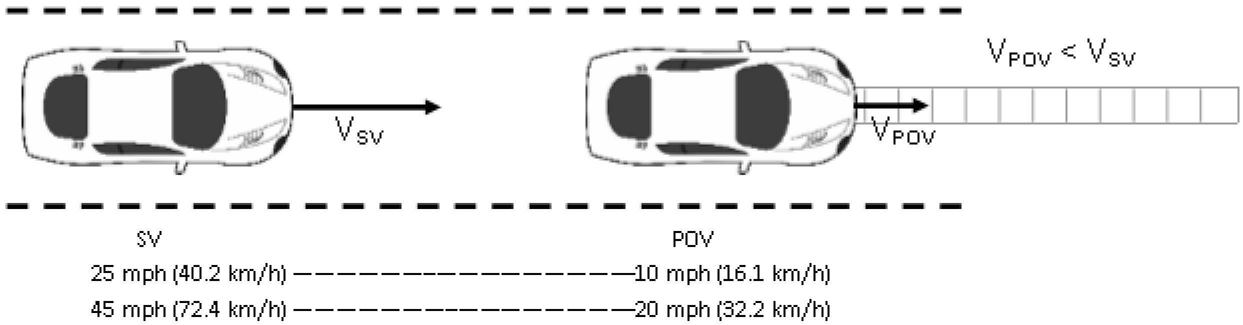


Figure 2. Depiction of Test 2

a. Procedure

The SV ignition was cycled prior to each test run. The tests were conducted two ways. In the first, the POV was driven at a constant 10.0 mph (16.1 km/h) in the center of the lane of travel while the SV was driven at 25.0 mph (40.2 km/h), in the center lane of travel, toward the slower-moving POV. In the second, the POV was driven at a constant 20.0 mph (32.2 km/h) in the center of the lane of travel while the SV was driven at 45.0 mph (72.4 km/h), in the center lane of travel, toward the slower-moving POV. In both cases, the SV throttle pedal was released within 500 ms after t_{FCW}, i.e., within 500 ms of the FCW alert or SV brake application if no FCW alert was given. The SV brakes were applied at TTC = 1.0 seconds, assumed to be SV-to-POV distance of 22 ft (7 m) for an SV speed of 25 mph and 37 ft (11 m) for an SV speed of 45 mph.

The test concluded when either:

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

The SV driver then braked to a stop.

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

- The lateral distance between the centerline of the SV and POV to the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The yaw rate of the SV and POV could not deviate more than ±1 deg/sec during the validity period.
- The SV speed could not deviate more than ±1.0 mph (±1.6 km/h) during an interval defined by TTC = 5.0 seconds to t_{FCW} or impact if no FCW alert was given.
- The POV speed could not deviate more than ±1.0 mph (±1.6 km/h) during the validity period.

Table 2. Nominal Slower-Moving POV DBS Test Choreography

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

b. Criteria

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

3. <u>TEST 3 – SUBJECT VEHICLE ENCOUNTERS DECELERATING PRINCIPAL OTHER VEHICLE</u>

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

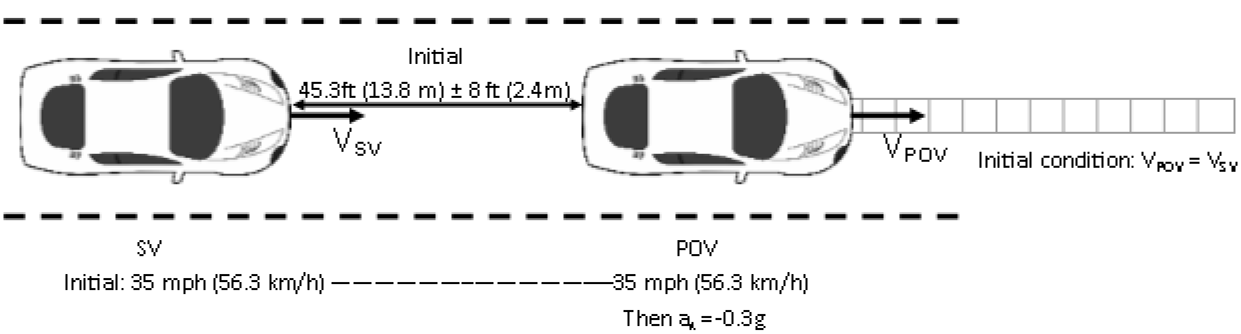


Figure 3. Depiction of Test 3

a. Procedure

The SV ignition was cycled prior to each test run. For this scenario both the POV and SV were driven at a constant 35.0 mph (56.3 km/h) in the center of the lane, with headway of 45.3 ft (13.8 m) ± 8 ft (2.4 m). Once these conditions were met, the POV tow vehicle brakes were applied to achieve 0.3 ± 0.03 g of deceleration within 1.5 ± 0.1 sec. The SV throttle pedal was released within 500 ms of t_{FCW} or SV brake application if no FCW alert was given. The SV brakes were applied when TTC was 1.4 seconds (31.5 ft (9.6 m)).

The test concluded when either:

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

The SV driver then braked to a stop.

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

- The lateral distance between the centerline of the SV and POV to the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The yaw rate of the SV and POV could not deviate more than ±1 deg/sec during the validity period.
- The SV speed could not deviate more than ±1.0 mph (1.6 km/h) during an interval defined by 3.0 seconds before the onset of POV braking to t_{FCW} or impact if no FCW alert was given.
- The POV speed could not deviate more than ±1.0 mph (1.6 km/h) during an interval of 3.0 seconds before the onset of POV braking.
- The SV- POV headway distance could not deviate more than ±8 ft (2.4 m) during an interval defined by the onset of the validity period to the onset of POV braking.
- The average POV deceleration could not deviate by more than ±0.03 g from the nominal 0.3 g deceleration during the interval beginning at 1.5 seconds after the onset of POV braking and ending either 250 ms prior to the POV coming to a stop or the SV coming into contact with the POV.

Table 3. Nominal Decelerating POV DBS Test Choreography

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

b. Criteria

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

4. TEST 4 – FALSE POSITIVE SUPPRESSION

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

a. Procedure

This test was conducted at two speeds, 25 mph (40.2 km/h) and 45 mph (72.4 km/h). The SV was driven directly towards, and over, the STP, which was positioned in the center of a travel lane, with its longest sides parallel to the road edge. The test concluded when the front of the SV reached the leading edge of the STP.

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

- The lateral distance between the centerline of the SV to the center of the travel lane could not deviate more than ±1 ft (0.3 m) during the validity period.
- The yaw rate of the SV could not deviate more than ±1 deg/sec during the validity period.
- The SV speed could not deviate from the nominal speed by more than 1.0 mph (1.6 km/h) during an interval of 2 seconds prior to the throttle being released.
- The throttle pedal was modulated using smooth inputs until an FCW alert was presented or a TTC = 2.1 s, at which point the SV driver released the throttle pedal within 500 ms.
- The SV brakes were then applied at TTC = 1.1 seconds.
    - For SV test speed of 25 mph, TTC = 1.1 seconds is taken to occur at an SV-to-STP distance of 40 ft (12.3 m).
    - For SV test speed of 45 mph, TTC = 1.1 seconds is taken to occur at an SV-to-STP distance of 73 ft (22.1 m).

b. Criteria

In order to pass the False Positive test series, the magnitude of the SV deceleration reduction attributable to DBS intervention must have been less than or equal to 1.5 times the average of the deceleration experienced by the baseline command from the braking actuator for at least five of seven valid test trials.

B. General Information

1. T_{FCW}

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

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

Table 4. Auditory and Tactile Warning Filter Parameters

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

2. GENERAL VALIDITY CRITERIA

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

- The SV driver seatbelt was latched.
- If any load had been placed on the SV front passenger seat (e.g., for instrumentation), the vehicle's front passenger seatbelt was latched.
- The SV was driven at the nominal speed in the center of the travel lane, toward the POV or STP.
- The driver used the least amount of steering input necessary to maintain SV position in the center of the travel lane during the validity period; use of abrupt

steering inputs or corrections was avoided.

- The yaw rate of the SV did not exceed ±1.0 deg/s from the onset of the validity period to the instant SV deceleration exceeded 0.25 g.
- The SV driver did not apply any force to the brake pedal during the during the applicable validity period. All braking shall be performed by the programmable brake controller.
- The lateral distance between the centerline of the SV and the centerline of the POV or STP did not deviate more than ±1 ft (0.3 m) during the applicable validity period.

3. VALIDITY PERIOD

The valid test interval began:

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

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

Test 3: 3 seconds before the onset of POV braking

Test 4: When the SV-to-STP TTC = 5.1 seconds

The valid test interval ended:

Test 1: When either of the following occurred:

- The SV came into contact with the POV (assessed by using GPS-based range data); or
- The SV came to a stop before making contact with the POV.

Tests 2 and 3: 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 4: The front of the SV reached the leading edge of the STP.

4. STATIC INSTRUMENTATION CALIBRATION

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

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

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

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

5. NUMBER OF TRIALS

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

6. TRANSMISSION

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

C. Principal Other Vehicle

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

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

- A POV shell which is a visually and dimensionally accurate representation of a passenger car.
- A slider and load frame assembly to which the shell is attached.
- A two-rail track on which the slider operates.
- A road-based lateral restraint track.
- A tow vehicle.

The key requirements of the POV element are to:

- Provide an accurate representation of a real vehicle to DBS sensors, including cameras and radar.
- Be resistant to damage and inflict little or no damage to the SV as a result of

repeated SV-to-POV impacts.

The key requirements of the POV delivery system are to:

- Accurately control the nominal POV speed up to 35 mph (56 km/h).
- Accurately control the lateral position of the POV within the travel lane.
- Allow the POV to move away from the SV after an impact occurs.

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

D. Foundation Brake System Characterization

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

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

E. Brake Control

1. SUBJECT VEHICLE PROGRAMMABLE BRAKE CONTROLLER

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

- Constant pedal displacement. By maintaining constant actuator stroke, the position of the vehicle's brake pedal remains fixed for the duration of the input. To achieve this, the brake controller modulates application force.
- Hybrid control. Hybrid control uses position-based control to command the initial brake application rate and actuator position, then changes to force-based control to command a reduction of applied force to a predetermined force. This force is maintained until the end of the braking maneuver by allowing the brake controller to modulate actuator displacement.

2. SUBJECT VEHICLE BRAKE PARAMETERS

- Each test run began with the brake pedal in its natural resting position, with no preload or position offset.
- The onset of the brake application was considered to occur when the brake actuator had applied 2.5 lbf (11 N) of force to the brake pedal.
- The magnitude of the brake application was that needed to produce 0.4 g deceleration, as determined in the foundation brake characterization.
- The SV brake application rate was between 9 to 11 in/s (229 to 279 mm/s), where the application rate is defined as the slope of a linear regression line applied to brake pedal position data over a range from 25% to 75% of the commanded input magnitude.
- If the brake application rate could not be achieved due to brake pedal movement during AEB activation, the application rate requirement was removed. Instead, the brakes were applied 1 second after the onset of FCW and the target brake pedal displacement was achieved within 250 ms.

3. POV AUTOMATIC BRAKING SYSTEM

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

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

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

F. Instrumentation

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

Table 5. Test Instrumentation and Equipment

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Tire Pressure Gauge	Vehicle Tire Pressure	0-100 psi 0-690 kPa	< 1% error between 20 and 100 psi	Omega DPG8001	17042707002	By: DRI Date: 10/5/2021 Due: 10/5/2022
Platform Scales	Vehicle Total, Wheel, and Axle Load	2200 lb/platform	0.1% of reading	Intercomp SW wireless	0410MN20001	By: DRI Date: 2/11/2022 Due: 2/11/2023
Linear (string) encoder	Throttle pedal travel	50 in	0.05 in	TE Connectivity SE1-50	K3161858	By: DRI Date: 1/18/2022 Due: 1/18/2023
Load Cell	Force applied to brake pedal					By: DRI
		0-250 lb	0.05% FS	Stellar Technology PNC700	2002506	Date: 2/25/2022 Due: 2/25/2023
		0-250 lb	0.05% FS	Stellar Technology PNC700	2002505	Date: 3/30/2022 Due: 3/30/2023
Differential Global Positioning System	Position, Velocity	Latitude: ±90 deg Longitude: ±180 deg Altitude: 0-18 km Velocity: 0-1000 knots	Horizontal Position: ±1 cm Vertical Position: ±2 cm Velocity: 0.05 km/h	Trimble GPS Receiver, 5700 (base station and in-vehicle)	00440100989	N/A

Table 5. Test Instrumentation and Equipment (continued)

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Multi-Axis Inertial Sensing System	Position; Longitudinal, Lateral, and Vertical Accels; Lateral, Longitudinal and Vertical Velocities; Roll, Pitch, Yaw Rates; Roll, Pitch, Yaw Angles	Accels ± 10g, Angular Rate ±100 deg/s, Angle >45 deg, Velocity >200 km/h	Accels .01g, Angular Rate 0.05 deg/s, Angle 0.05 deg, Velocity 0.1 km/h	Oxford Inertial +		By: Oxford Technical Solutions
					2182	Date: 11/19/2021 Due: 11/19/2023
					2258	Date: 4/28/2021 Due: 4/28/2023
Real-Time Calculation of Position and Velocity Relative to Lane Markings (LDW) and POV (FCW)	Distance and Velocity to lane markings (LDW) and POV (FCW)	Lateral Lane Dist: ±30 m Lateral Lane Velocity: ±20 m/sec Longitudinal Range to POV: ±200 m Longitudinal Range Rate: ±50 m/sec	Lateral Distance to Lane Marking: ±2 cm Lateral Velocity to Lane Marking: ±0.02m/sec Longitudinal Range: ±3 cm Longitudinal Range Rate: ±0.02 m/sec	Oxford Technical Solutions (OXTS), RT-Range	97	N/A
Microphone	Sound (to measure time at alert)	Frequency Response: 80 Hz – 20 kHz	Signal-to-noise: 64 dB, 1 kHz at 1 Pa	Audio-Technica AT899	N/A	N/A
Light Sensor	Light intensity (to measure time at alert)	Spectral Bandwidth: 440-800 nm	Rise time < 10 msec	DRI designed and developed Light Sensor	N/A	N/A
Accelerometer	Acceleration (to measure time at alert)	±5g	≤ 3% of full range	Silicon Designs, 2210-005	N/A	N/A

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Coordinate Measurement Machine	Inertial Sensing System Coordinates	0-8 ft 0-2.4 m	±.0020 in. ±.051 mm (Single point articulation accuracy)	Faro Arm, Fusion	UO8-05-08-06636	By: DRI Date: 1/6/2022 Due: 1/6/2023

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

APPENDIX A

Photographs

LIST OF FIGURES

Figure A1. Front View of Subject Vehicle

Figure A2. Rear View of Subject Vehicle

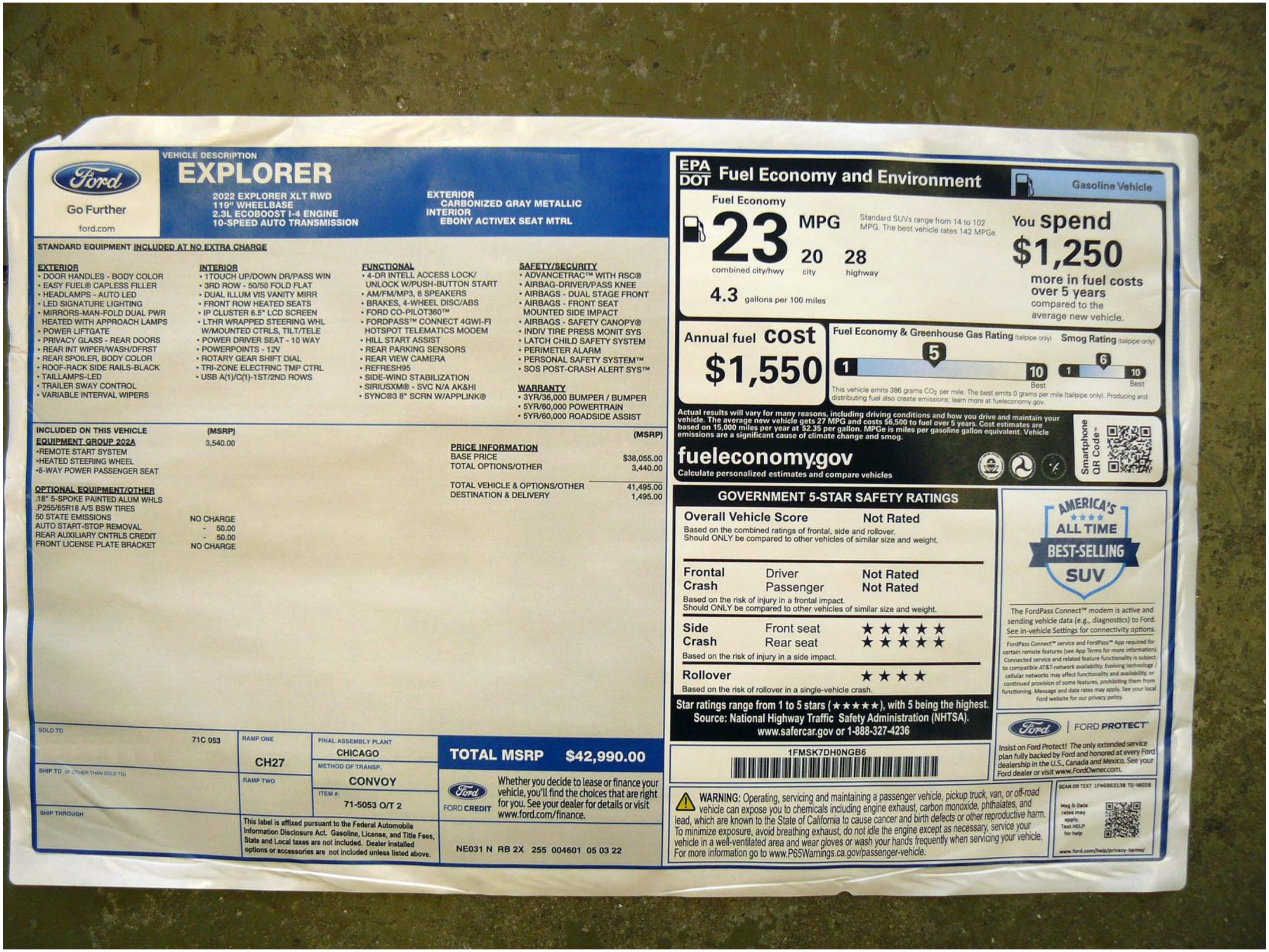


Figure A3. Window Sticker (Monroney Label)

Figure A4. Vehicle Certification Label

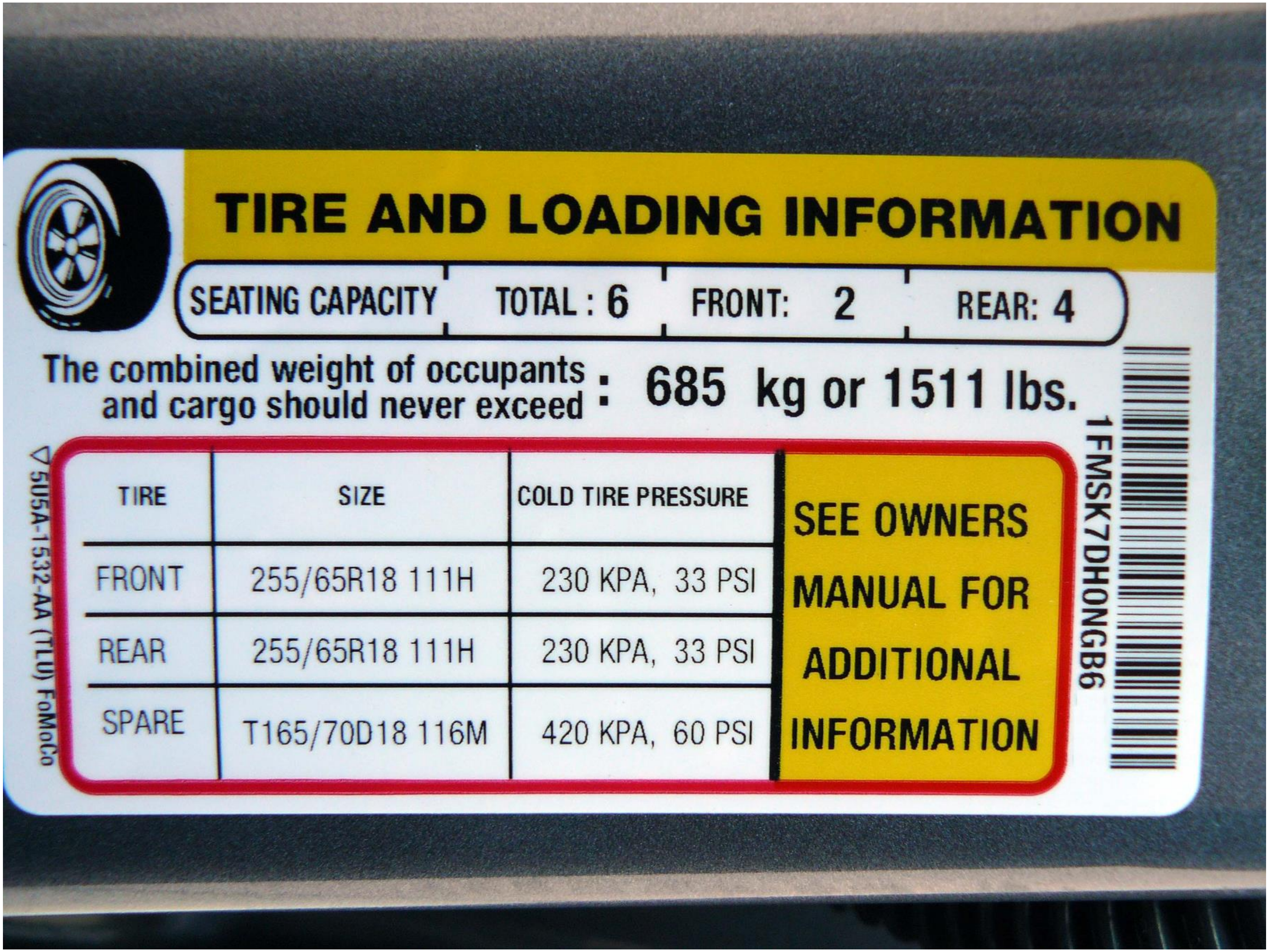


Figure A5. Tire Placard

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

Figure A7. Load Frame/Slider of SSV

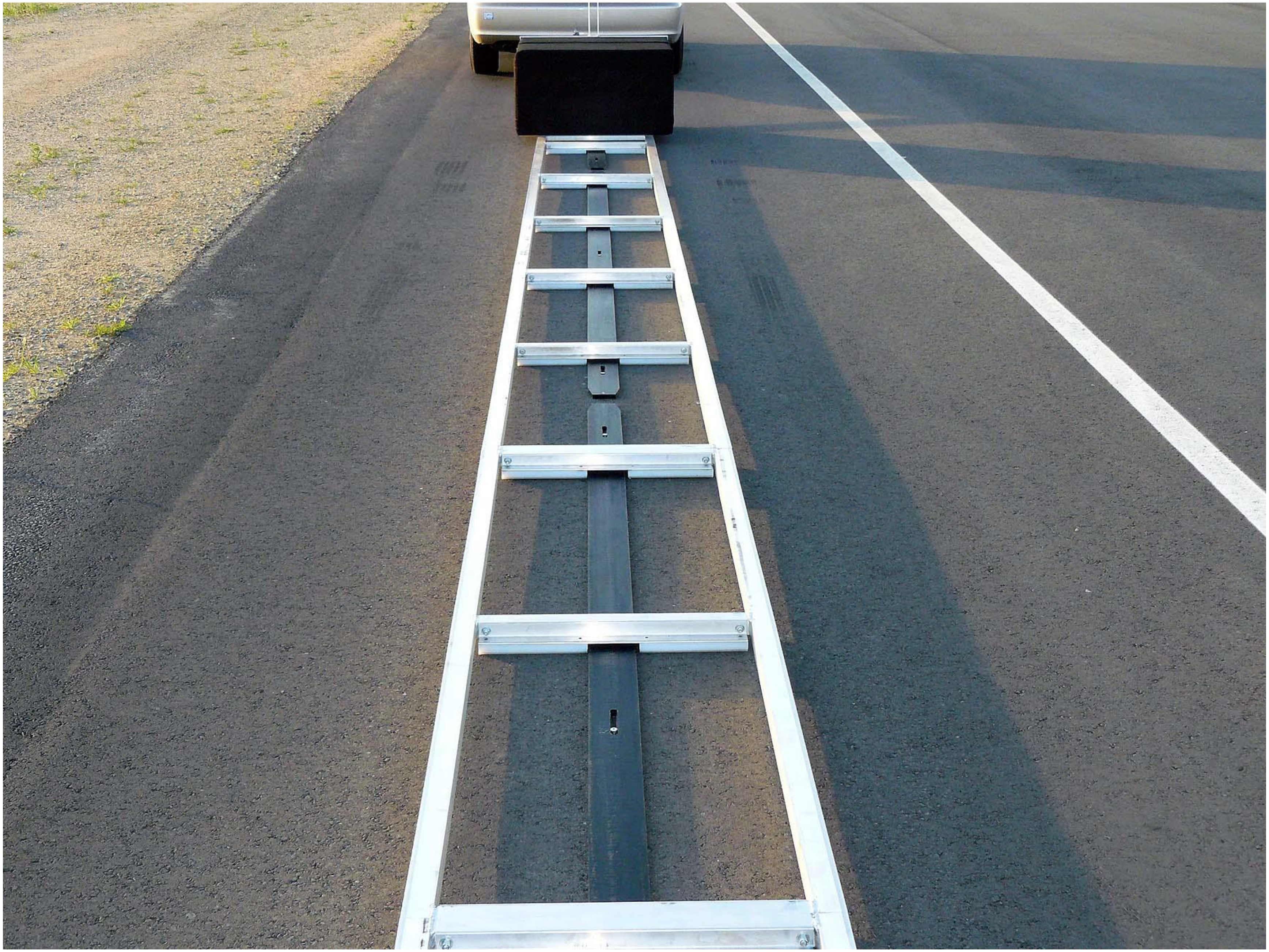


Figure A8. Two-Rail Track and Road-Based Lateral Restraint Track

Figure A9. Steel Trench Plate

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

Figure A11. Sensors for Detecting Auditory and Visual Alerts

Figure A12. Computer Installed in Subject Vehicle

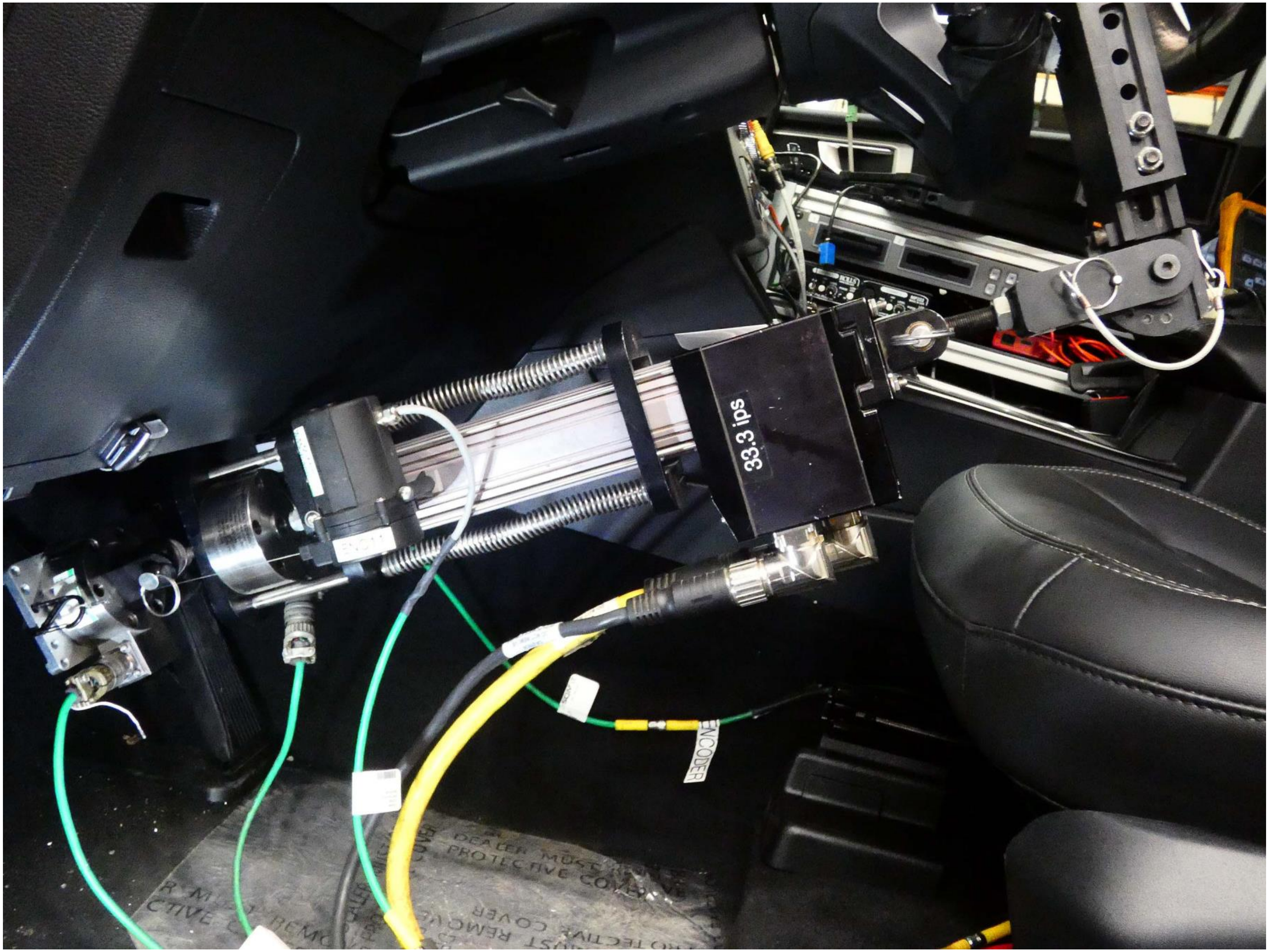


Figure A13. Brake Actuator Installed in Subject Vehicle

Figure A14. Brake Actuator Installed in POV System

Figure A15. Alert Sensitivity Menu

Figure A16. Visual Alert

APPENDIX B

Excerpts from Owner's Manual

STEERING

Electric Power Steering

> **WARNING:** The electric power steering system has diagnostic checks that continuously monitor the system. If a fault is detected, a message displays in the information display. Stop your vehicle as soon as it is safe to do so. Switch the ignition off. After at least 10 seconds, switch the ignition on and watch the information display for a steering system warning message. If a steering system warning message returns, have the system checked as soon as possible.

> **WARNING:** If the system detects an error, you may not feel a difference in the steering, however a serious condition may exist. Have your vehicle checked as soon as possible. Failure to do so may result in loss of steering control.

Your vehicle has an electric power steering system, there is no fluid reservoir, no maintenance is required.

If your vehicle loses electrical power while you are driving, electric power steering assistance is lost. The steering system still operates and you can steer your vehicle manually. Manually steering your vehicle requires more effort.

Extreme continuous steering may increase the effort required for you to steer your vehicle, this increased effort prevents overheating and permanent damage to the steering system. You do not lose the ability to steer your vehicle manually. Typical steering and driving maneuvers allow the system to cool and return to normal operation.

Steering Tips

If the steering wanders or pulls, check for:

- Correct tire pressures.
- Uneven tire wear.
- Loose or worn suspension components.
- Loose or worn steering components.
- Improper vehicle alignment.

Note: *A high crown in the road or high crosswinds may also make the steering seem to wander or pull.*

Adaptive Learning (If Equipped)

The electronic power steering system adaptive learning helps correct road irregularities and improves overall handling and steering feel. It communicates with the brake system to help operate advanced stability control and accident avoidance systems. Additionally, whenever the battery is disconnected or a new battery installed, you must drive your vehicle a short distance before the system relearns the strategy and reactivates all systems.

PRE-COLLISION ASSIST

> **WARNING:** You are responsible for controlling your vehicle at all times. The system is designed to be an aid and does not relieve you of your responsibility to drive with due care and attention. Failure to follow this instruction could result in the loss of control of your vehicle, personal injury or death.

WARNING: The system does not detect vehicles that are driving in a different direction, cyclists or animals. Apply the brakes when necessary. Failure to follow this instruction could result in the loss of control of your vehicle, personal injury or death.

WARNING: The system does not operate during hard acceleration or steering. Failure to take care may lead to a crash or personal injury.

WARNING: The system may fail or operate with reduced function during cold and severe weather conditions. Snow, ice, rain, spray and fog can adversely affect the system. Keep the front camera and radar free of snow and ice. Failure to take care may result in the loss of control of your vehicle, serious personal injury or death.

WARNING: Some situations and objects prevent hazard detection. For example low or direct sunlight, inclement weather, unconventional vehicle types, and pedestrians. Apply the brakes when necessary. Failure to follow this instruction could result in the loss of control of your vehicle, personal injury or death.

WARNING: The system cannot help prevent all crashes. Do not rely on this system to replace driver judgment and the need to maintain a safe distance and speed.

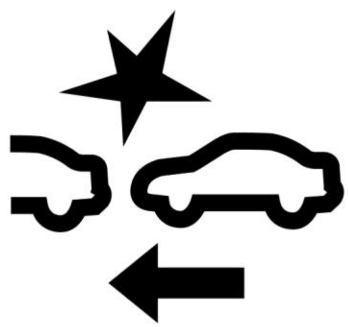
Using the Pre-Collision Assist System

The system is active at speeds above approximately 3 mph (5 km/h) and pedestrian detection is active at speeds up to 50 mph (80 km/h).

E156130

If your vehicle is rapidly approaching another stationary vehicle, a vehicle traveling in the same direction as yours, or a pedestrian within your driving path, the system is designed to provide three levels of functionality:

1. Alert
2. Brake Support
3. Active Braking



Alert: When active, a flashing visual warning appears and an audible warning tone sounds.

Brake Support: The system is designed to help reduce the impact speed by preparing the brakes for rapid braking. Brake support does not automatically apply the brakes. If you press the brake pedal, the system could apply additional braking up to maximum braking force, even if you lightly press the brake pedal.

Active Braking: Active braking may activate if the system determines that a collision is imminent. The system may help the driver reduce impact damage or avoid the crash completely.

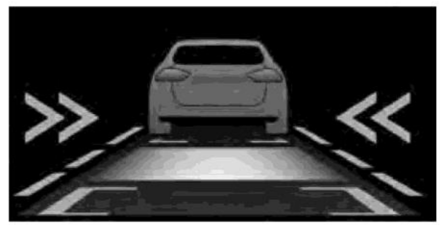
Note: *Brake Support and Active Braking are active at speeds up to 75 mph (120 km/h). If your vehicle has a radar sensor included with Adaptive Cruise Control, then Brake Support and Active Braking are active up to the maximum speed of the vehicle.*

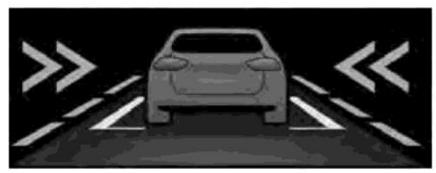
Note: *If you perceive Pre-Collision Assist alerts as being too frequent or disturbing, then you can reduce the alert sensitivity, though the manufacturer recommends using the highest sensitivity setting where possible. Setting lower sensitivity would lead to fewer and later system warnings.*

Note: *Pre-Collision Assist turns off when you manually disable AdvanceTrac or when you select deep snow/sand mode.*

Distance Indication and Alert (If Equipped)

Distance Indication and Alert is a function that provides the driver with a graphical indication of the time gap to other preceding vehicles traveling in the same direction. Distance Indication and Alert shows one of the graphics that follow in the information display.





If the time gap to a preceding vehicle is small, a red visual indication displays to the driver.

Note: *Distance Indication and Alert deactivates and the graphics do not display when Adaptive Cruise Control is active.*

Speed	Sensitivity	Graphics	Distance Gap	Time Gap
62 mph (100 km/h)	Normal	Grey	>82 ft (25 m)	>0.9sec
62 mph (100 km/h)	Normal	Yellow	56–82 ft (17–25 m)	0.6sec — 0.9sec
62 mph (100 km/h)	Normal	Red	<56 ft (17 m)	<0.6sec

Evasive Steering Assist (If Equipped)

If your vehicle is rapidly approaching a stationary vehicle or a vehicle traveling in the same direction as your vehicle, the system is designed to help you steer around the vehicle.

The system only activates when all of the following occur:

- The Pre-Collision Assist system detects a vehicle ahead and starts to apply Active Braking.
- You turn the steering wheel in an attempt to steer around the vehicle.

After you turn the steering wheel, the system applies additional steering torque to help you steer around the vehicle. After you pass the vehicle, the system applies steering torque in the opposite direction to encourage you to steer back into the lane. The system deactivates after you fully pass the vehicle.

Note: *The system does not automatically steer around a vehicle. If you do not turn the steering wheel, the system does not activate.*

Note: *The system does not activate if the distance to the vehicle ahead is too small and the system cannot avoid a crash.*

Adjusting the Pre-Collision Assist Settings

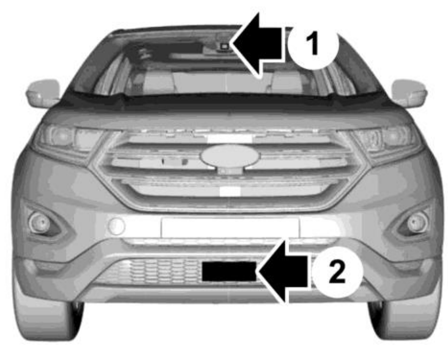
You can adjust the following settings by using the touchscreen. See **Settings** (page 464).

- You can change Alert and Distance Alert sensitivity to one of three possible settings.
- You can switch Distance Indication and Alert on or off.
- If required, you can switch Active Braking on or off.
- If required, you can switch Evasive Steering Assist on or off.

Note: *Active Braking and Evasive Steering Assist automatically turn on every time you switch the ignition on.*

Note: *If you switch Active Braking off, Evasive Steering Assist turns off.*

Blocked Sensors



1	Camera.
2	Radar sensor (if equipped).

If a message regarding a blocked sensor or camera appears in the information display, the radar signals or camera images are obstructed. If your vehicle has a radar sensor, it is behind the fascia cover in the center of the lower grille. With a blocked sensor or camera, the Pre-Collision Assist system may not function, or performance may reduce. The following table lists possible causes and actions for when this message displays.

Camera Troubleshooting

Cause	Action
The windshield in front of the camera is dirty or obstructed in some way.	Clean the outside of the windshield in front of the camera.
The windshield in front of the camera is clean but the message remains in the display screen.	Wait a short time. It may take several minutes for the camera to detect that there is no obstruction.

Radar Troubleshooting (If Equipped)

Cause	Action
The surface of the radar in the grille is dirty or obstructed in some way.	Clean the grille surface in front of the radar or remove the object causing the obstruction.
The surface of the radar in the grille is clean but the message remains in the display screen.	Wait a short time. It may take several minutes for the radar to detect that there is no obstruction.
Heavy rain, spray, snow or fog is interfering with the radar signals.	The Pre-Collision Assist system is temporarily disabled. Pre-Collision Assist automatically reactivates a short time after the weather conditions improve.
Swirling water or snow or ice on the surface of the road may interfere with the radar signals.	The Pre-Collision Assist system is temporarily disabled. Pre-Collision Assist automatically reactivates a short time after the weather conditions improve.
Radar is out of alignment due to a front end impact.	Contact an authorized dealer to have the radar checked for proper coverage and operation.

Note: *Proper system operation requires a clear view of the road by the camera. Have any windshield damage in the area of the camera's field of view repaired.*

Note: *If something hits the front end of your vehicle or damage occurs and your vehicle has a radar sensor, the radar sensing zone may change. This could cause missed or false detections. Contact an authorized dealer to have the radar checked for proper coverage and operation.*

APPENDIX C

Run Log

Subject Vehicle: **2022 Ford Explorer RWD** Test start date: **6/28/2022**

Principal Other Vehicle: **SSV** Test end date: **6/30/2022**

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
	Brake characterization and determination						See Appendix D
43	Static Run						
44	**Stopped POV**	Y	2.21	6.64	1.04	Pass	
45		Y	2.15	8.99	0.99	Pass	
46		Y	2.16	7.32	0.98	Pass	
47		Y	2.18	7.91	1.02	Pass	
48		Y	2.19	6.29	0.99	Pass	
49		Y	2.19	10.22	1.01	Pass	
50		Y	2.15	8.47	1.02	Pass	
51	Static Run						
52	**Slower POV, 25 vs 10**	Y	1.88	0.02	0.78	Pass	
53		Y	1.75	4.26	0.98	Pass	
54		Y	1.93	4.63	0.94	Pass	
55		Y	1.80	4.10	0.96	Pass	
56		Y	1.77	4.08	0.97	Pass	
57		Y	1.70	5.02	0.96	Pass	

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
58		Y	1.83	4.55	0.95	Pass	
59	Static run						
60	**Slower POV, 45 vs 20**	N					Invalid due to nonzeroed brake force
61		N					Invalid due to nonzeroed brake force
62		N					Invalid due to nonzeroed brake force
63		N					POV Speed
64		N					Invalid due to nonzeroed brake force
65		N					Invalid due to nonzeroed brake force
66		N					Invalid due to nonzeroed brake force
67		N					Invalid due to nonzeroed brake force
68	Static run						
69	**Decelerating POV, 35**	N					Invalid due to nonzeroed brake force
70		N					Invalid due to nonzeroed brake force
71		N					Invalid due to nonzeroed brake force
72		N					Invalid due to nonzeroed brake force

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
73		N					Invalid due to nonzeroed brake force
74		N					Invalid due to nonzeroed brake force
75		N					Invalid due to nonzeroed brake force
76	Static run						
77	Static Run						
78	**Slower POV, 45 vs 20**	Y	2.68	10.47	1.02	Pass	
79		Y	2.56	10.03	1.01	Pass	
80		Y	2.44	12.63	1.04	Pass	
81		Y	2.62	11.88	1.02	Pass	
82		Y	2.63	10.67	1.04	Pass	
83		Y	2.36	9.56	1.01	Pass	
84		Y	2.82	8.75	1.03	Pass	
85		Y	2.69	10.31	1.02	Pass	
86	Static run						
87	**Decelerating POV, 35**	Y	1.76	4.79	0.89	Pass	
88		Y	1.64	7.00	1.03	Pass	
89		N					Early Braking
90		N					Early Braking, Throttle Drop

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
91		N					Early Braking
92		Y	1.74	5.95	0.99	Pass	
93		N					POV Braking
94		Y	1.74	6.54	0.96	Pass	
95		Y	1.77	5.19	0.99	Pass	
96		Y	1.66	5.57	0.94	Pass	
97		Y	1.66	3.15	0.92	Pass	
98	Static run						
10	STP - Static run						
11	**Baseline, 25**	Y			0.41		
12		Y			0.43		
13		Y			0.43		
14		Y			0.42		
15		Y			0.43		
16		Y			0.44		
17		Y			0.45		
18	STP - Static run						
19	**Baseline, 45**	Y			0.49		

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
20		Y			0.49		
21		Y			0.49		
22		Y			0.49		
23		Y			0.49		
24		Y			0.49		
25		Y			0.49		
26	STP - Static run						
27	**STP False Positive, 25**	Y			0.43	Pass	
28		Y			0.41	Pass	
29		Y			0.43	Pass	
30		Y			0.42	Pass	
31		Y			0.42	Pass	
32		Y			0.42	Pass	
33		Y			0.41	Pass	
34	STP - Static run						
35	**STP False Positive, 45**	Y			0.45	Pass	
36		Y			0.49	Pass	
37		Y			0.49	Pass	

Run	Test Type	Valid Run?	FCW TTC (s)	Minimum Distance (ft)	Peak Deceleration (g)	Pass/Fail	Notes
38		Y			0.49	Pass	
39		Y			0.49	Pass	
40		Y			0.49	Pass	
41		Y			0.50	Pass	
42	STP - Static run						

APPENDIX D

Brake Characterization

Subject Vehicle: **2022 Ford Explorer RWD**

Test start date: **6/28/2022**

Test end date: **6/30/2022**

DBS Initial Brake Characterization				
Run Number	**Stroke at 0.4 g (in)**	**Force at 0.4 g (lb)**	**Slope**	**Intercept**
1	1.50	19.88	1.00	-0.33
2	1.40	17.70	0.96	-0.41
3	1.44	18.69	0.95	-0.43

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					Brk Rate
5		35	N					Throttle Drop
6		35	Y	0.448	1.32		1.18	
7		35	Y	0.412	1.26		1.22	
8		25	Y	0.399	1.26		1.26	
9		45	Y	0.422	1.26		1.19	

Appendix E

TIME HISTORY PLOTS

LIST OF FIGURES

Description of Time History Plots

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

Time History Plot Description

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

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

Time history figures include the following sub-plots:

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

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

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

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

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

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

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

- Pedal Position – Position of the accelerator pedal and brake pedal. The units for the brake pedal are inches and the units for the accelerator pedal are percent of full scale divided by 10.

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

Envelopes and Thresholds

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

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

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

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

For the Ax plot, if the scenario is an AEB brake to stop scenario, a vertical dashed black line is displayed for all plots indicating the moment of first POV braking. The yellow envelope in this case is relevant to the POV braking only. The left edge of the envelope is at 1.5 seconds after the first POV braking. A solid black threshold line extends horizontally 0.5 seconds to the left of the envelope. This threshold line represents the time during which the Ax of the Principal Other Vehicle must first achieve 0.27 g (the upper edge of the envelope, i.e., 0.30 g ± 0.03 g). A green circle or red asterisk is displayed at the moment the POV brake level achieves 0.27 g. A green circle indicates that the test was valid (the threshold was crossed during the appropriate interval) and a red asterisk indicates that the test was invalid (the threshold was crossed out of the appropriate interval).

For the pedal position plot:

- A thick black bar, green circle, or red asterisk appears on the brake pedal position data over the DBS controller brake onset period. The black bar signifies the time over which the brake application rate is determined, and the calculated brake application rate is displayed on the figure. If instead, a green dot or red asterisk is displayed, the brake application rate is being assessed under a newly developed requirement. For vehicles that exhibit brake pedal movement during the activation of the brake actuator, the target brake pedal displacement that results in 0.4 g of vehicle deceleration must be achieved within 250 ms of activation. If the target brake pedal displacement was achieved, a green circle is displayed. If not, a red asterisk is displayed.

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

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

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

For the brake force plots:

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

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

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

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

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

Color Codes

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

Color codes can be broken into four categories:

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

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

2. Validation envelope and threshold color codes:
   - Green envelope = time varying data must be within the envelope at all times in order to be valid
   - Yellow envelope = time varying data must be within limits at left and/or right ends
   - Blue envelope = visualized target range for the time varying data averaged over a period equal to the length of the envelope
   - Black threshold (Solid) = time varying data must cross this threshold in the time period shown in order to be valid
   - Black threshold (Dashed) = for reference only – this can include warning level thresholds, TTC thresholds, and acceleration thresholds.
   - Red threshold (Solid) = for reference only – indicates the activation of last-minute braking by the brake robot. Data after the solid red line is not used to determine test validity.

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

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

Other Notations

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

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

Examples of valid or passing time history plots for each test type (including passing, failing, and invalid runs) are shown in Figure E1 through E12. Figures E1 through E8 show passing runs for each of the 8 test types. Figure E9 shows an example of a passing brake characterization run. Figures E10 and E11 show examples of invalid runs. Figure E12 shows an example of a valid test that failed the DBS requirements. Time history data plots for the tests of the vehicle under consideration herein are provided beginning with Figure E13.

Notes

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

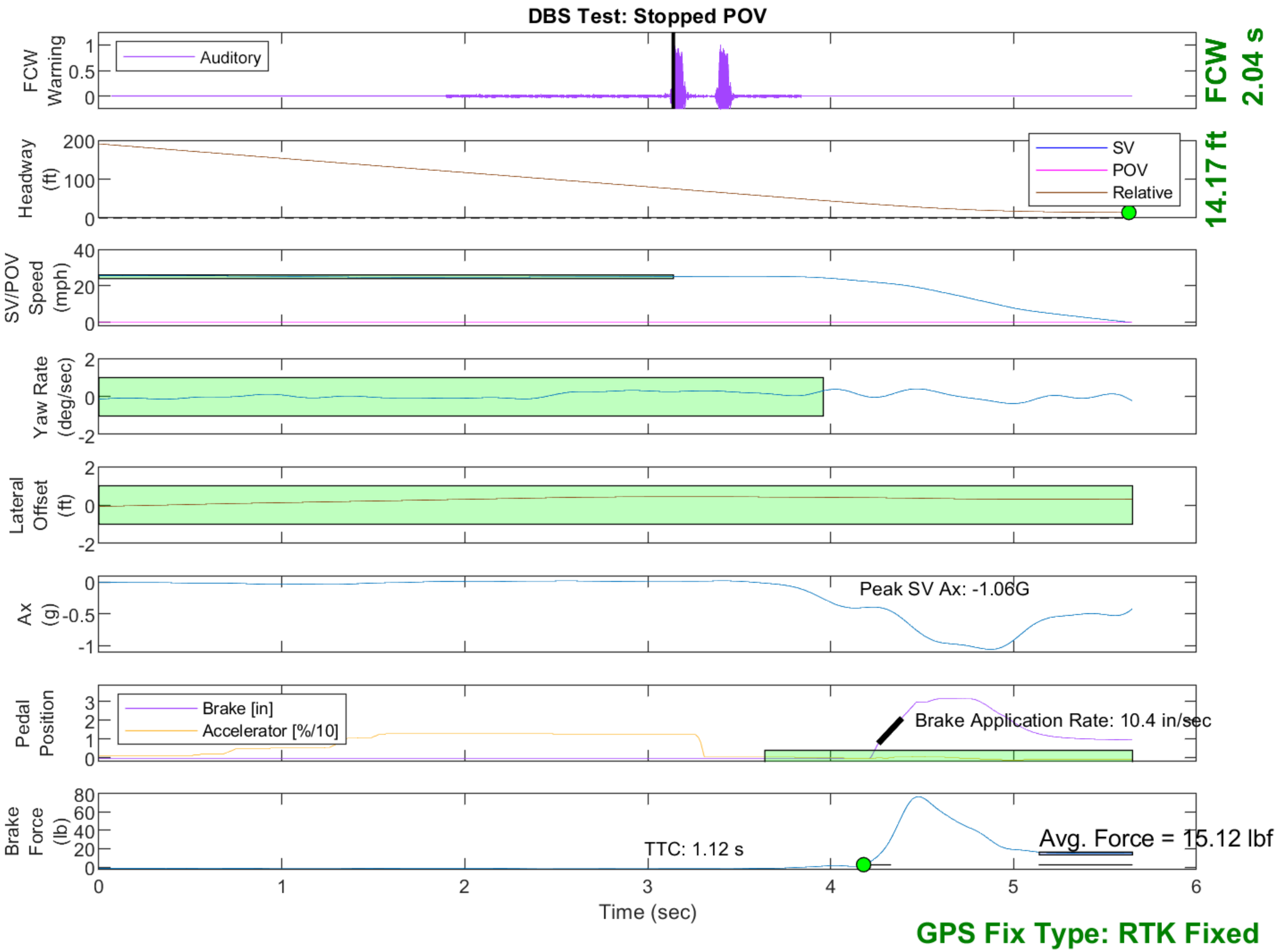


Figure E1. Example Time History for Stopped POV, Passing

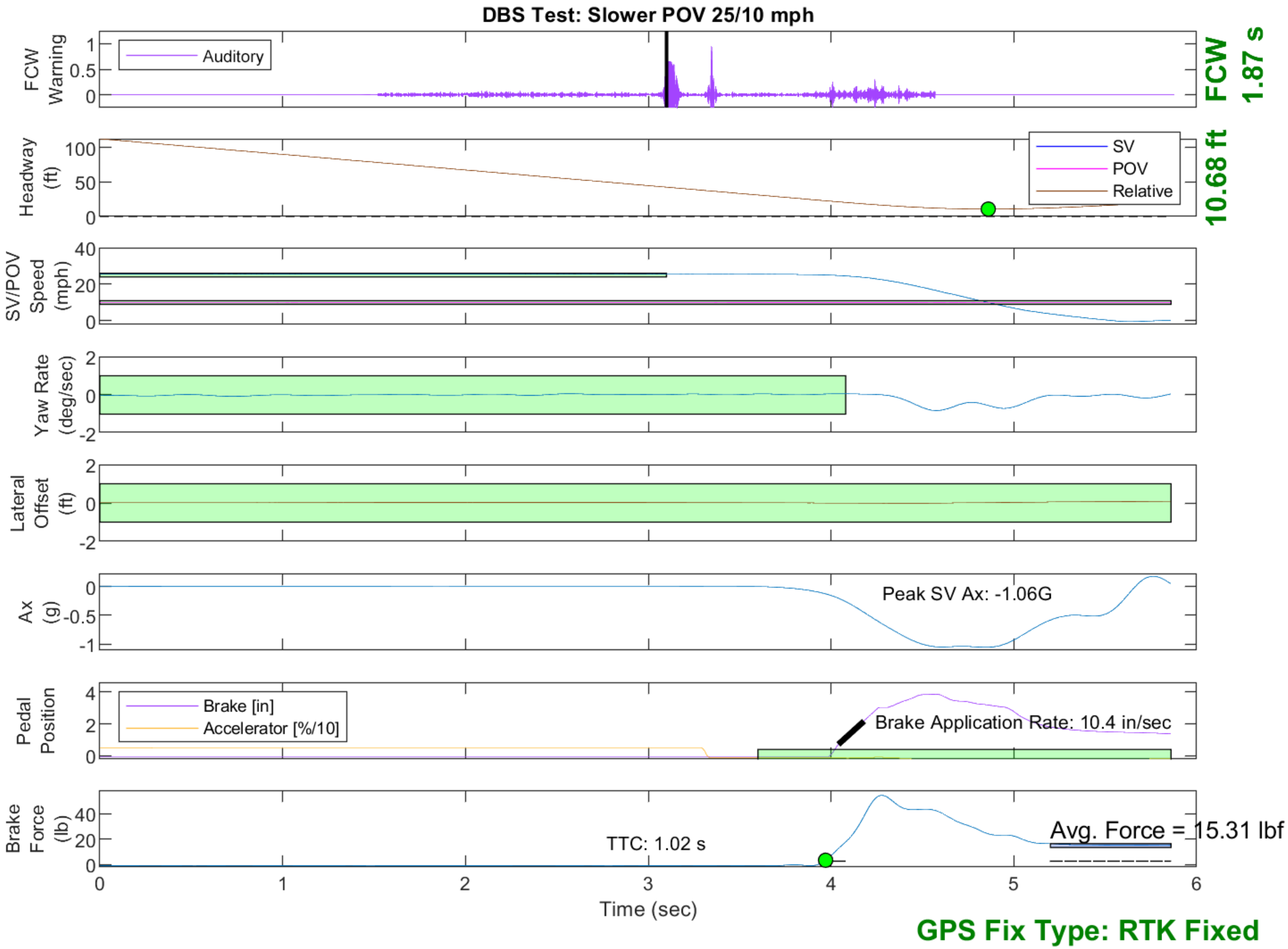


Figure E2. Example Time History for Slower POV 25 vs. 10, Passing

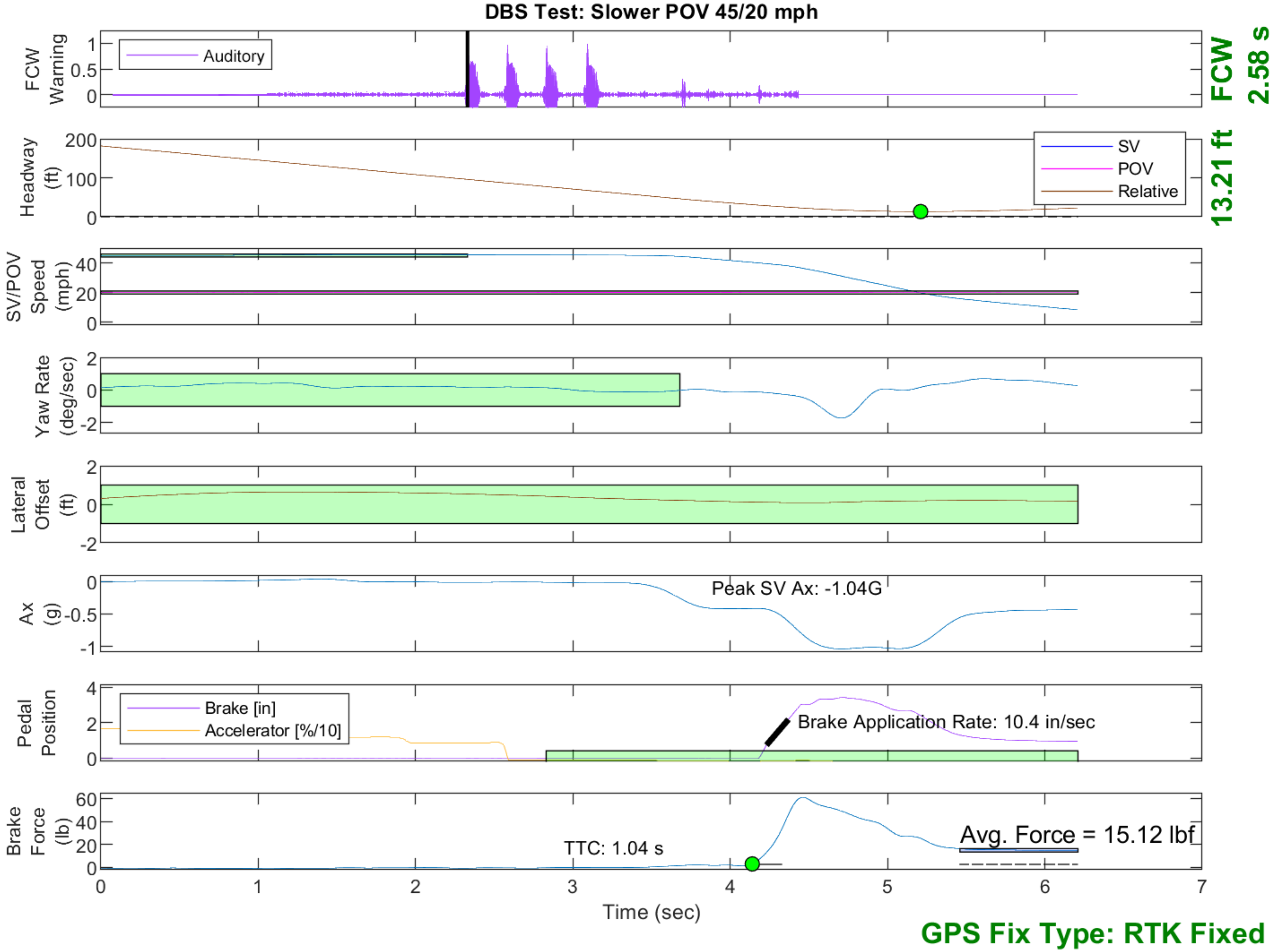


Figure E3. Example Time History for Slower POV 45 vs. 20, Passing

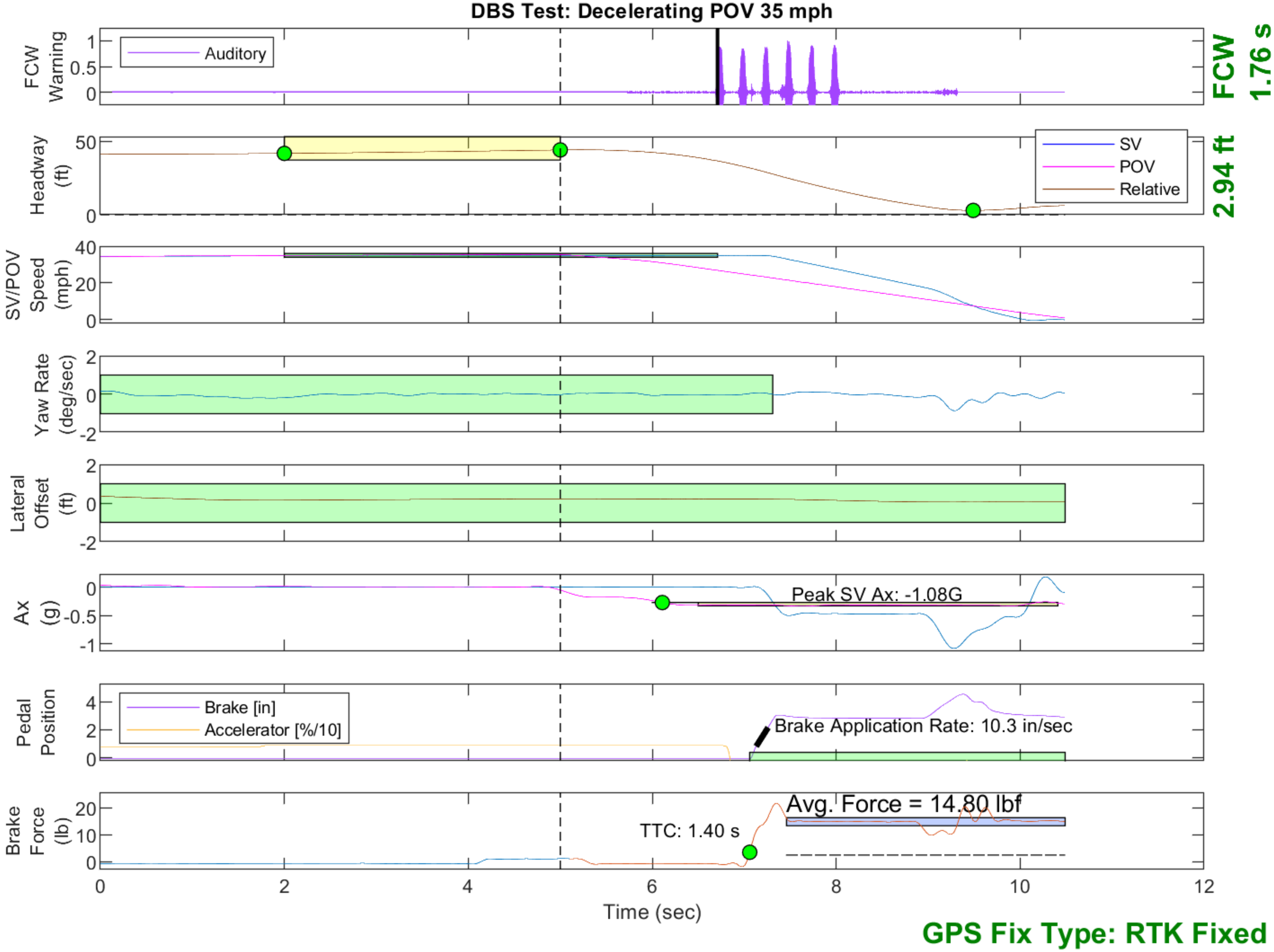


Figure E4. Example Time History for Decelerating POV 35, Passing

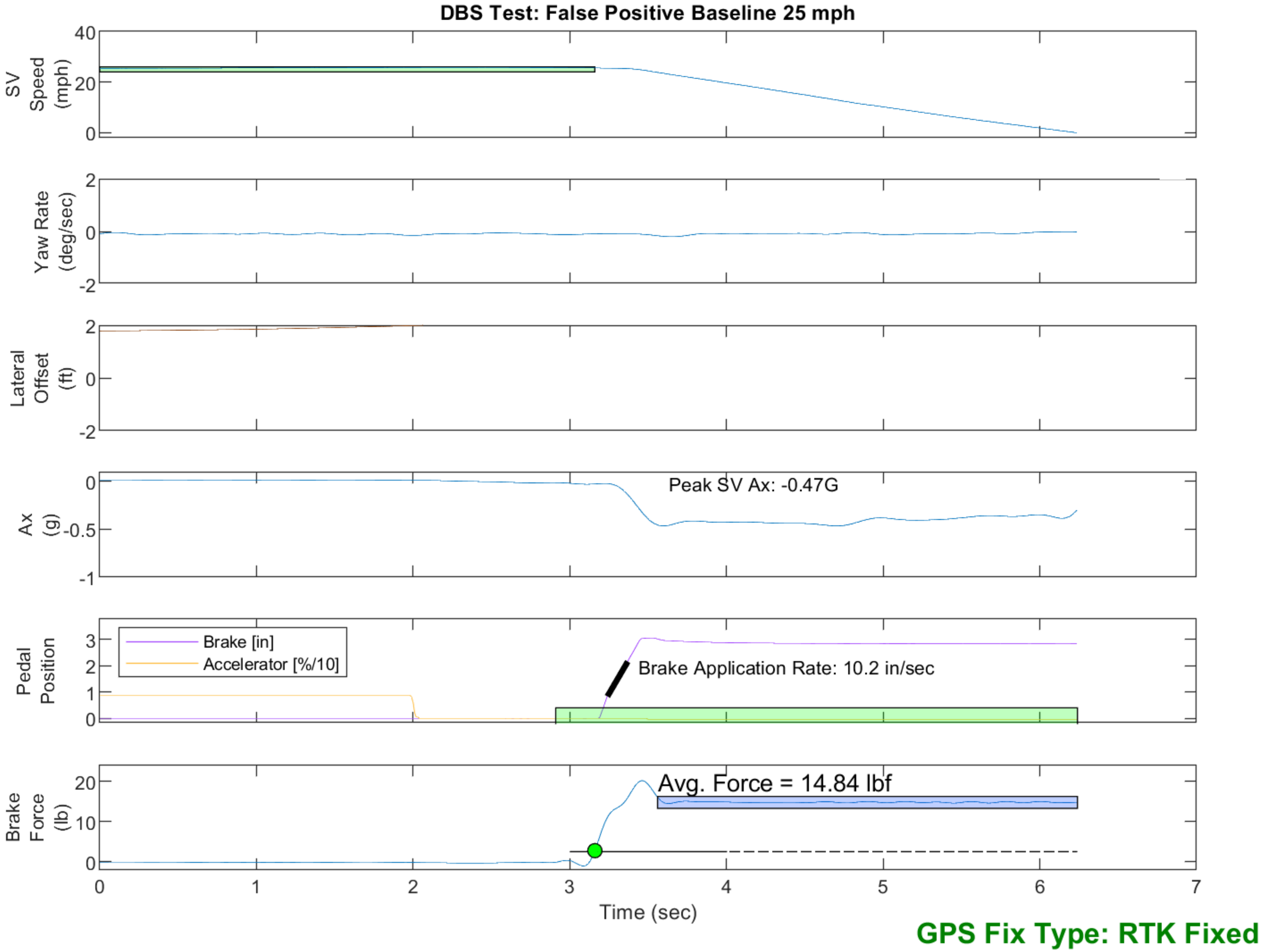


Figure E5. Example Time History for False Positive Baseline 25

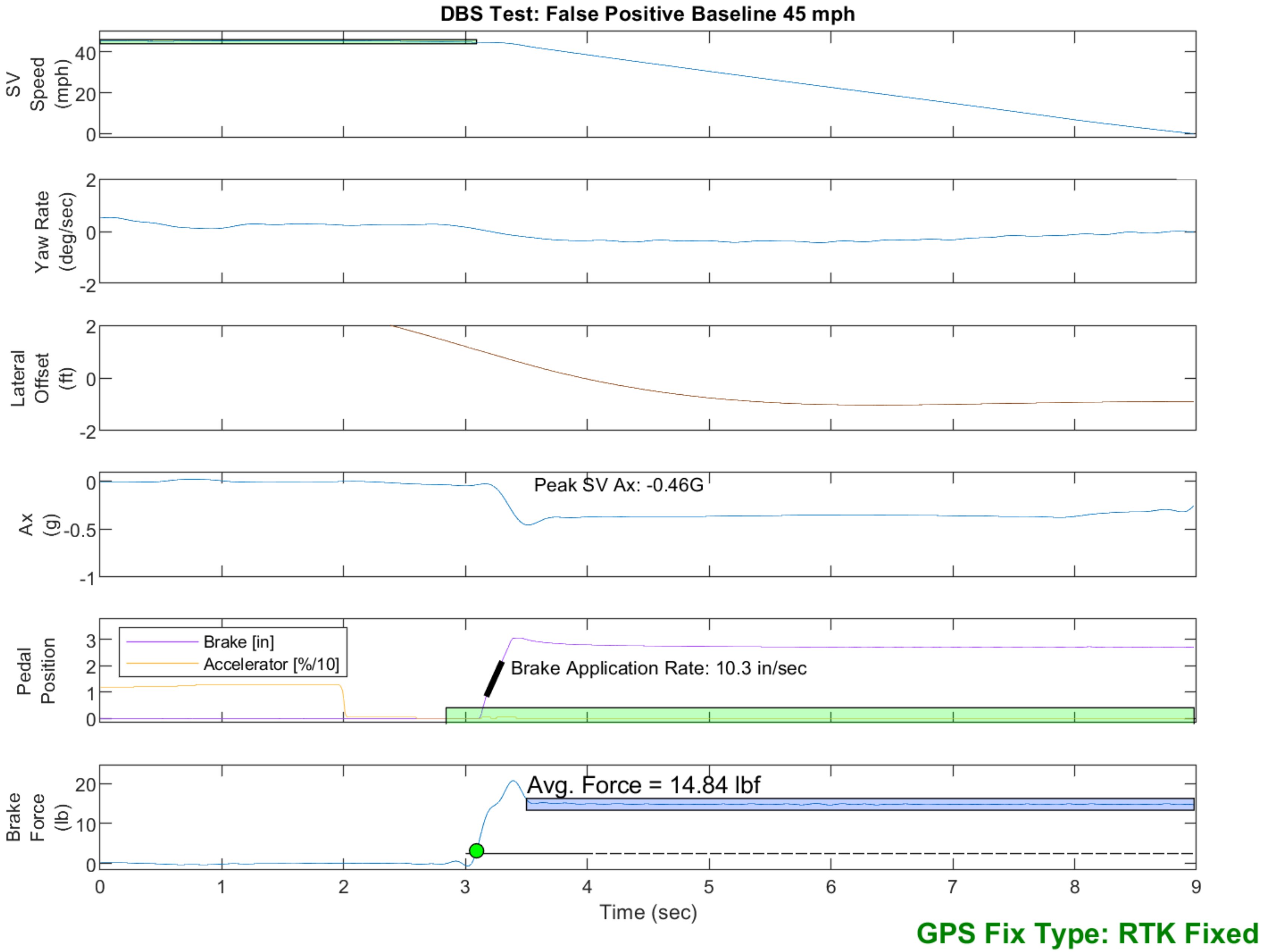


Figure E6. Example Time History for False Positive Baseline 45

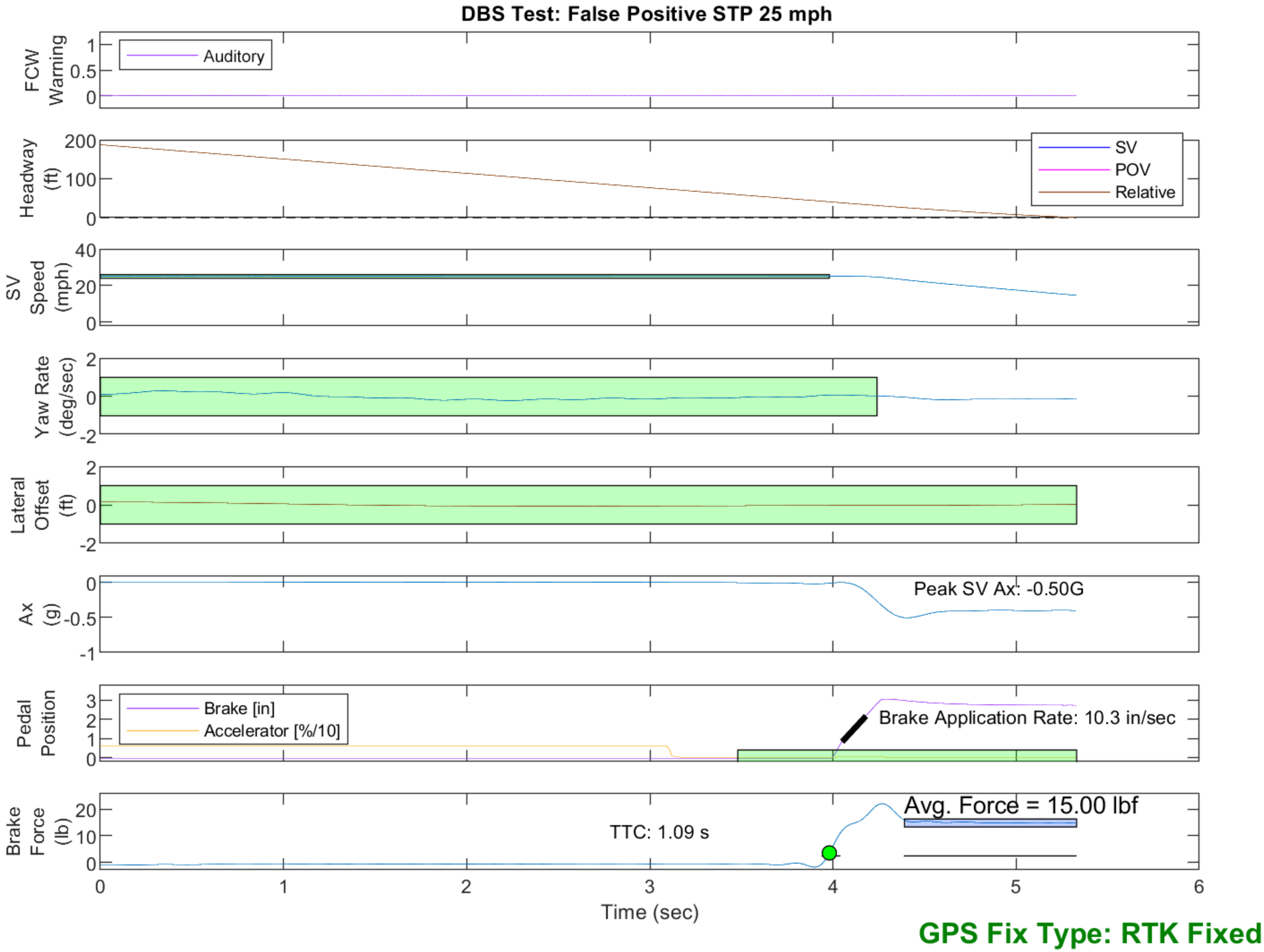


Figure E7. Example Time History for False Positive Steel Plate 25, Passing

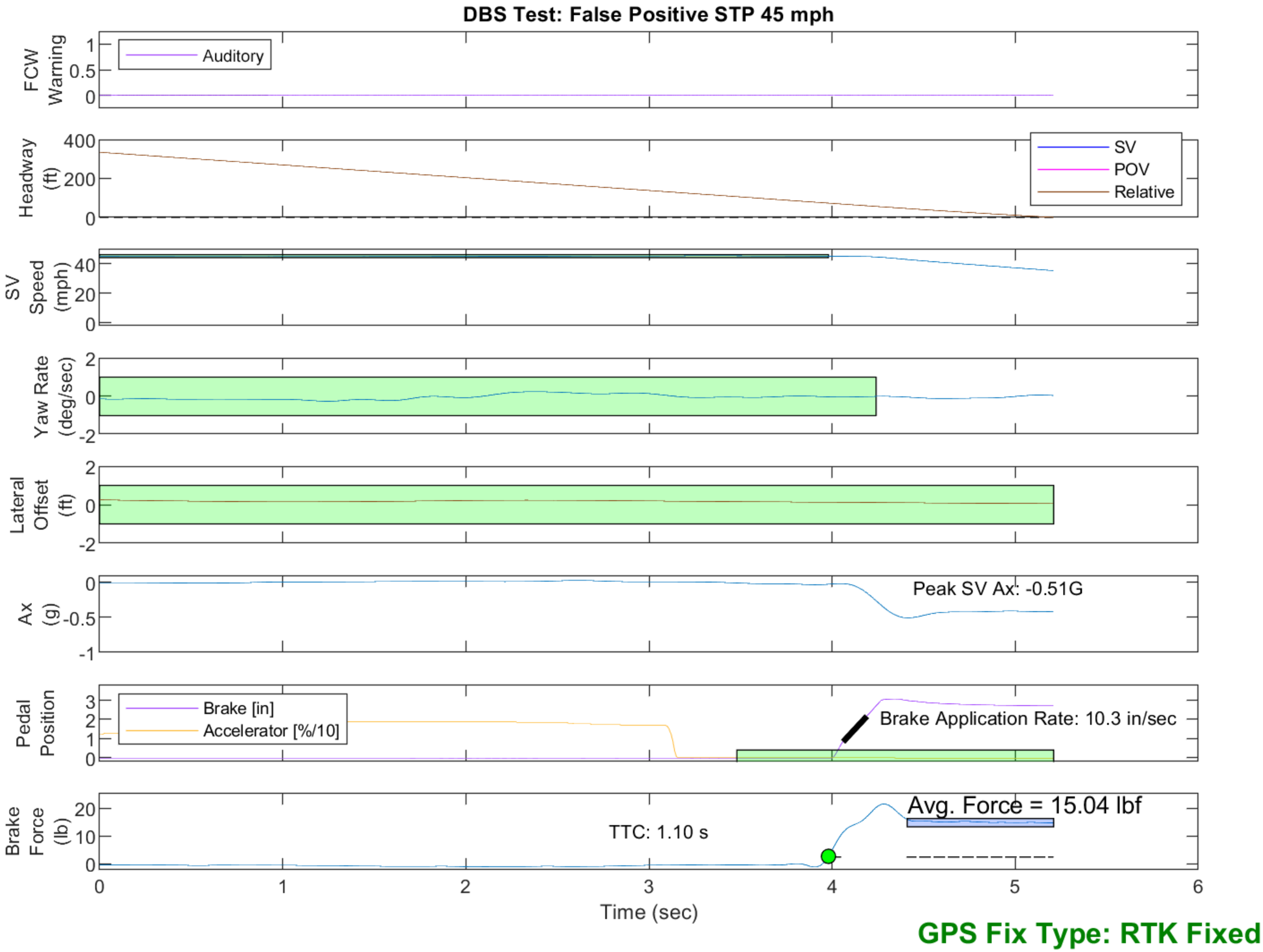


Figure E8. Example Time History for False Positive Steel Plate 45, Passing

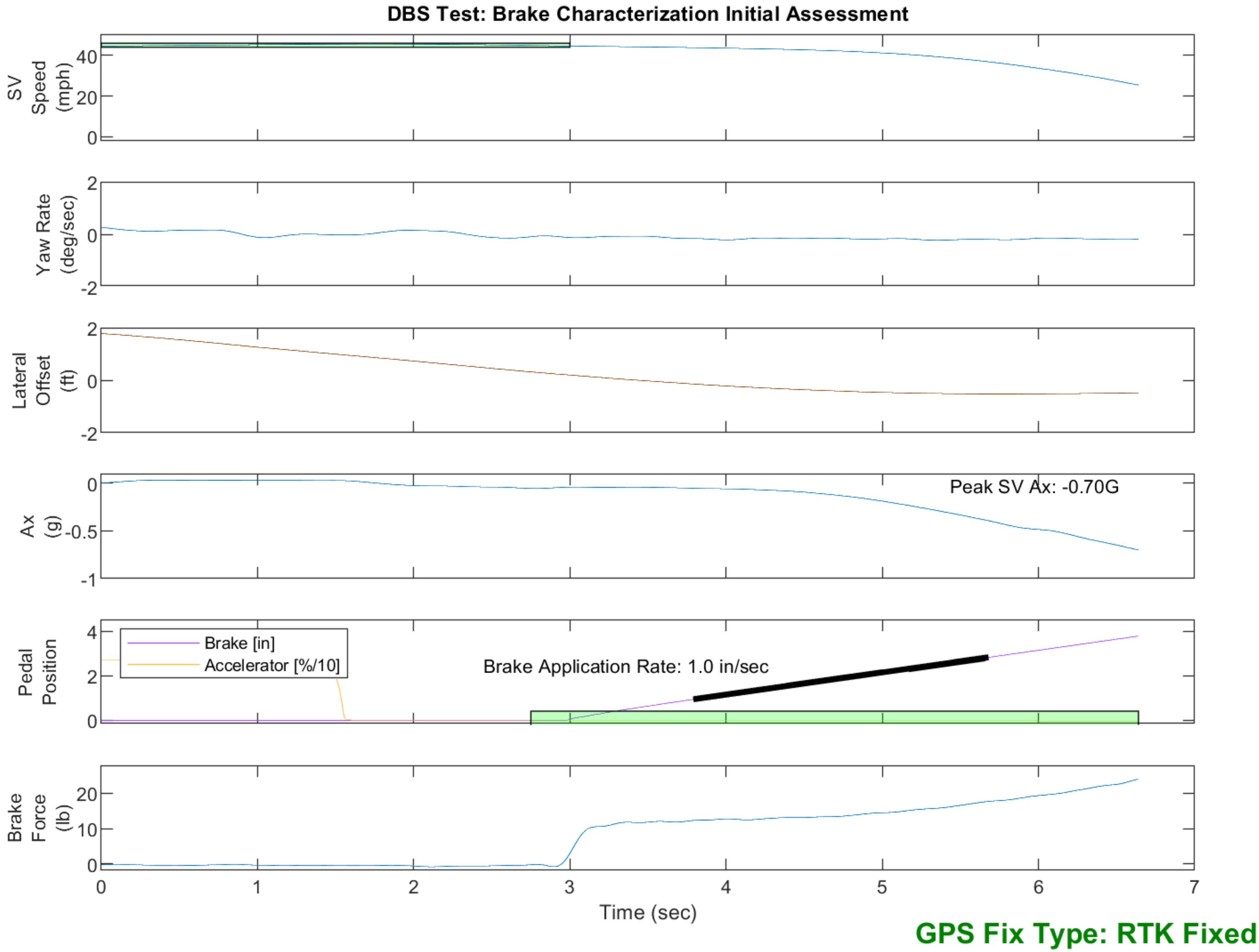


Figure E9. Example Time History for DBS Brake Characterization, Passing

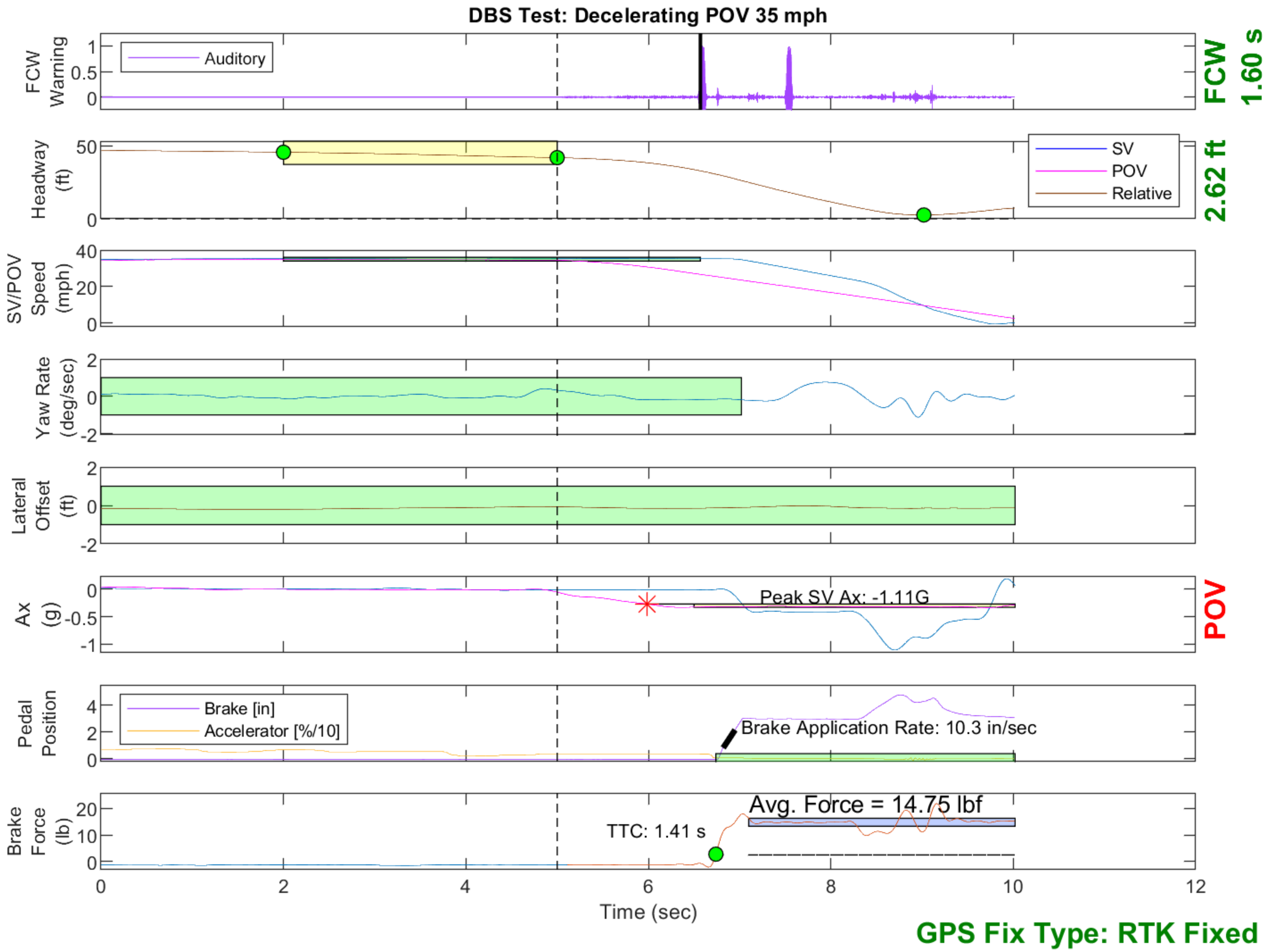


Figure E10. Example Time History Displaying Invalid POV Acceleration Criteria

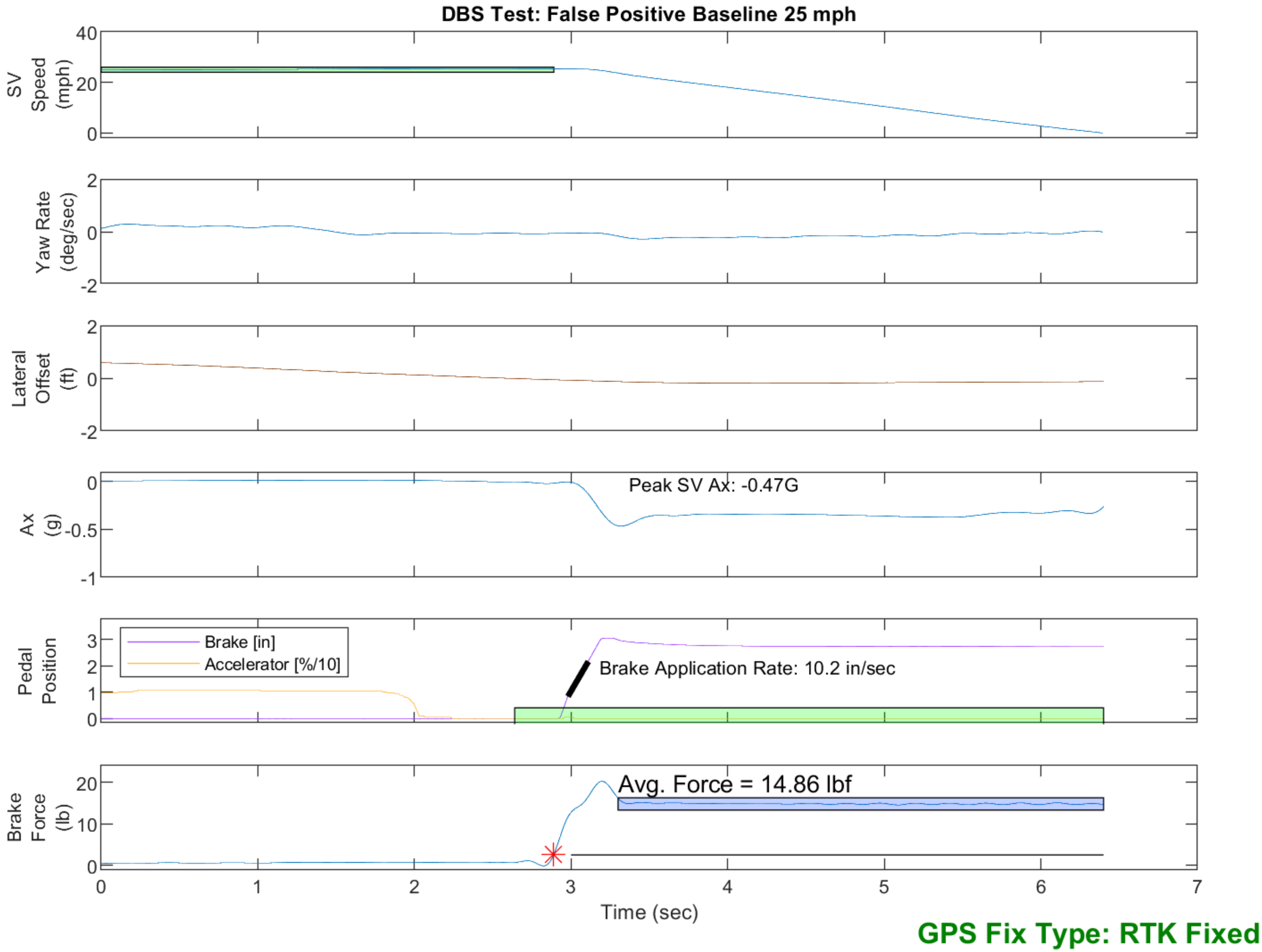


Figure E11. Example Time History Displaying Invalid Brake Force Criteria

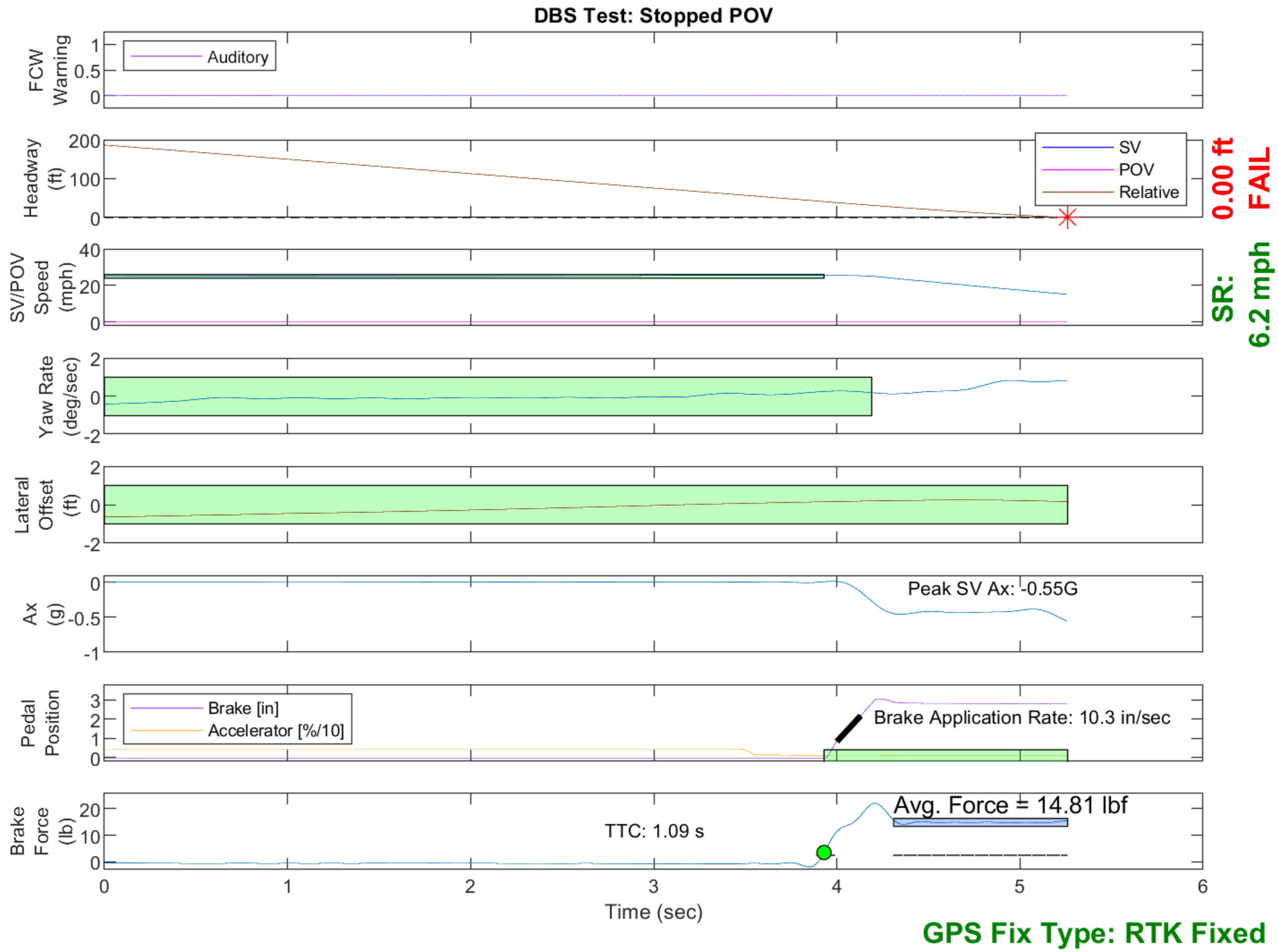


Figure E12. Example Time History for a Failed Run

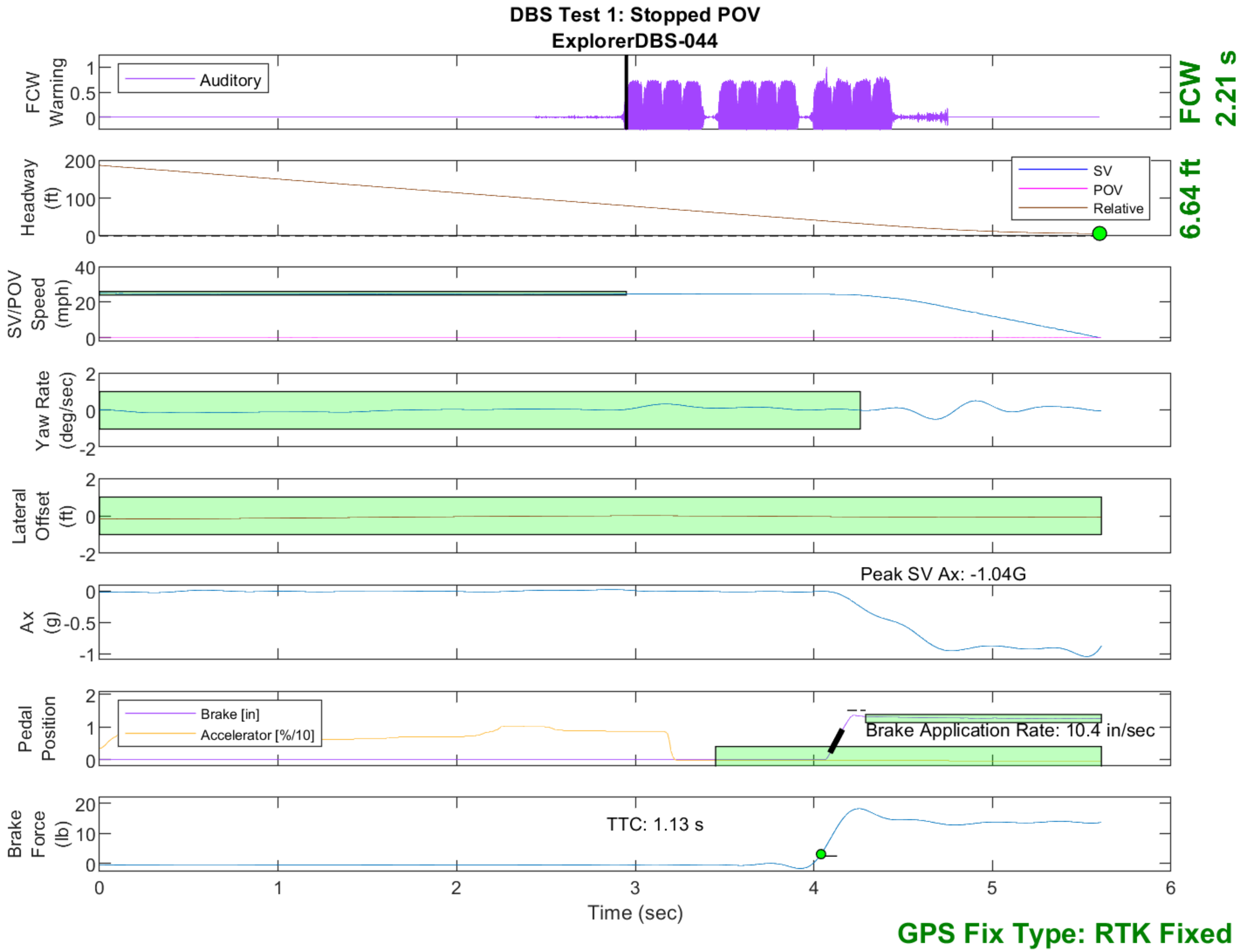


Figure E13. Time History for DBS Run 44, Test 1 - Stopped POV

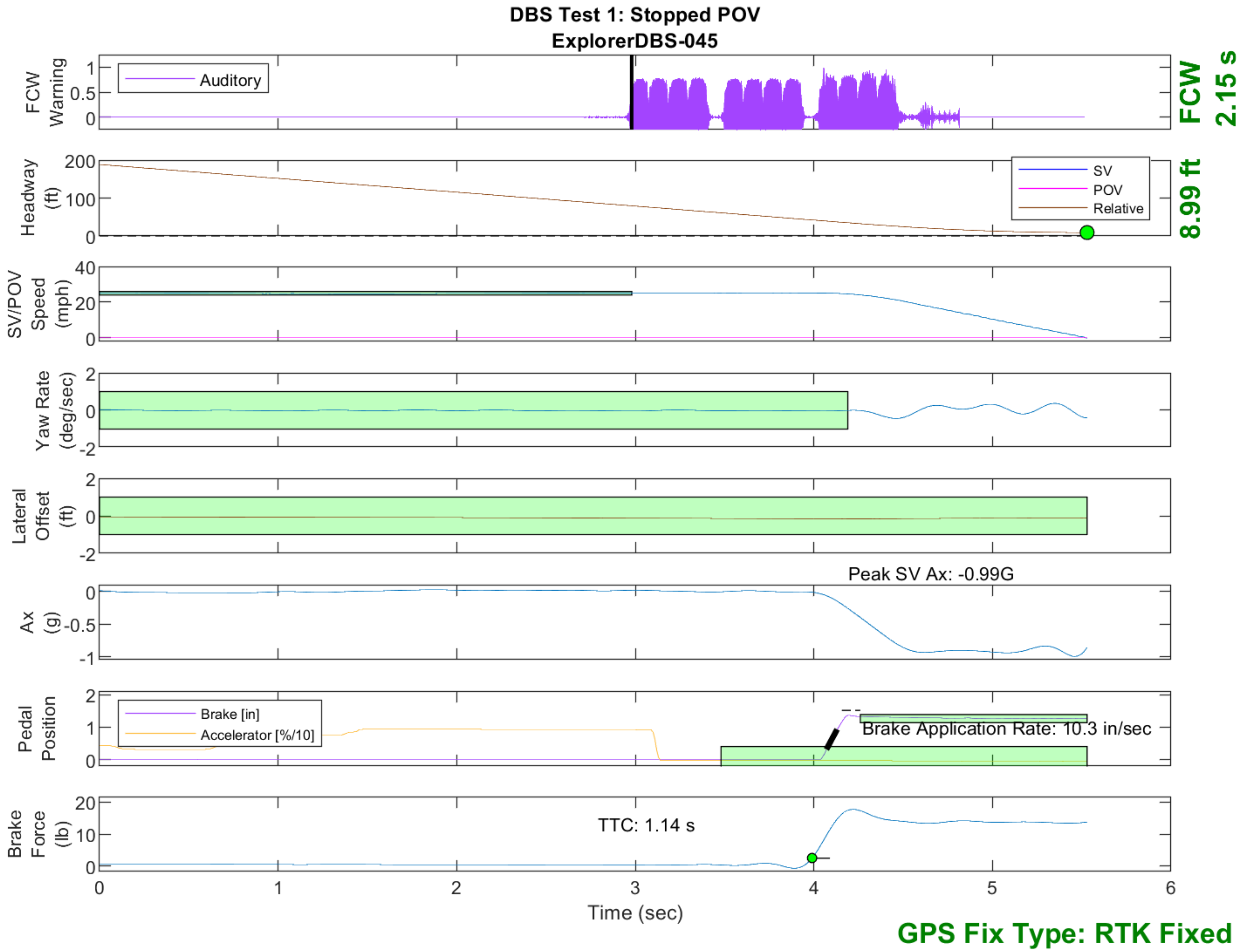


Figure E14. Time History for DBS Run 45, Test 1 - Stopped POV

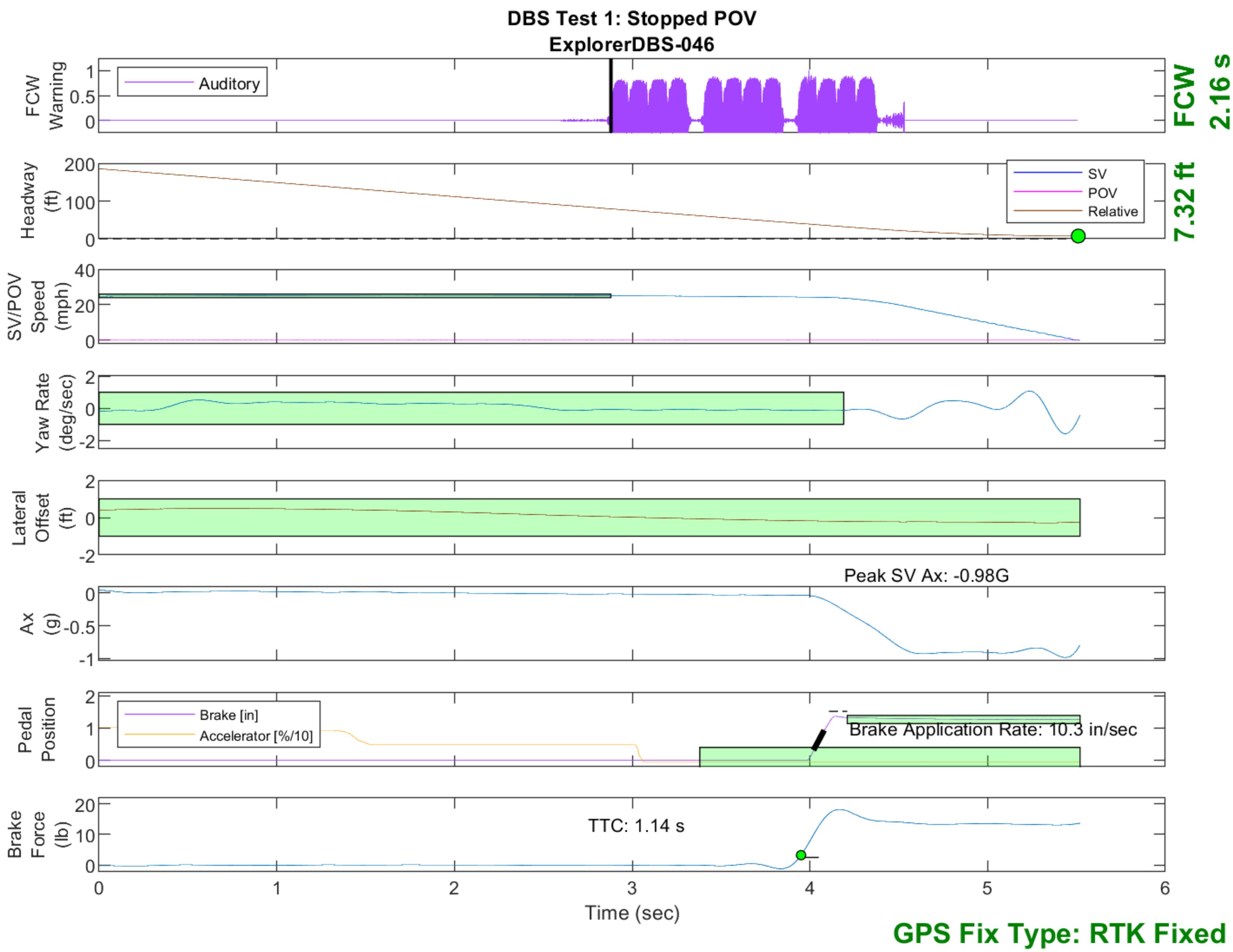


Figure E15. Time History for DBS Run 46, Test 1 - Stopped POV

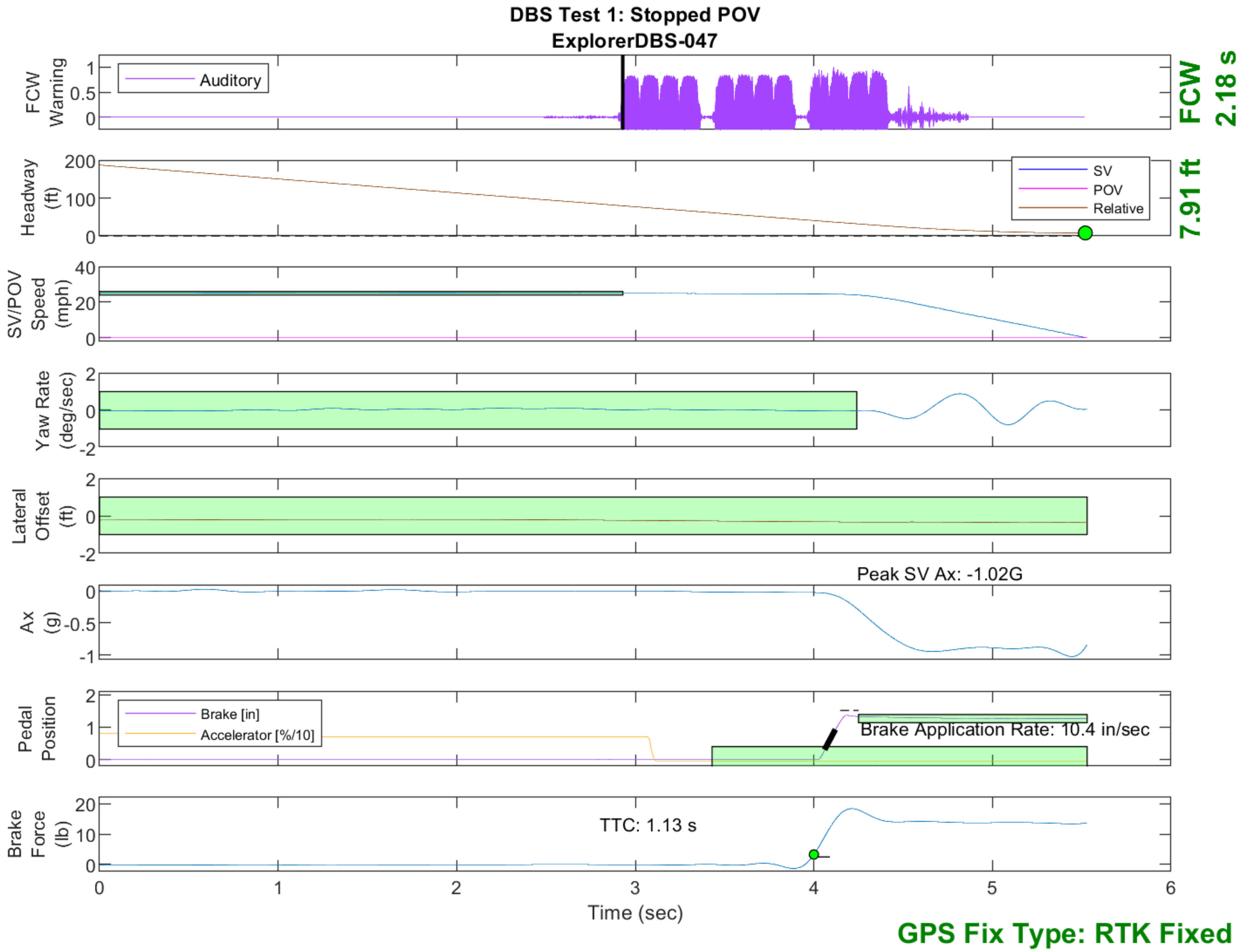


Figure E16. Time History for DBS Run 47, Test 1 - Stopped POV

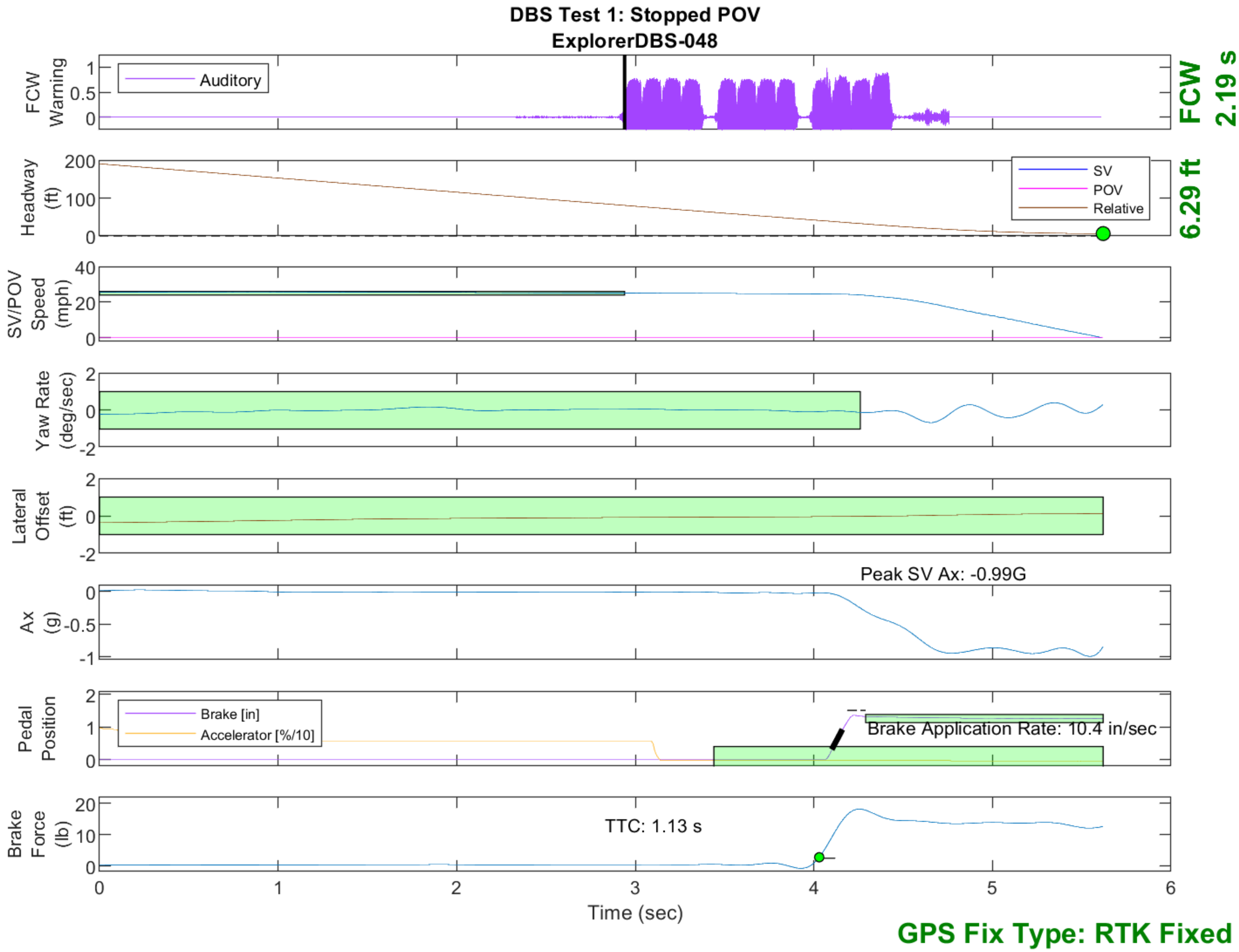


Figure E17. Time History for DBS Run 48, Test 1 - Stopped POV

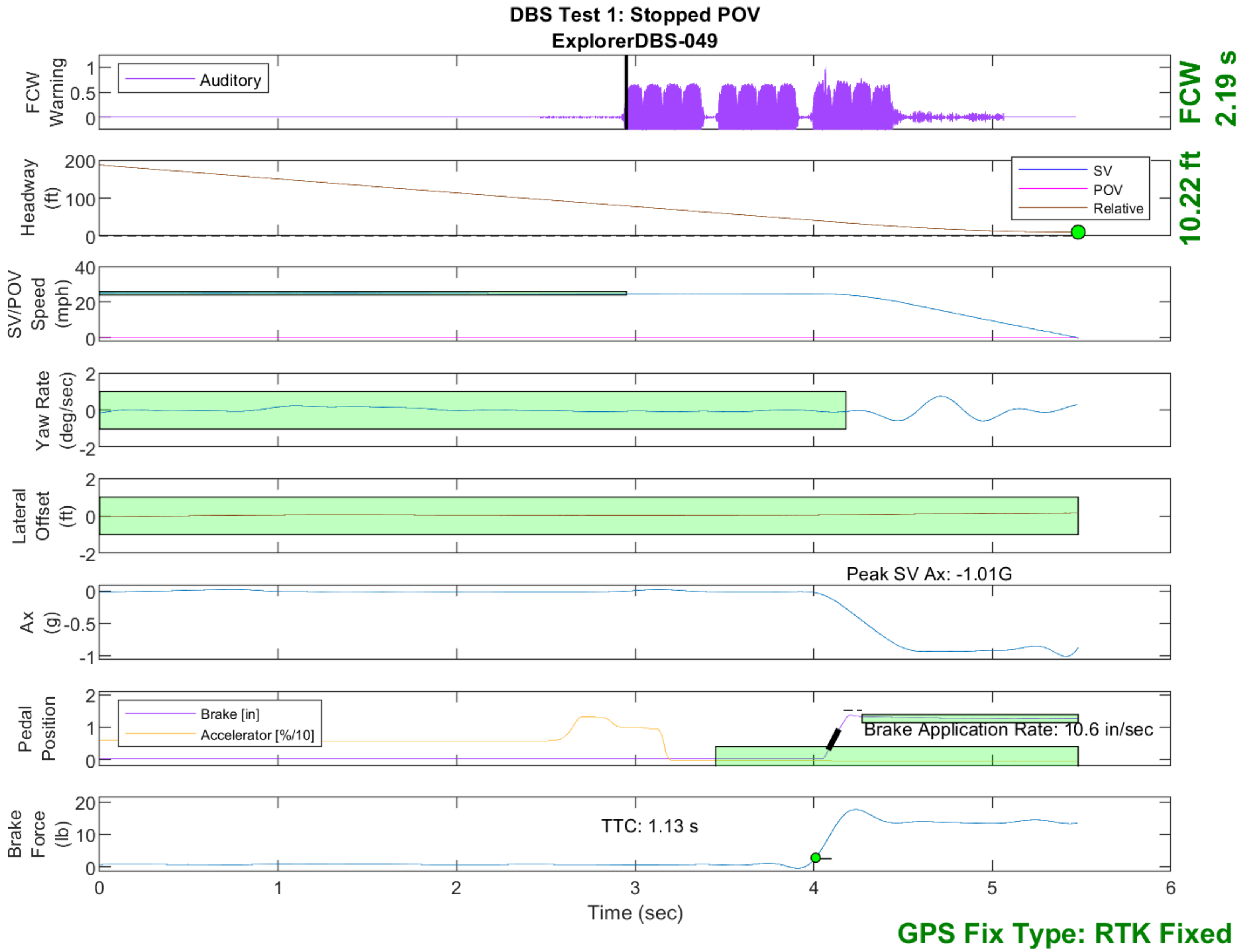


Figure E18. Time History for DBS Run 49, Test 1 - Stopped POV

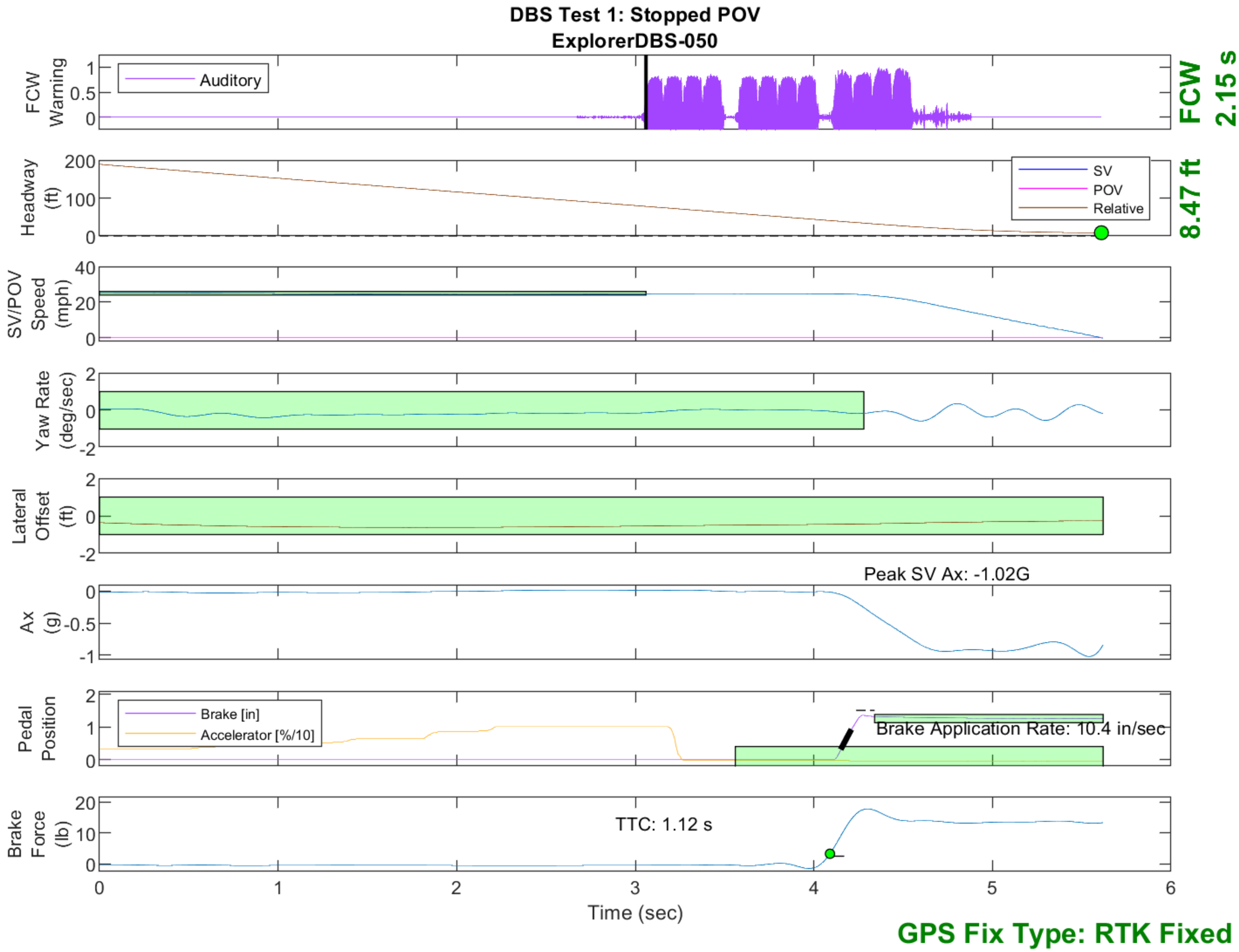


Figure E19. Time History for DBS Run 50, Test 1 - Stopped POV

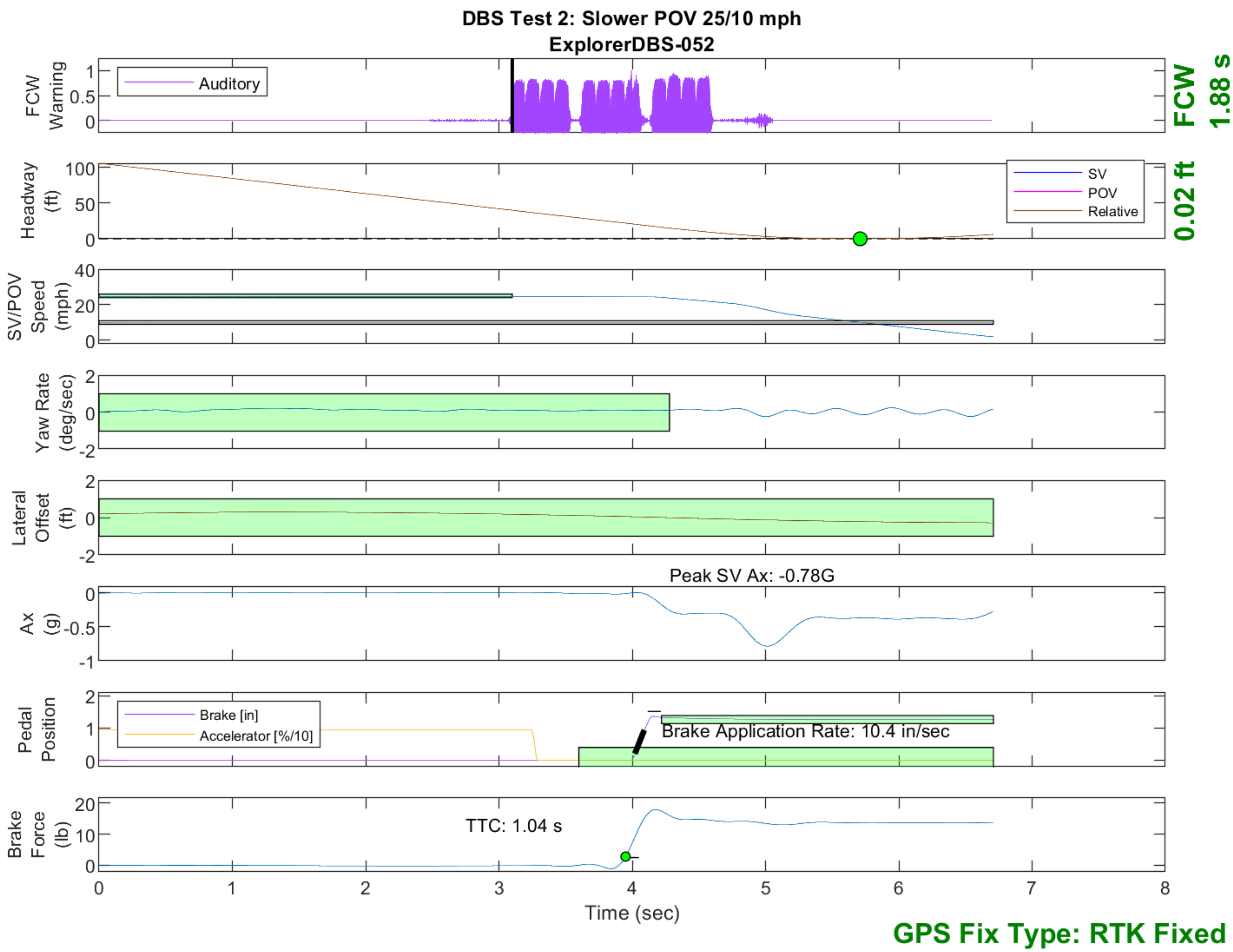


Figure E20. Time History for DBS Run 52, Test 2 - Slower Moving POV 25/10 mph

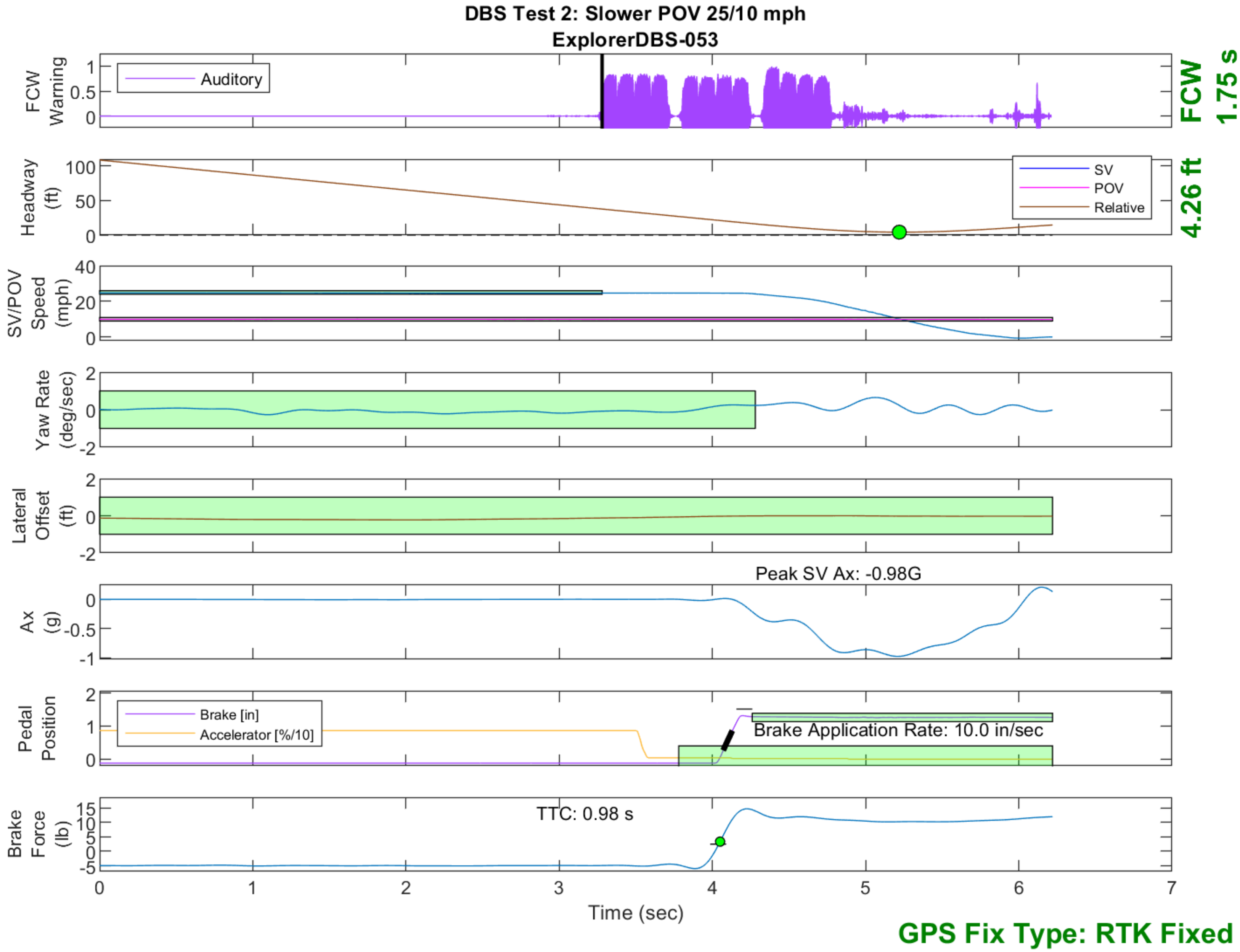


Figure E21. Time History for DBS Run 53, Test 2 - Slower Moving POV 25/10 mph

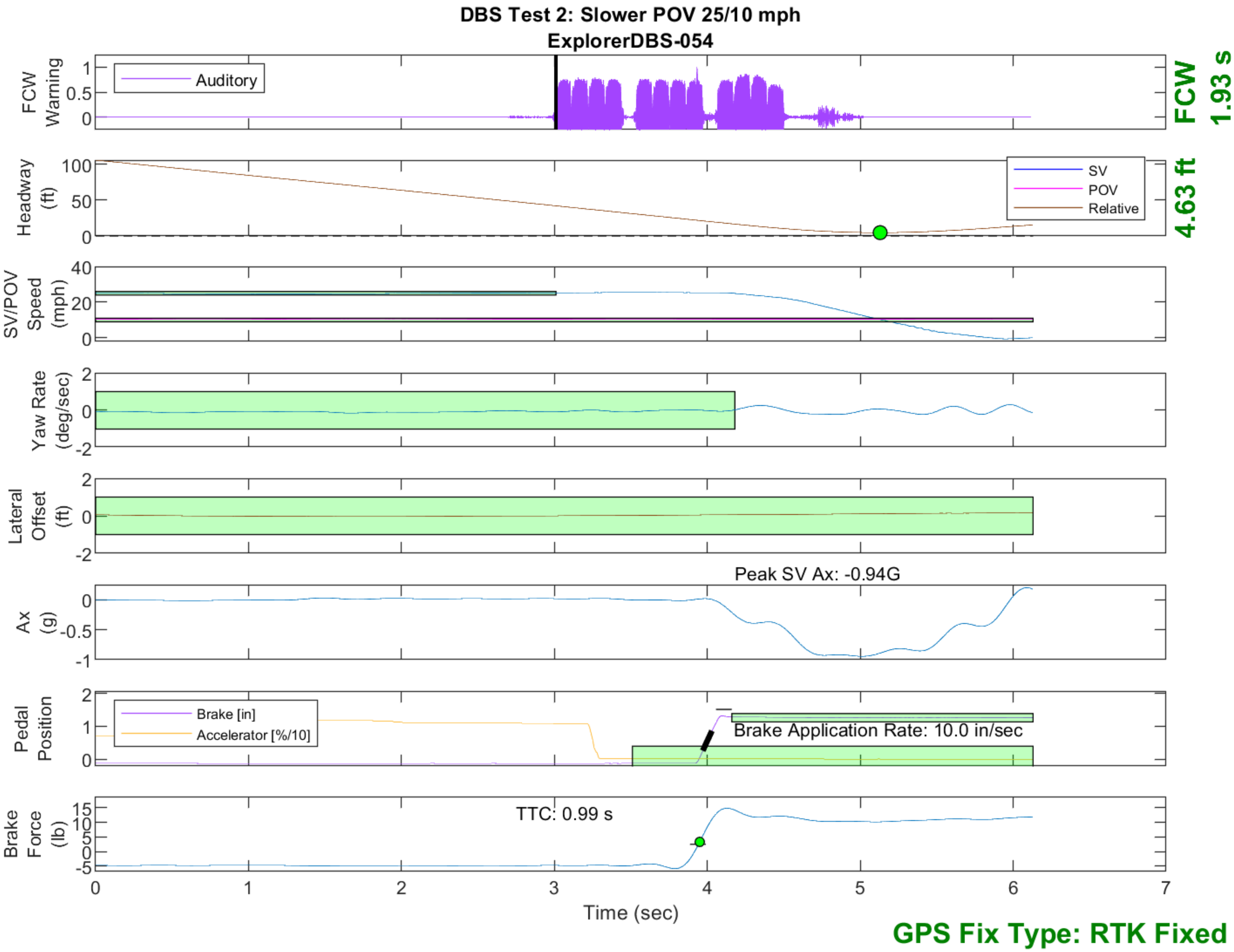


Figure E22. Time History for DBS Run 54, Test 2 - Slower Moving POV 25/10 mph

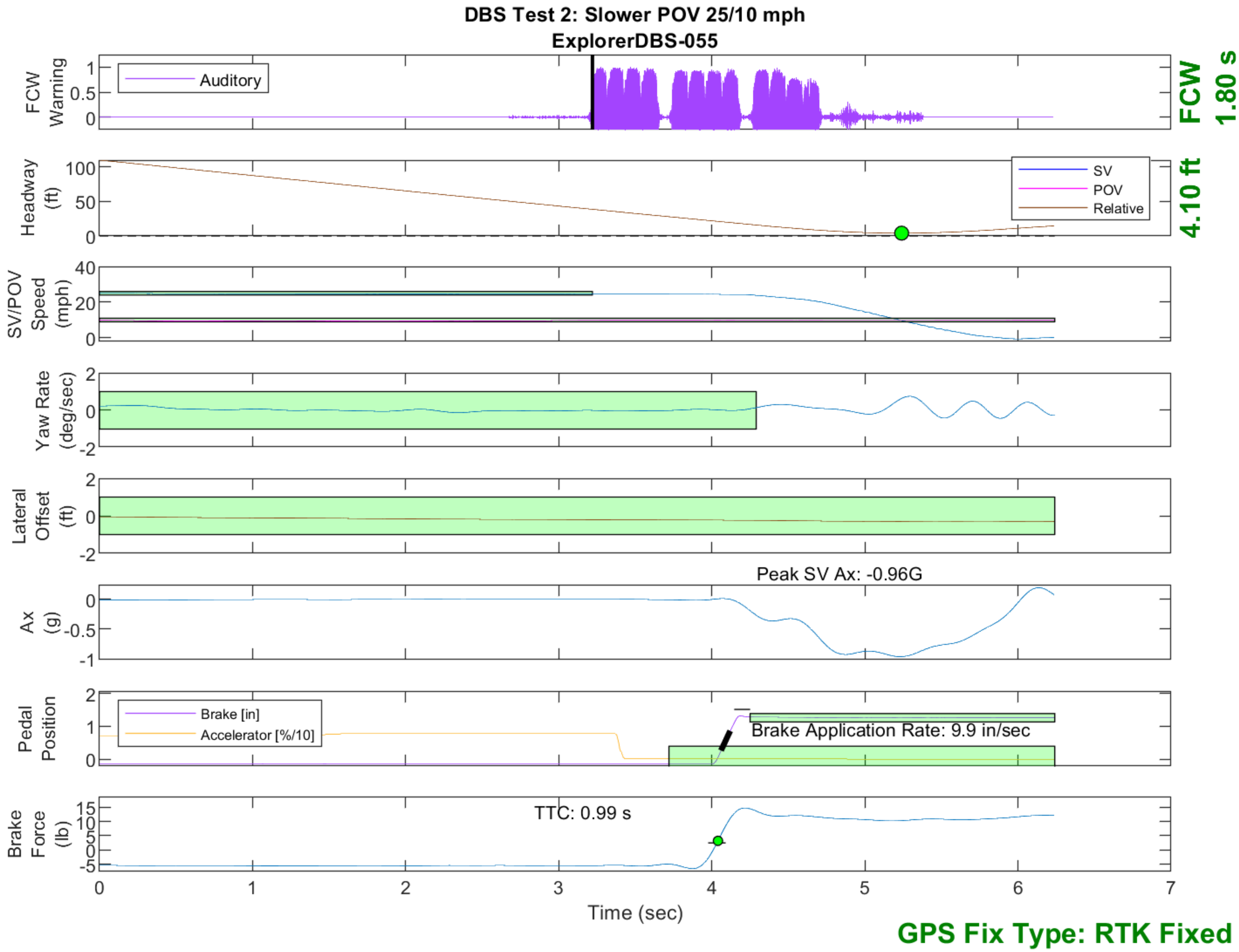


Figure E23. Time History for DBS Run 55, Test 2 - Slower Moving POV 25/10 mph

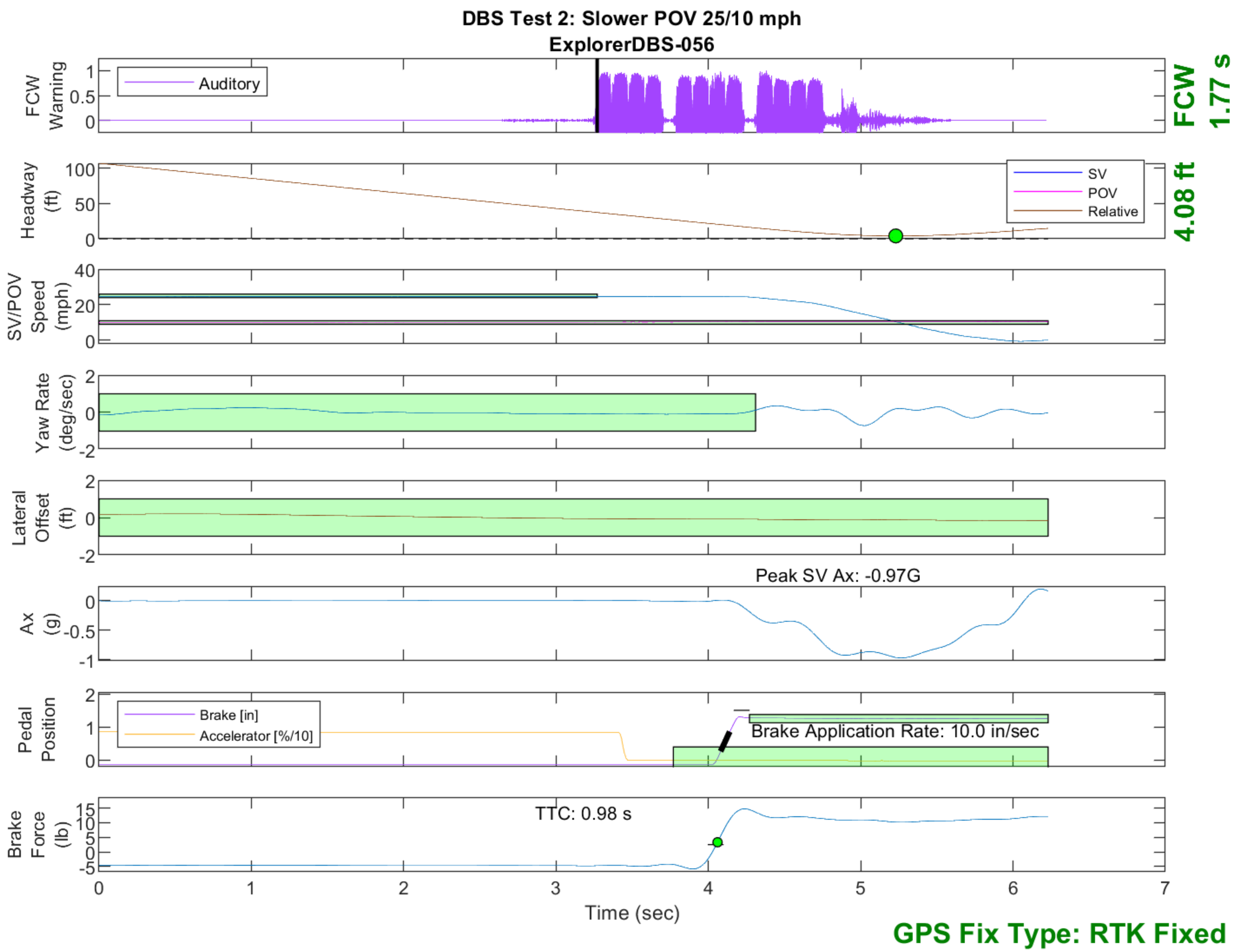


Figure E24. Time History for DBS Run 56, Test 2 - Slower Moving POV 25/10 mph

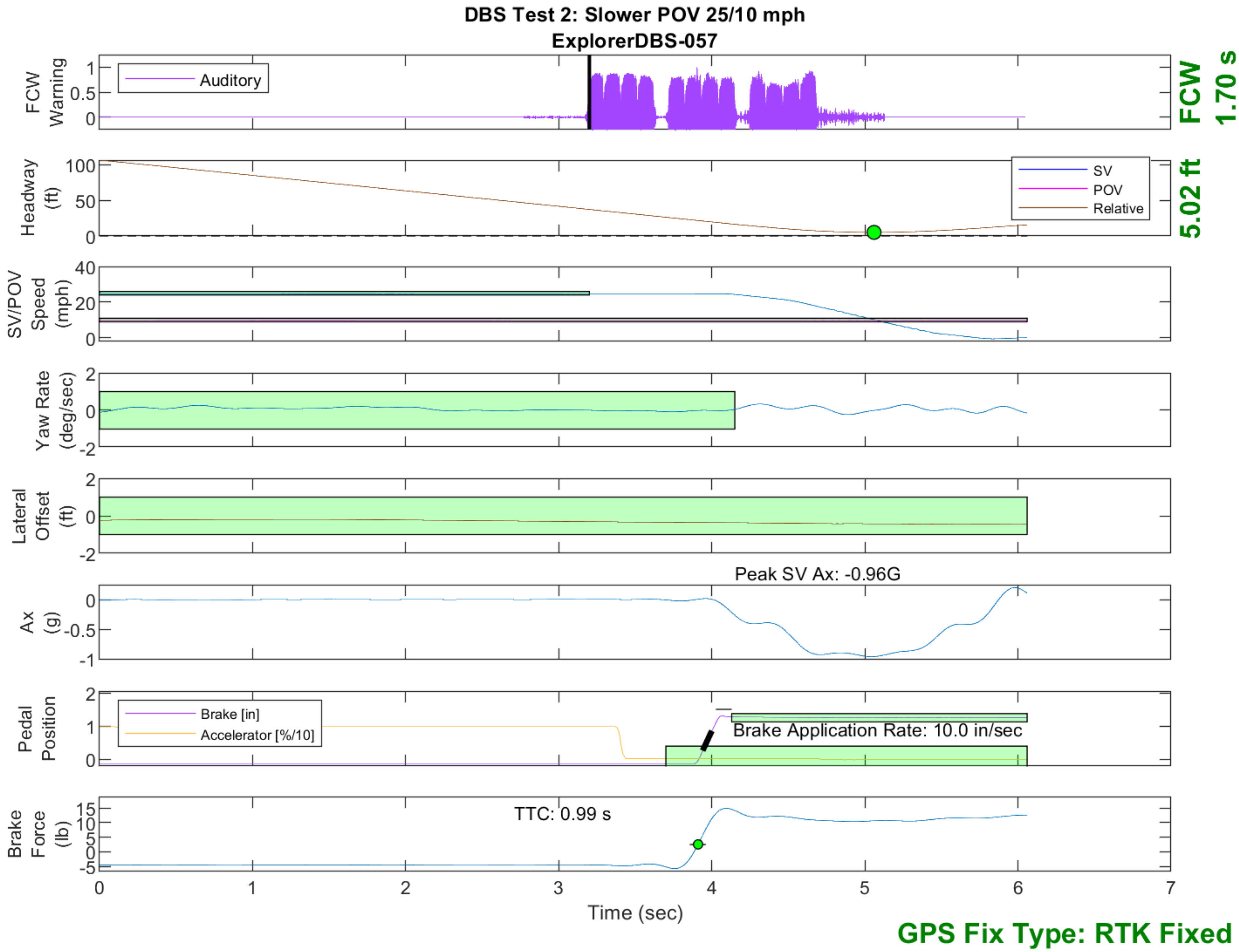


Figure E25. Time History for DBS Run 57, Test 2 - Slower Moving POV 25/10 mph

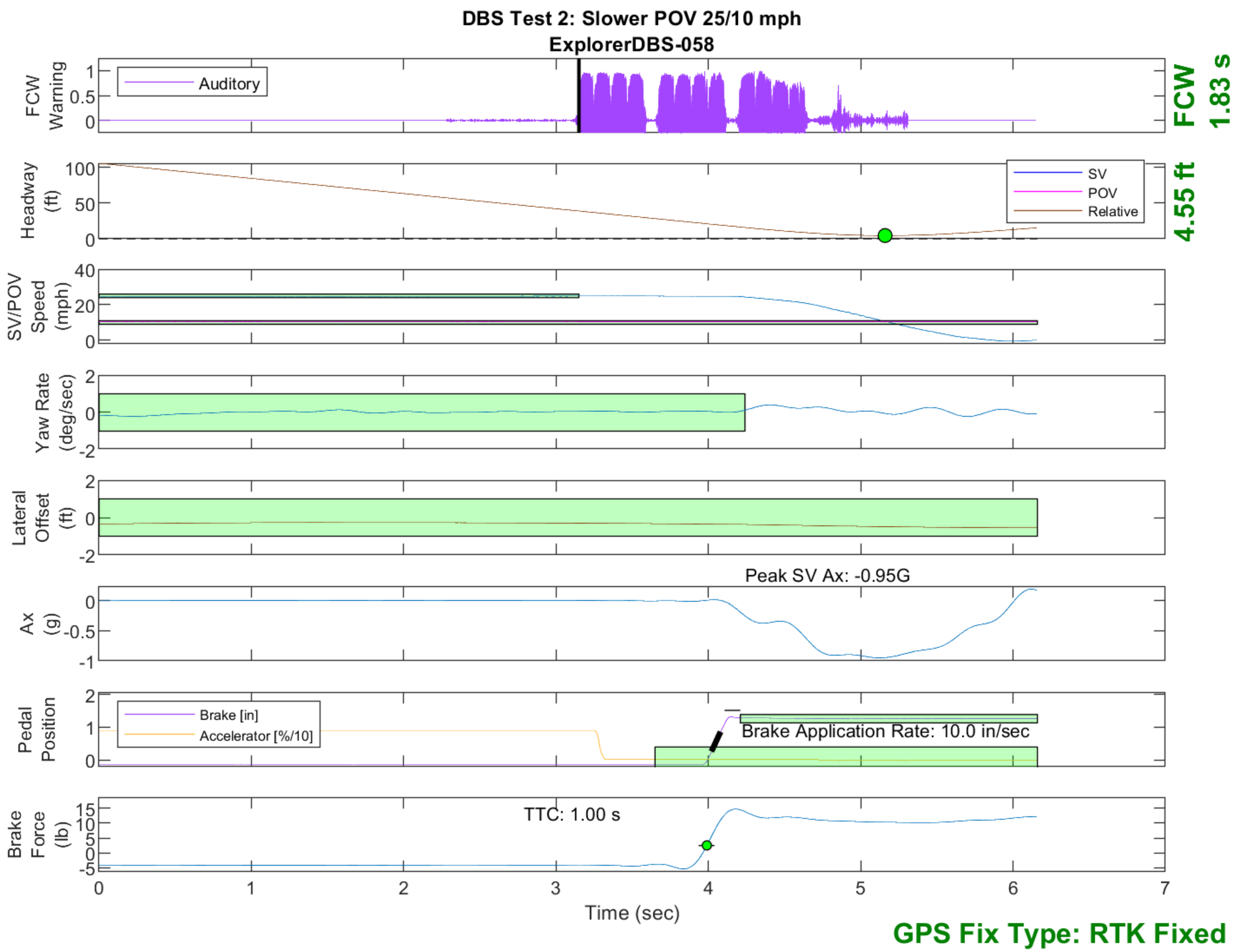


Figure E26. Time History for DBS Run 58, Test 2 - Slower Moving POV 25/10 mph

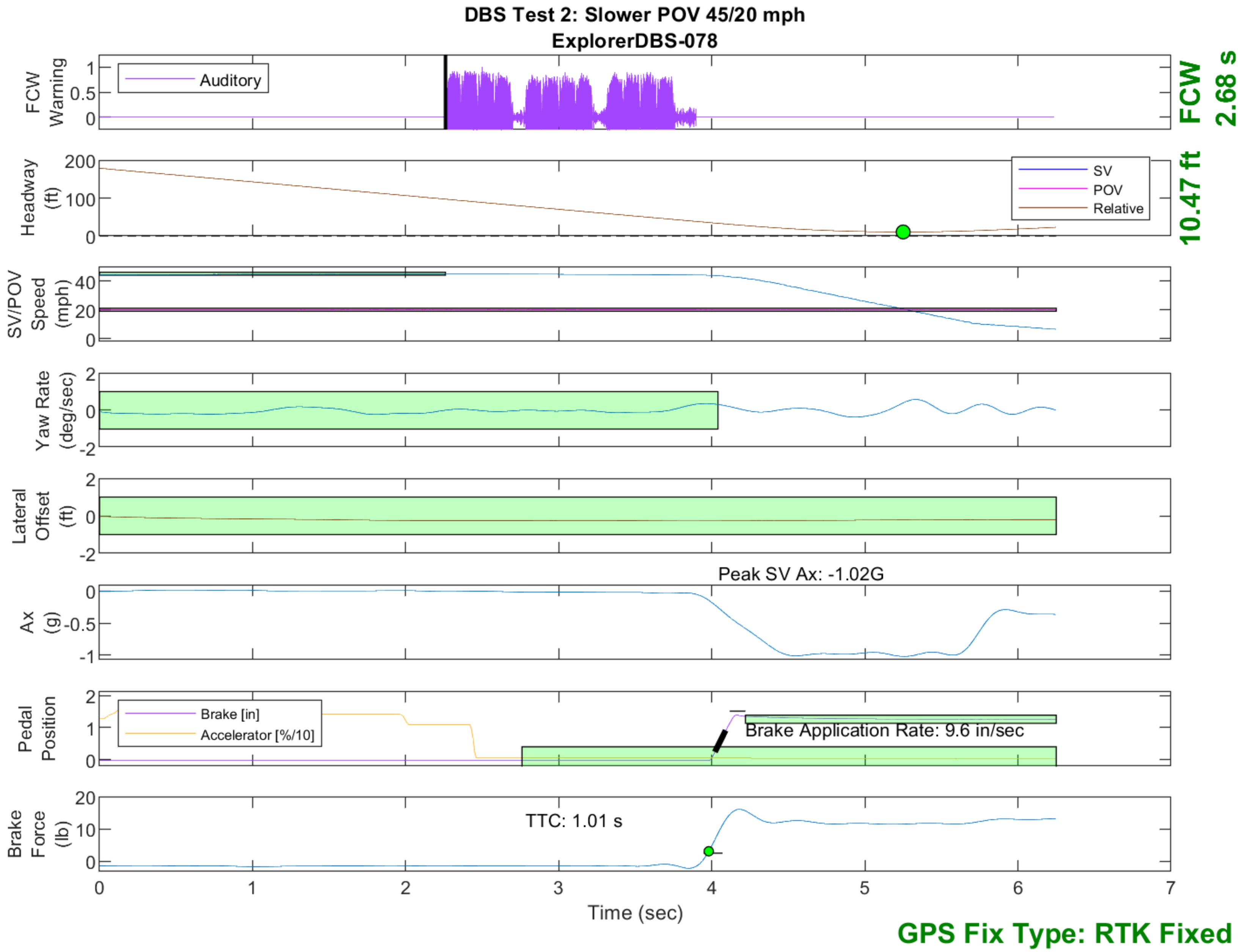


Figure E27. Time History for DBS Run 78, Test 2 - Slower Moving POV 45/20 mph

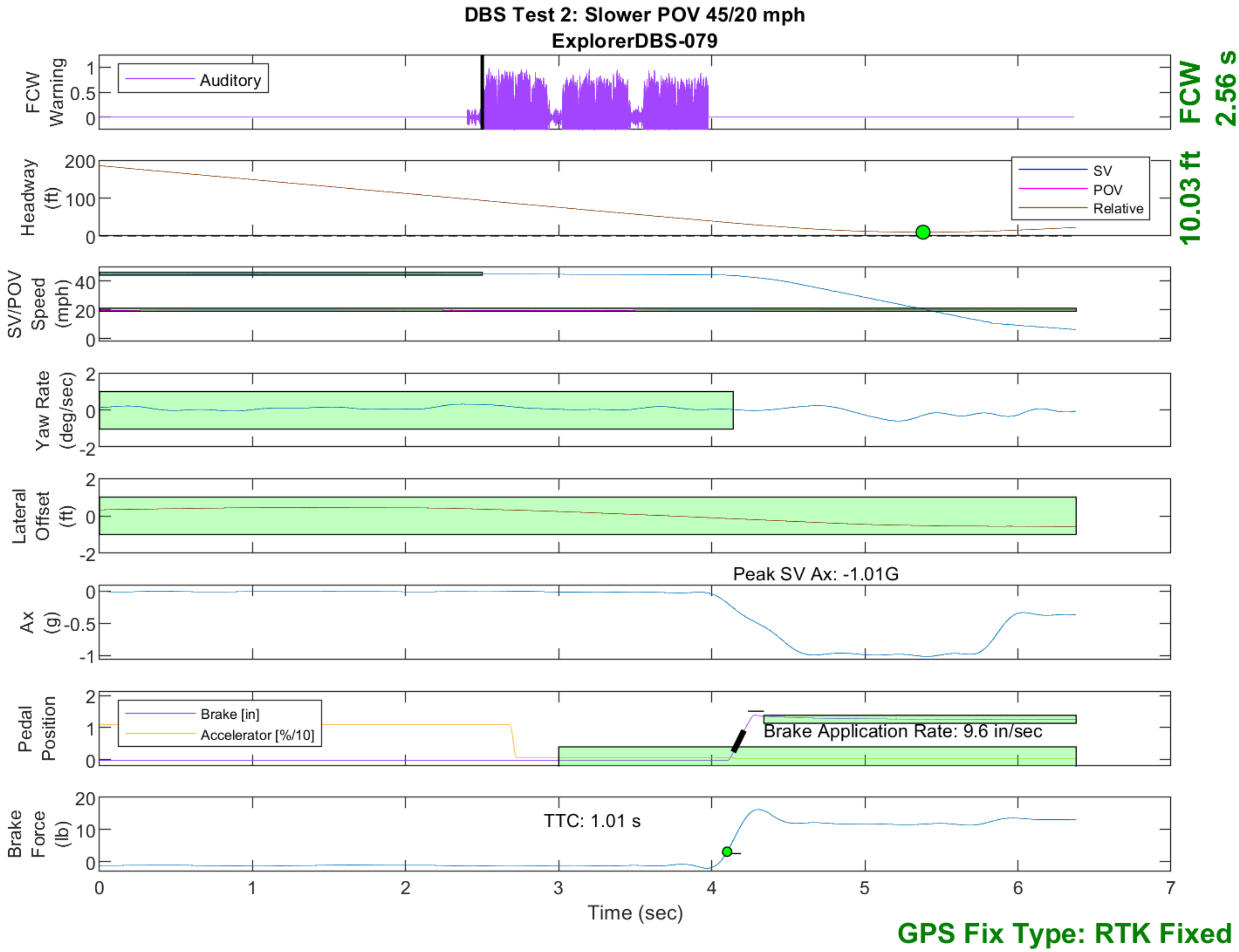


Figure E28. Time History for DBS Run 79, Test 2 - Slower Moving POV 45/20 mph

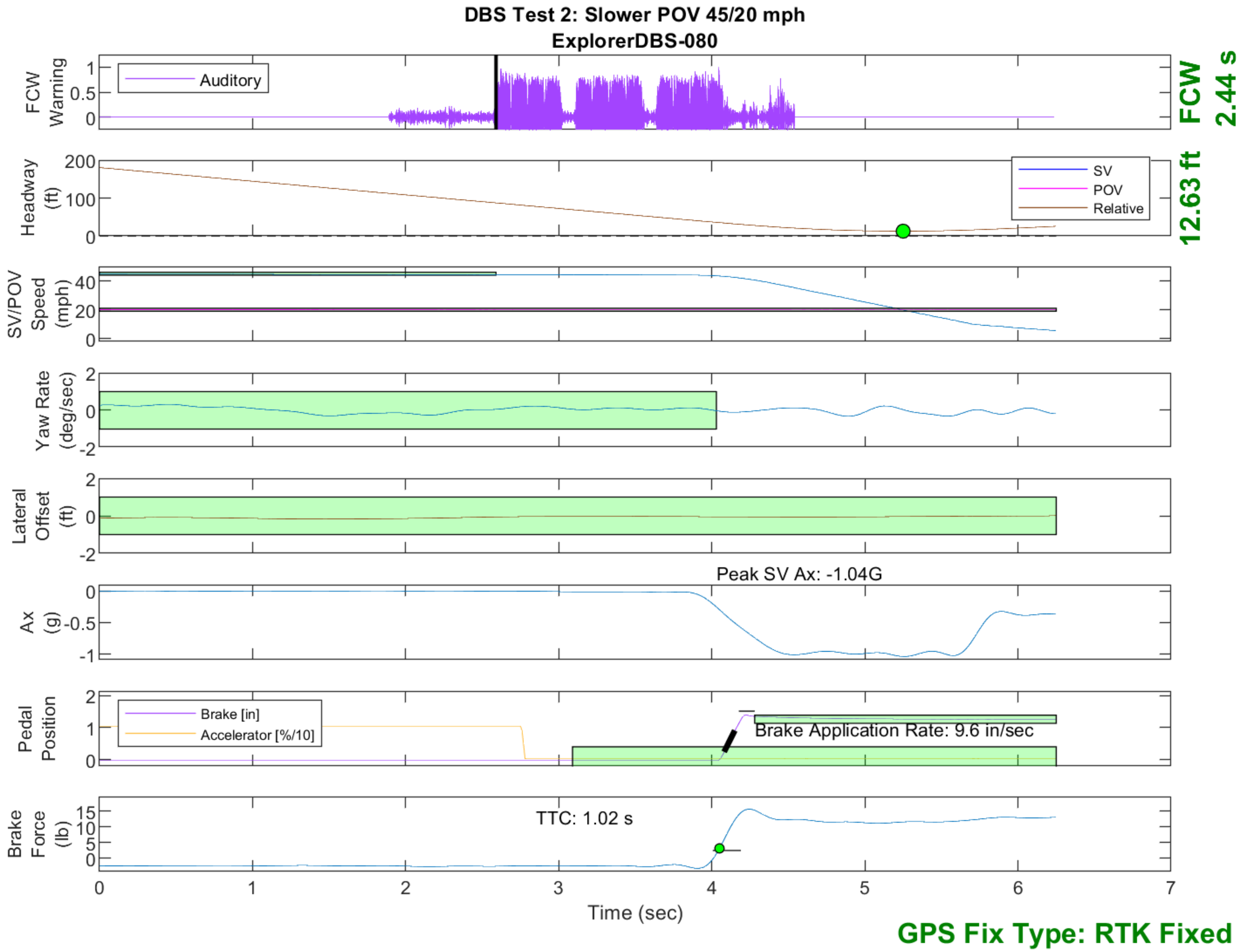


Figure E29. Time History for DBS Run 80, Test 2 - Slower Moving POV 45/20 mph

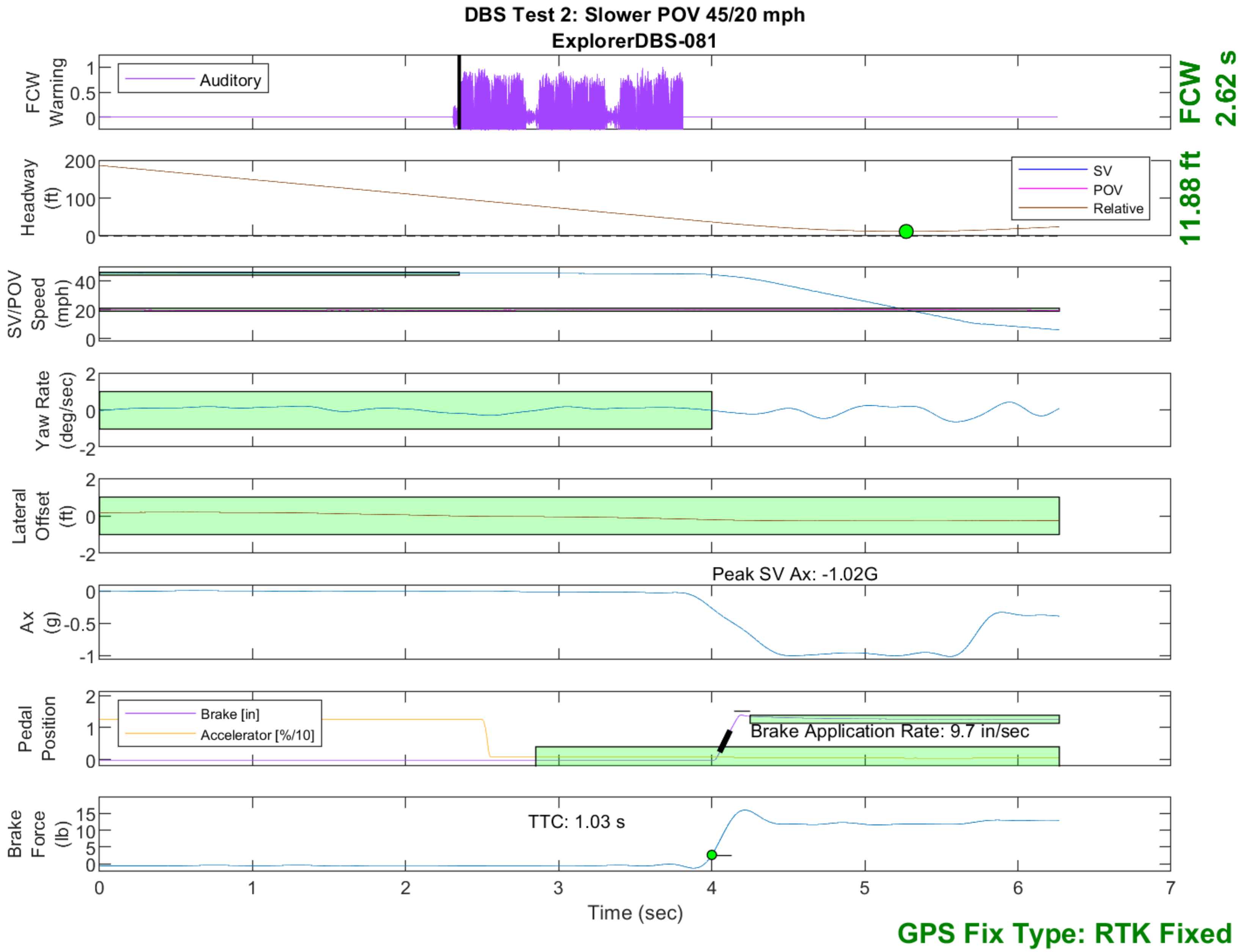


Figure E30. Time History for DBS Run 81, Test 2 - Slower Moving POV 45/20 mph

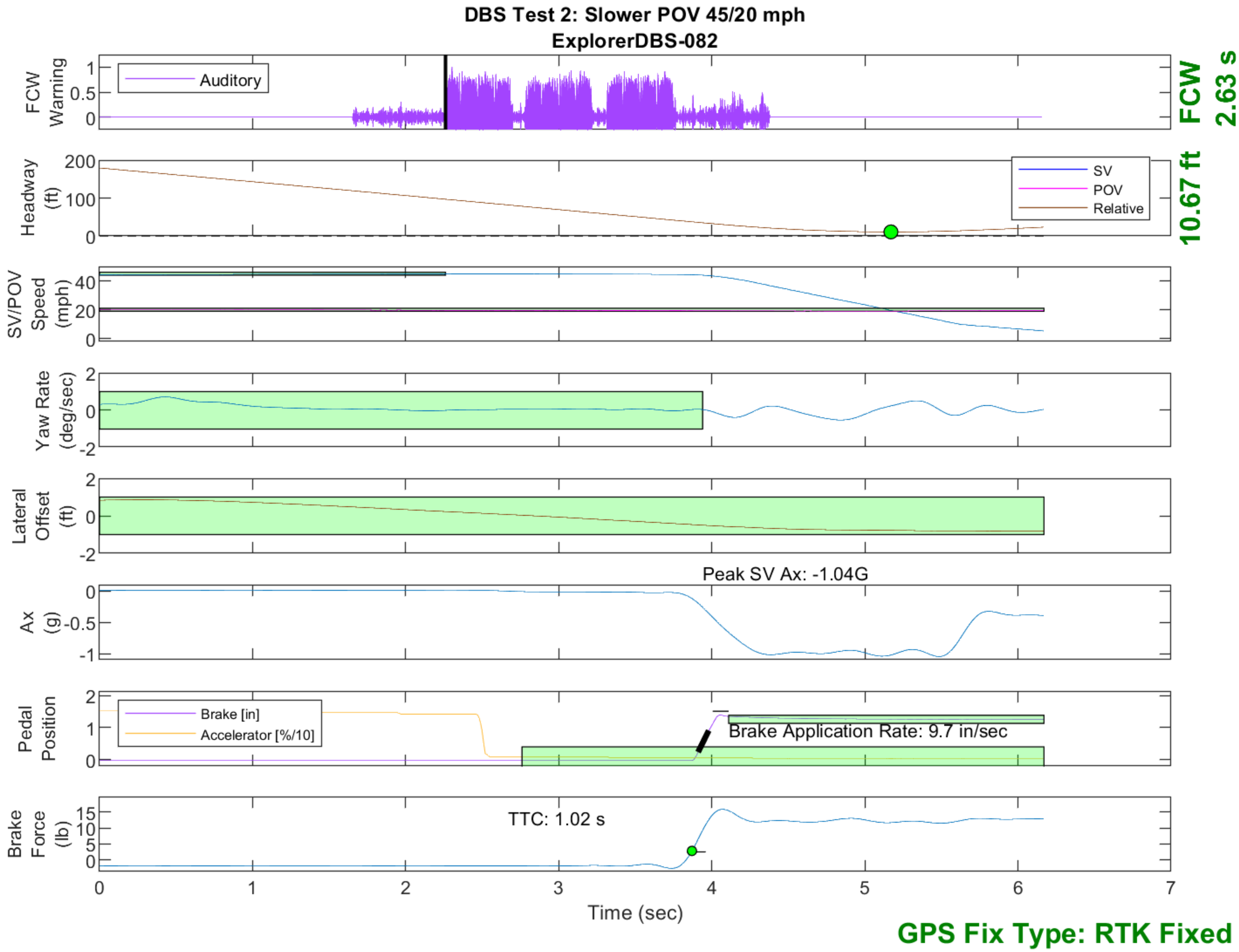


Figure E31. Time History for DBS Run 82, Test 2 - Slower Moving POV 45/20 mph

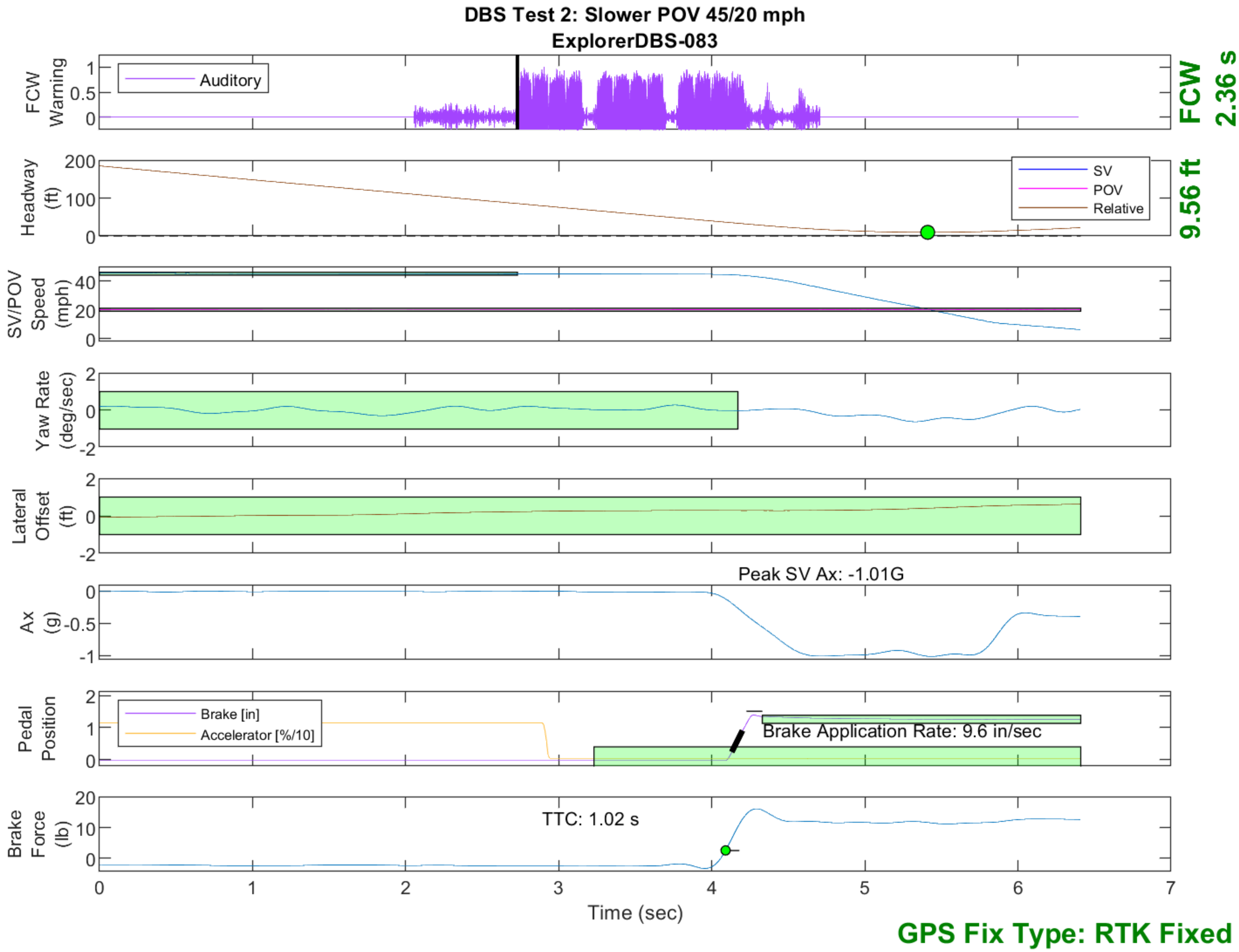


Figure E32. Time History for DBS Run 83, Test 2 - Slower Moving POV 45/20 mph

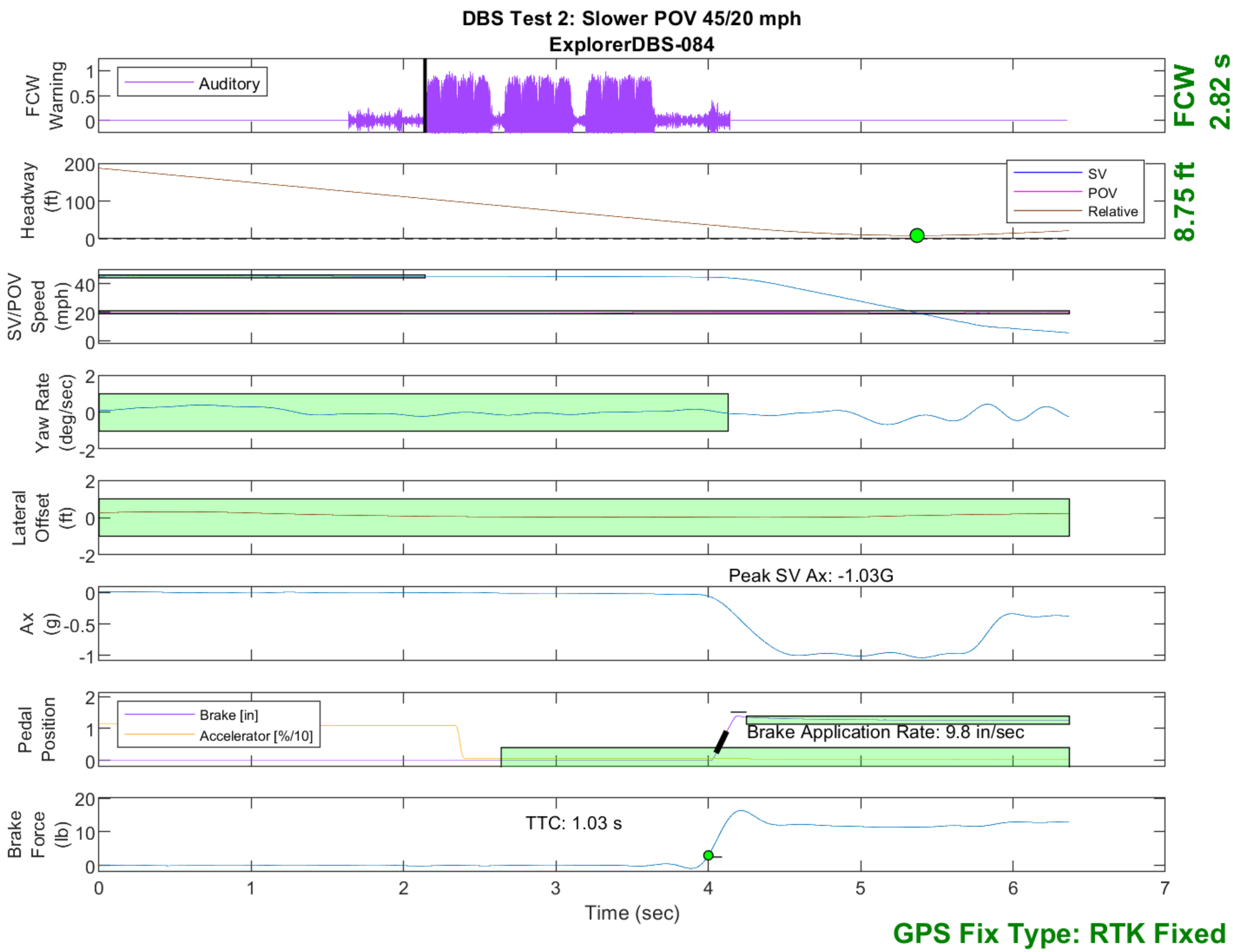


Figure E33. Time History for DBS Run 84, Test 2 - Slower Moving POV 45/20 mph

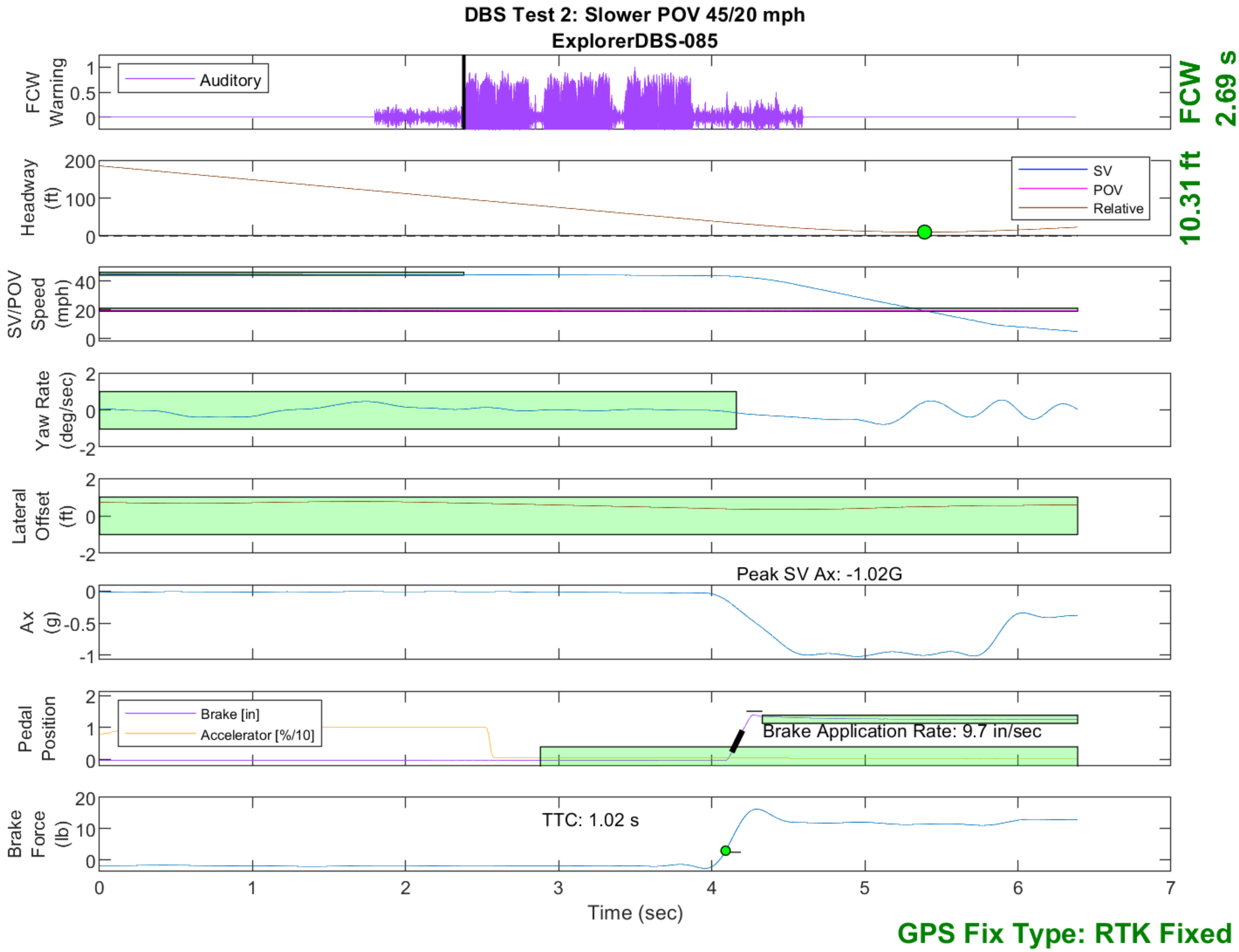


Figure E34. Time History for DBS Run 85, Test 2 - Slower Moving POV 45/20 mph

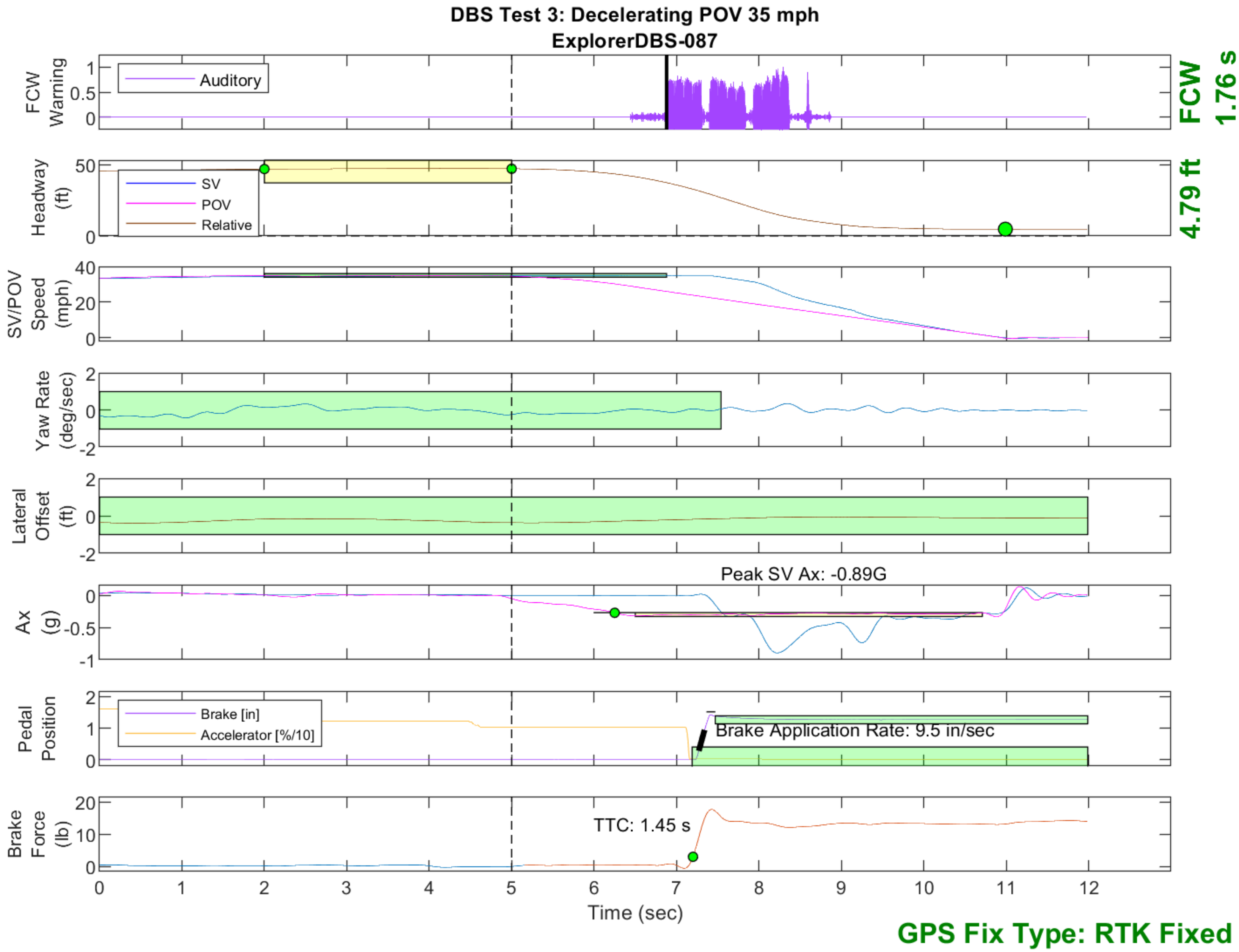


Figure E35. Time History for DBS Run 87, Test 3 - Decelerating POV 35 mph

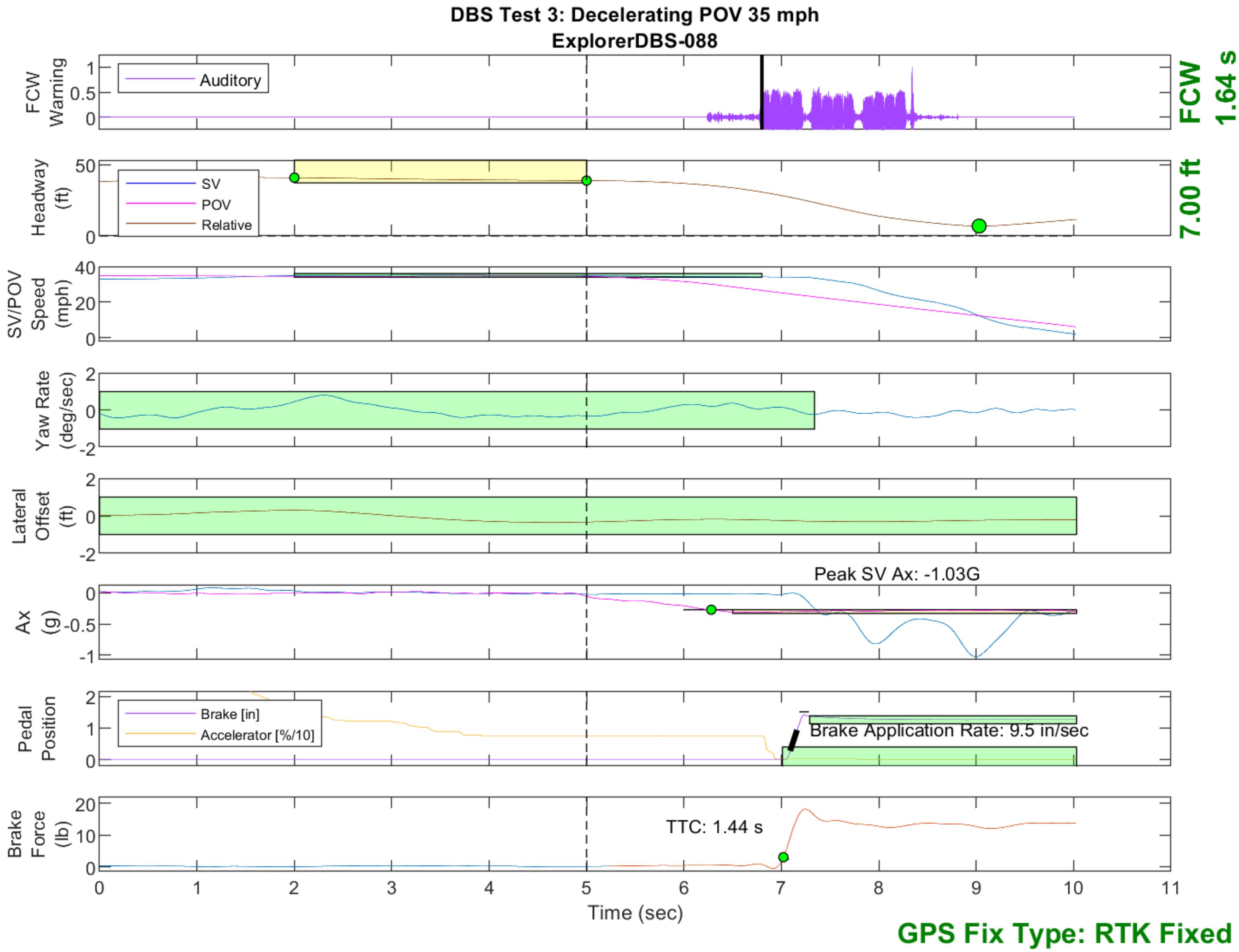


Figure E36. Time History for DBS Run 88, Test 3 - Decelerating POV 35 mph

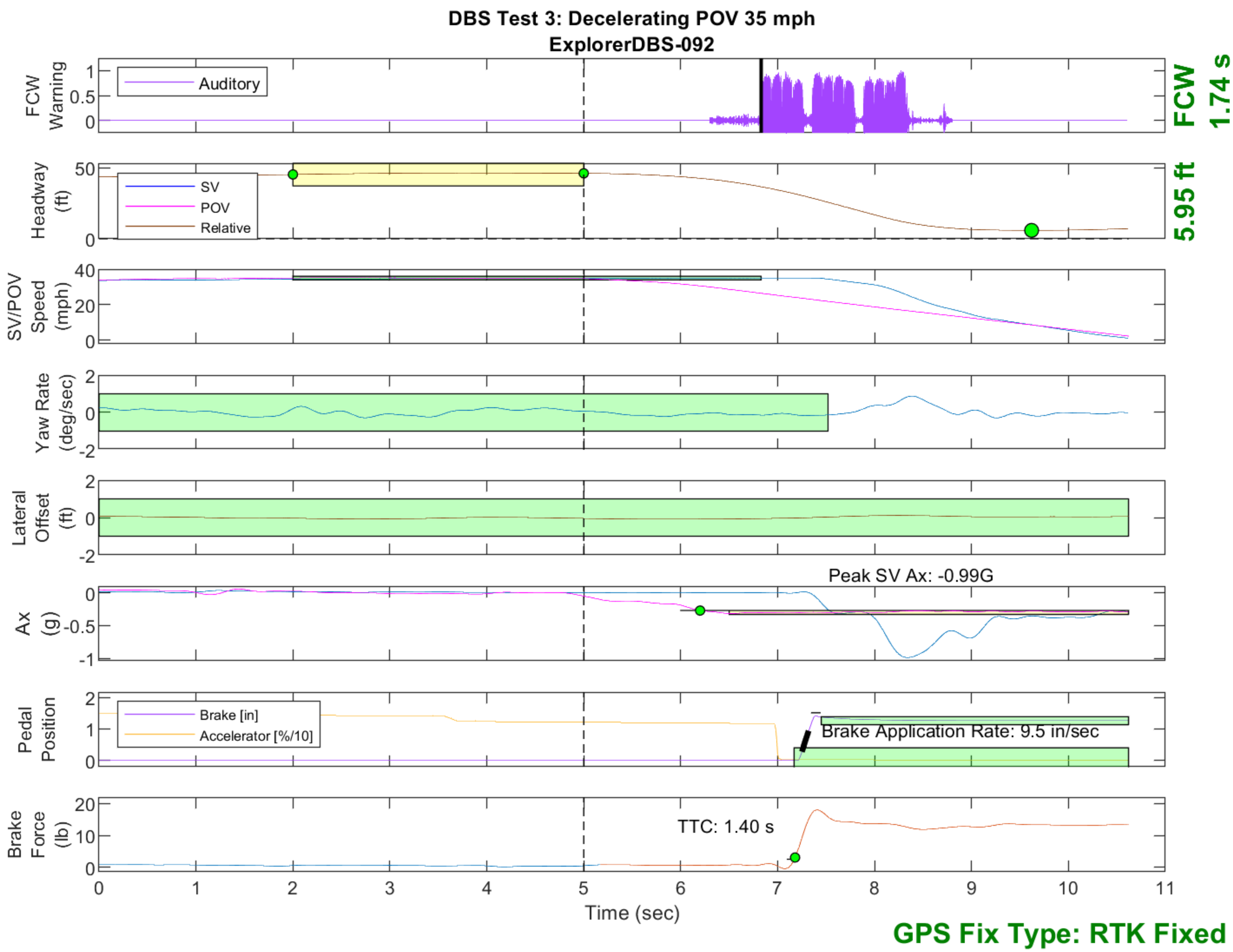


Figure E37. Time History for DBS Run 92, Test 3 - Decelerating POV 35 mph

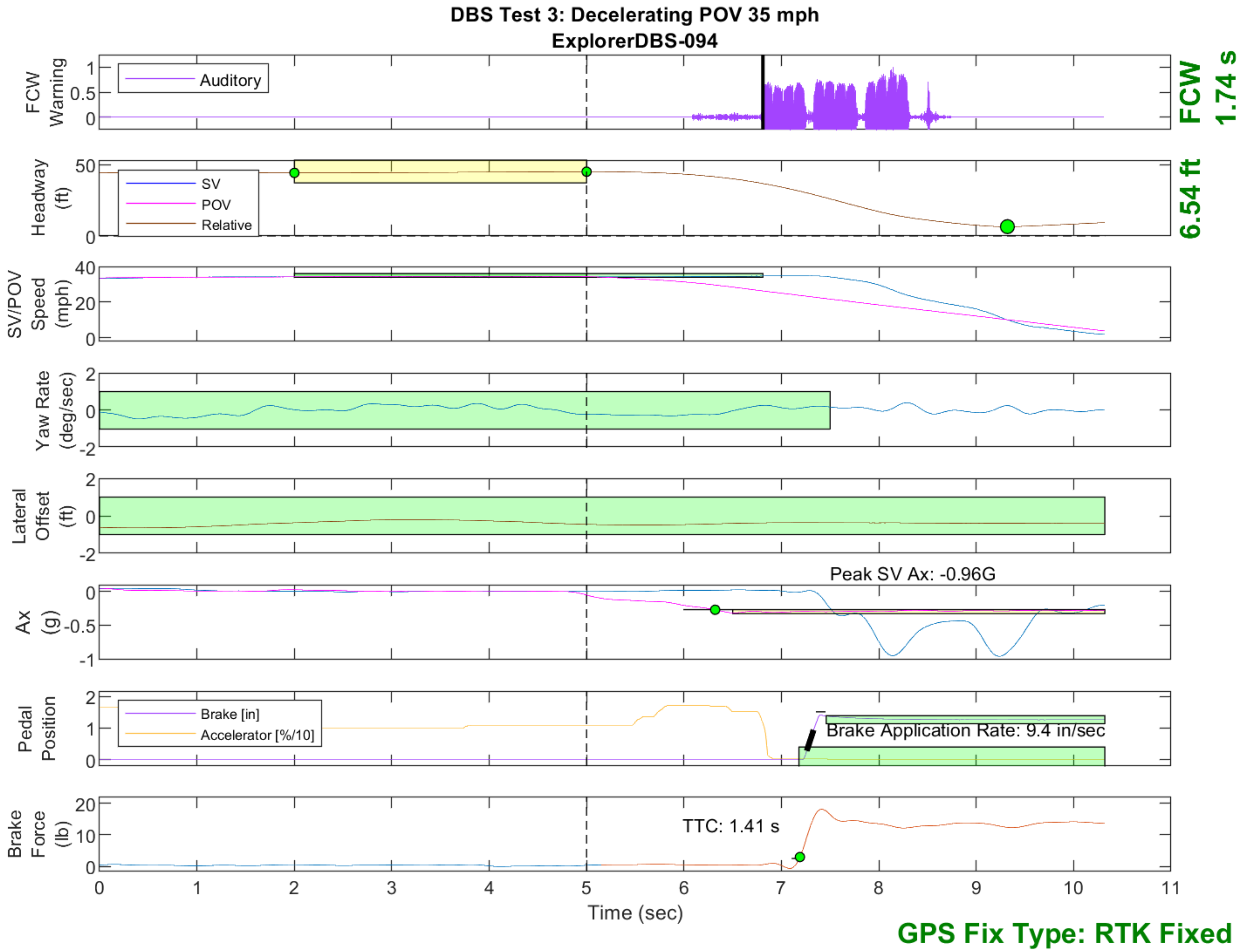


Figure E38. Time History for DBS Run 94, Test 3 - Decelerating POV 35 mph

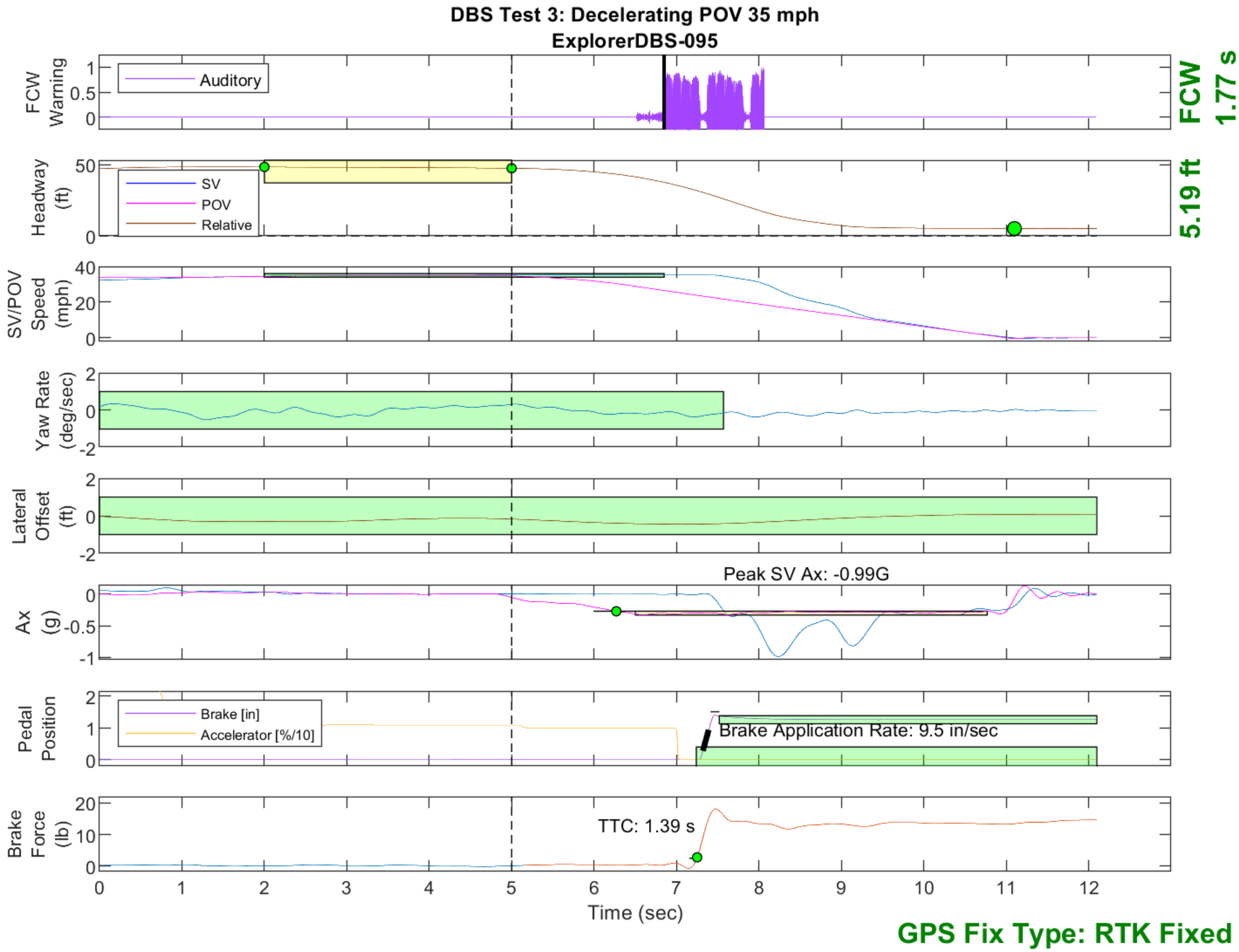


Figure E39. Time History for DBS Run 95, Test 3 - Decelerating POV 35 mph

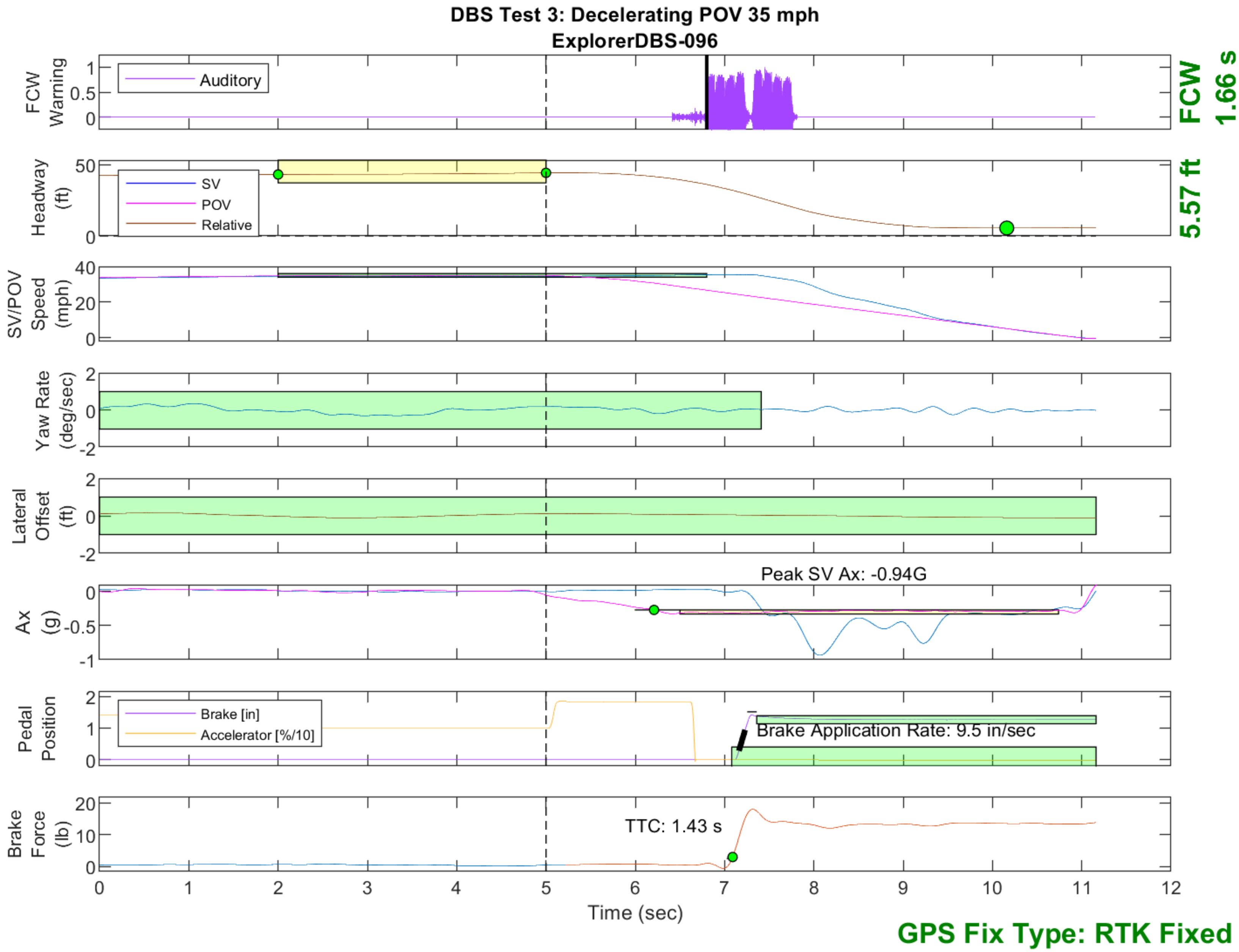


Figure E40. Time History for DBS Run 96, Test 3 - Decelerating POV 35 mph

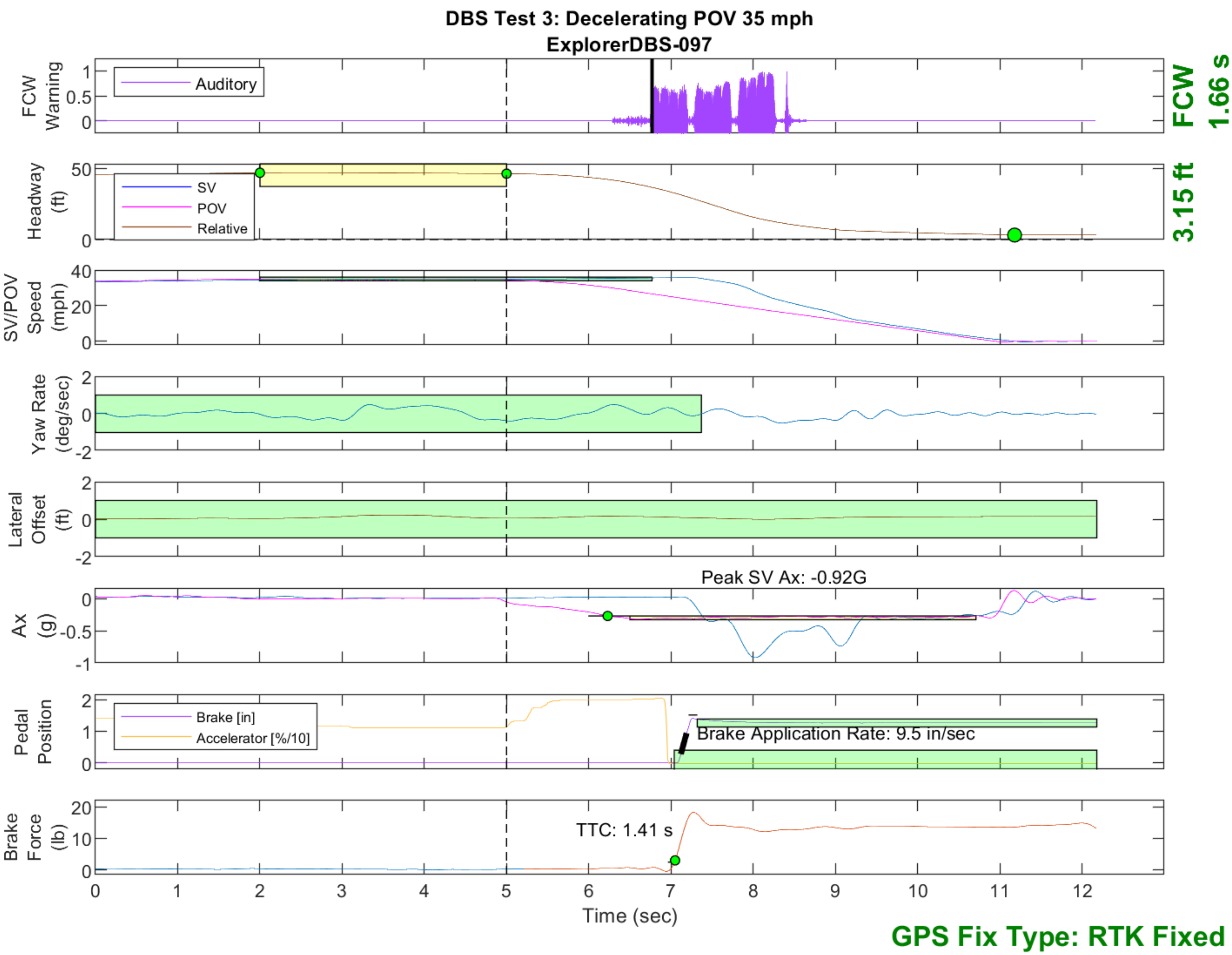


Figure E41. Time History for DBS Run 97, Test 3 - Decelerating POV 35 mph

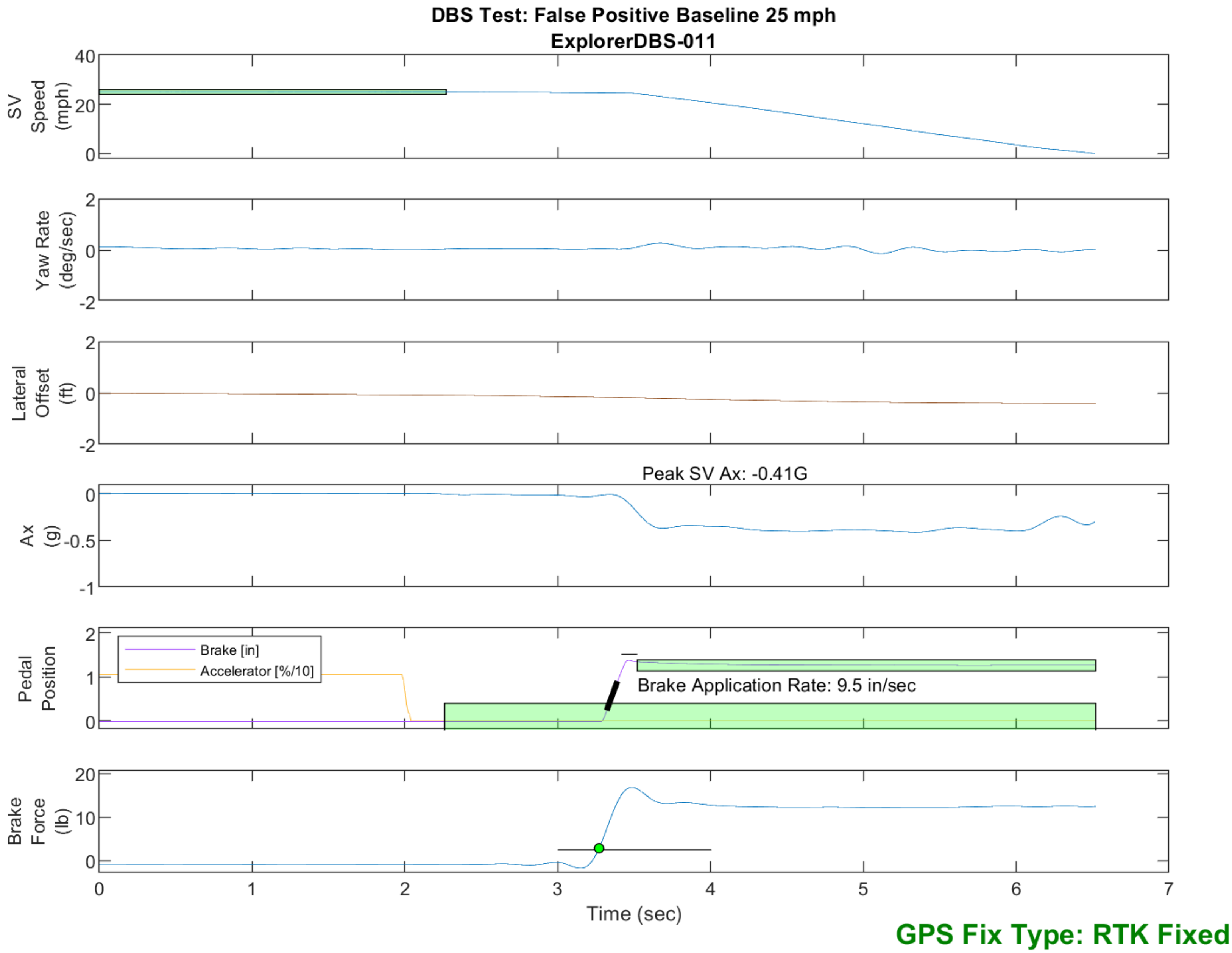


Figure E42. Time History for DBS Run 11, False Positive Baseline, SV 25 mph

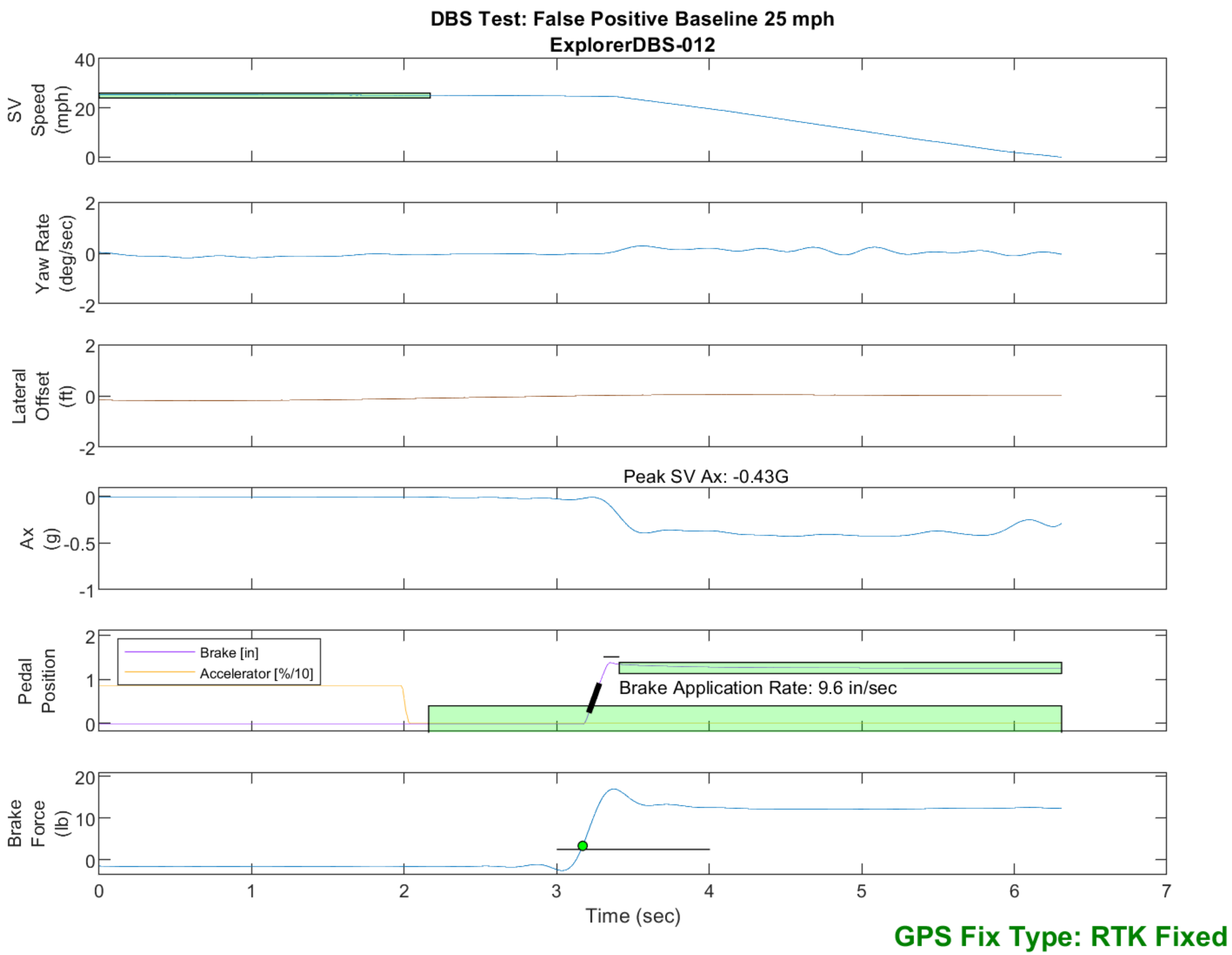


Figure E43. Time History for DBS Run 12, False Positive Baseline, SV 25 mph

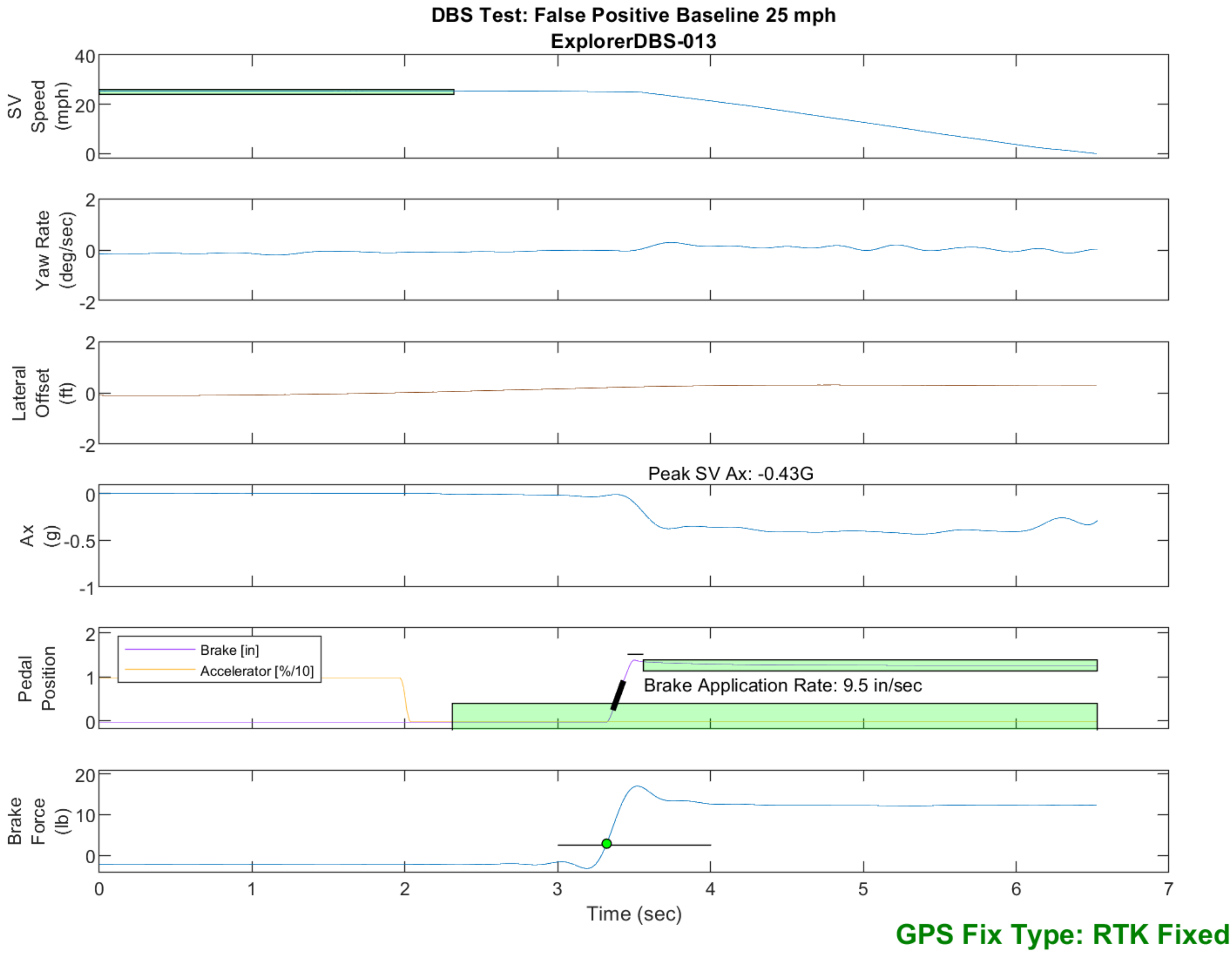


Figure E44. Time History for DBS Run 13, False Positive Baseline, SV 25 mph

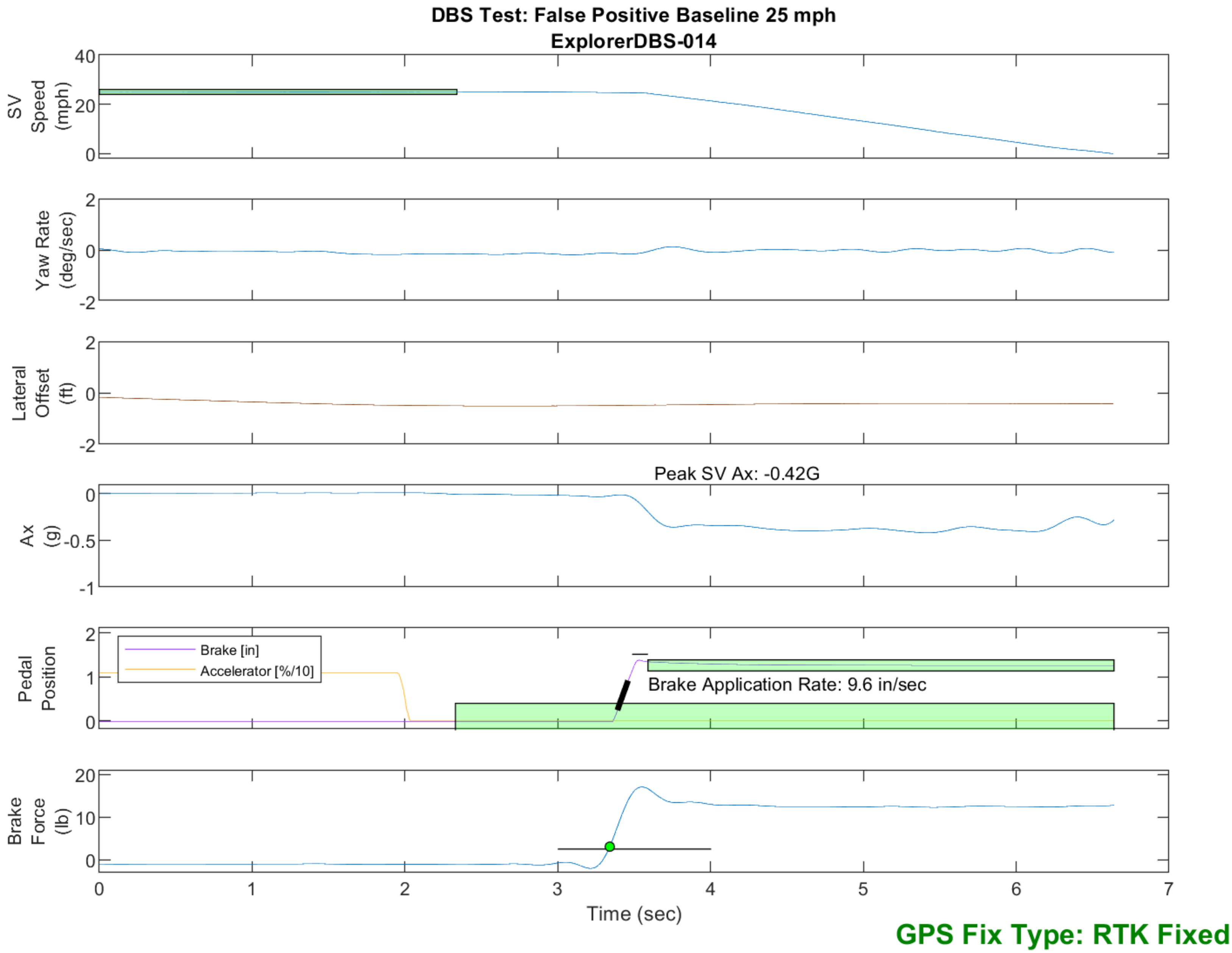


Figure E45. Time History for DBS Run 14, False Positive Baseline, SV 25 mph

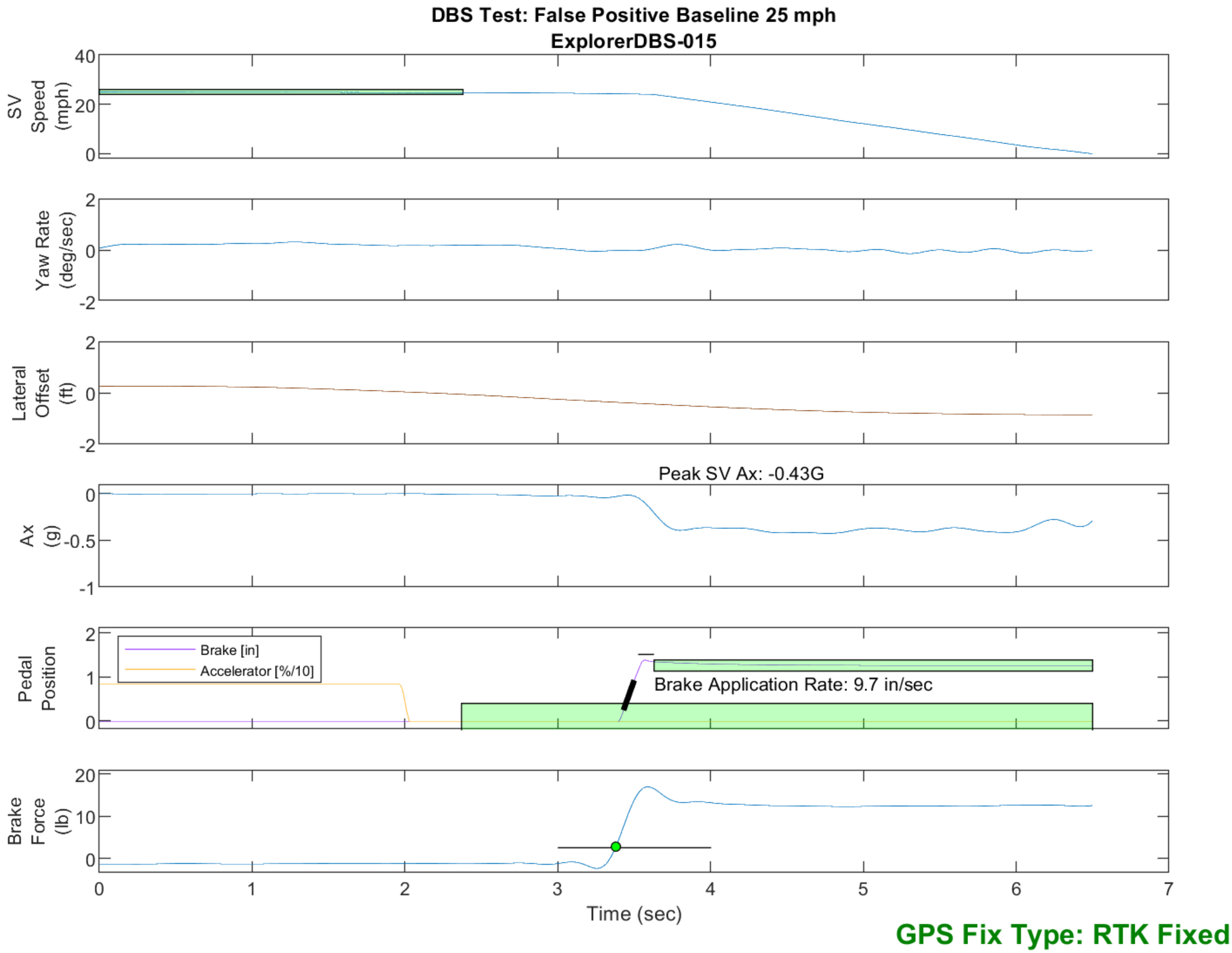


Figure E46. Time History for DBS Run 15, False Positive Baseline, SV 25 mph

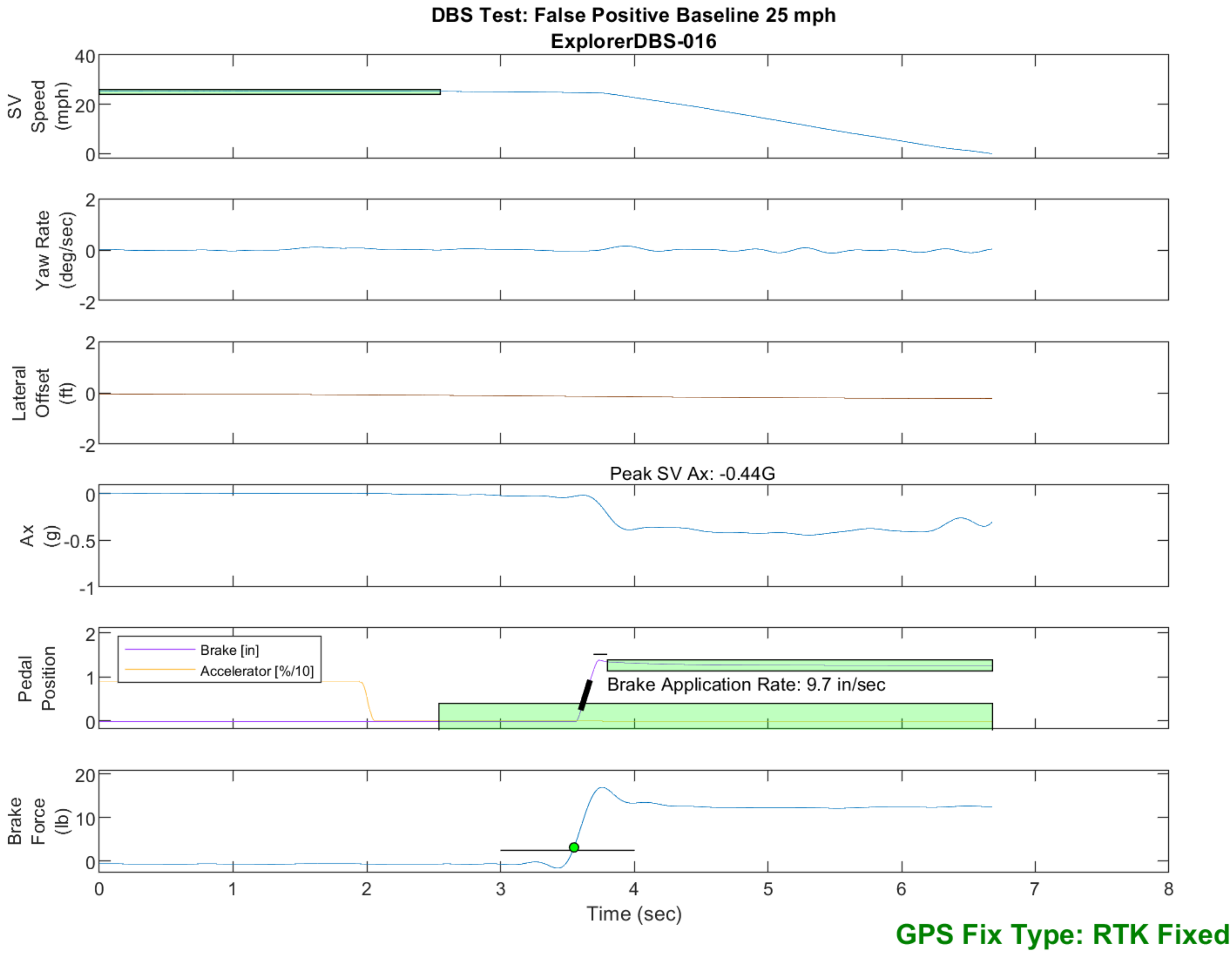


Figure E47. Time History for DBS Run 16, False Positive Baseline, SV 25 mph

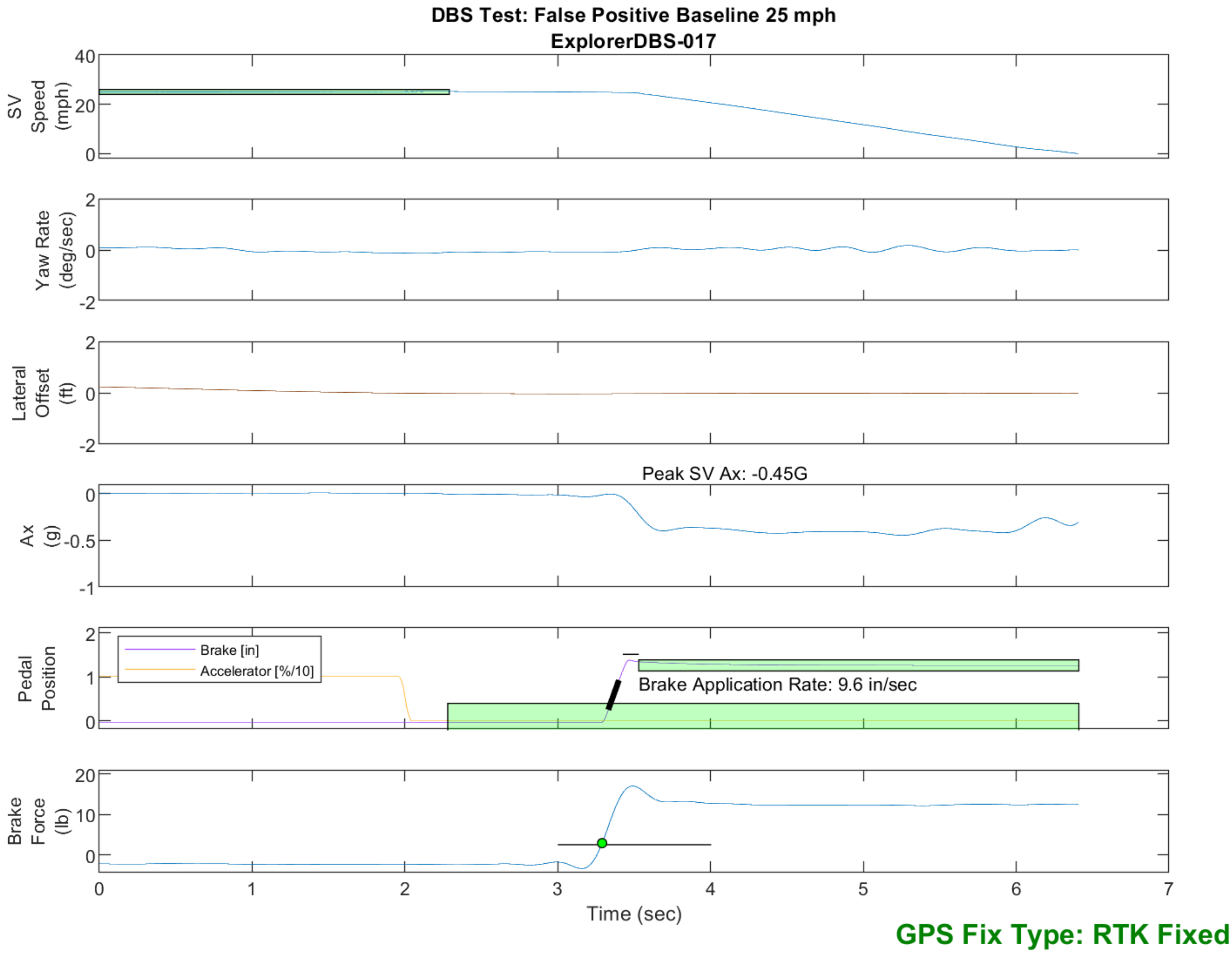


Figure E48. Time History for DBS Run 17, False Positive Baseline, SV 25 mph

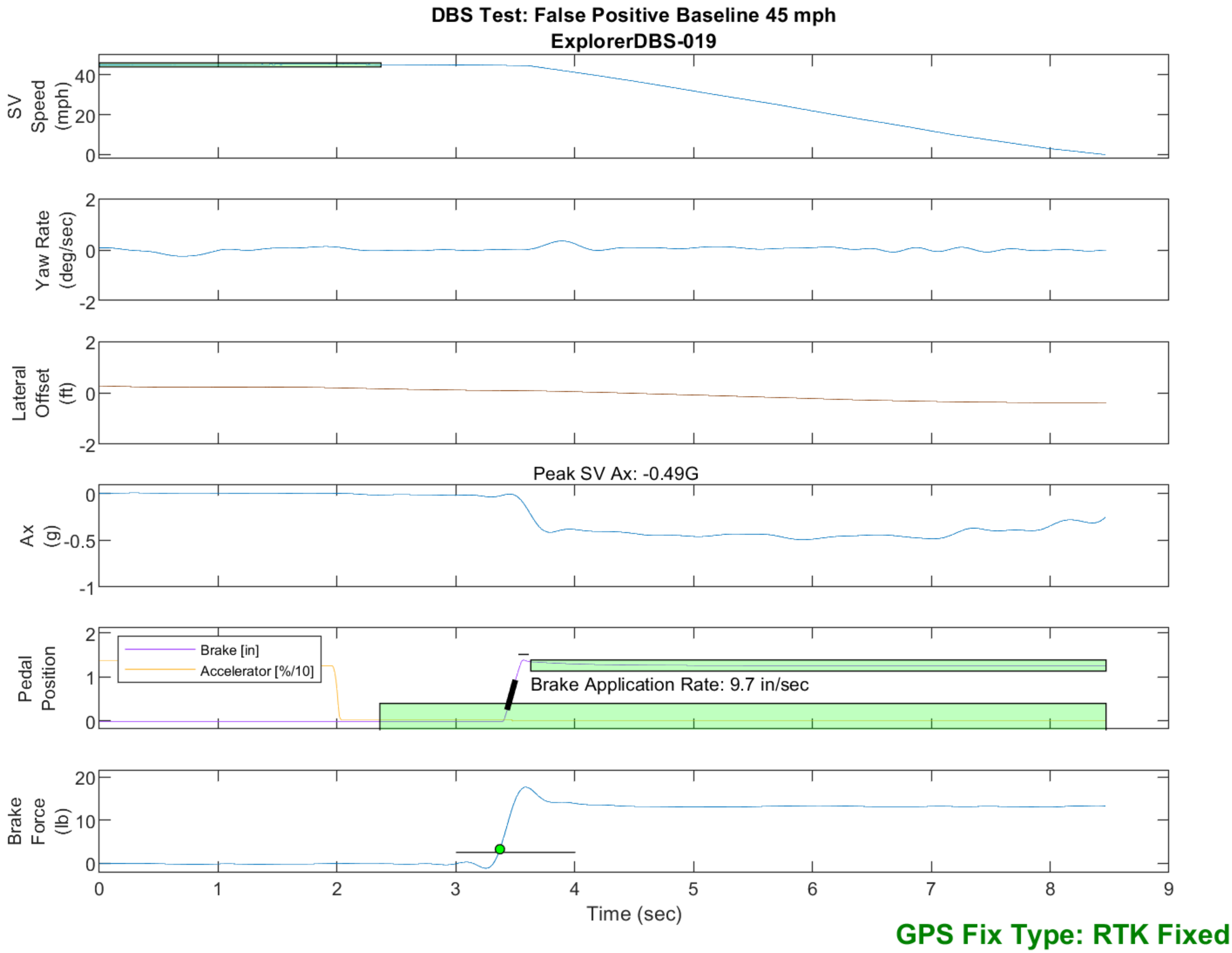


Figure E49. Time History for DBS Run 19, False Positive Baseline, SV 45 mph

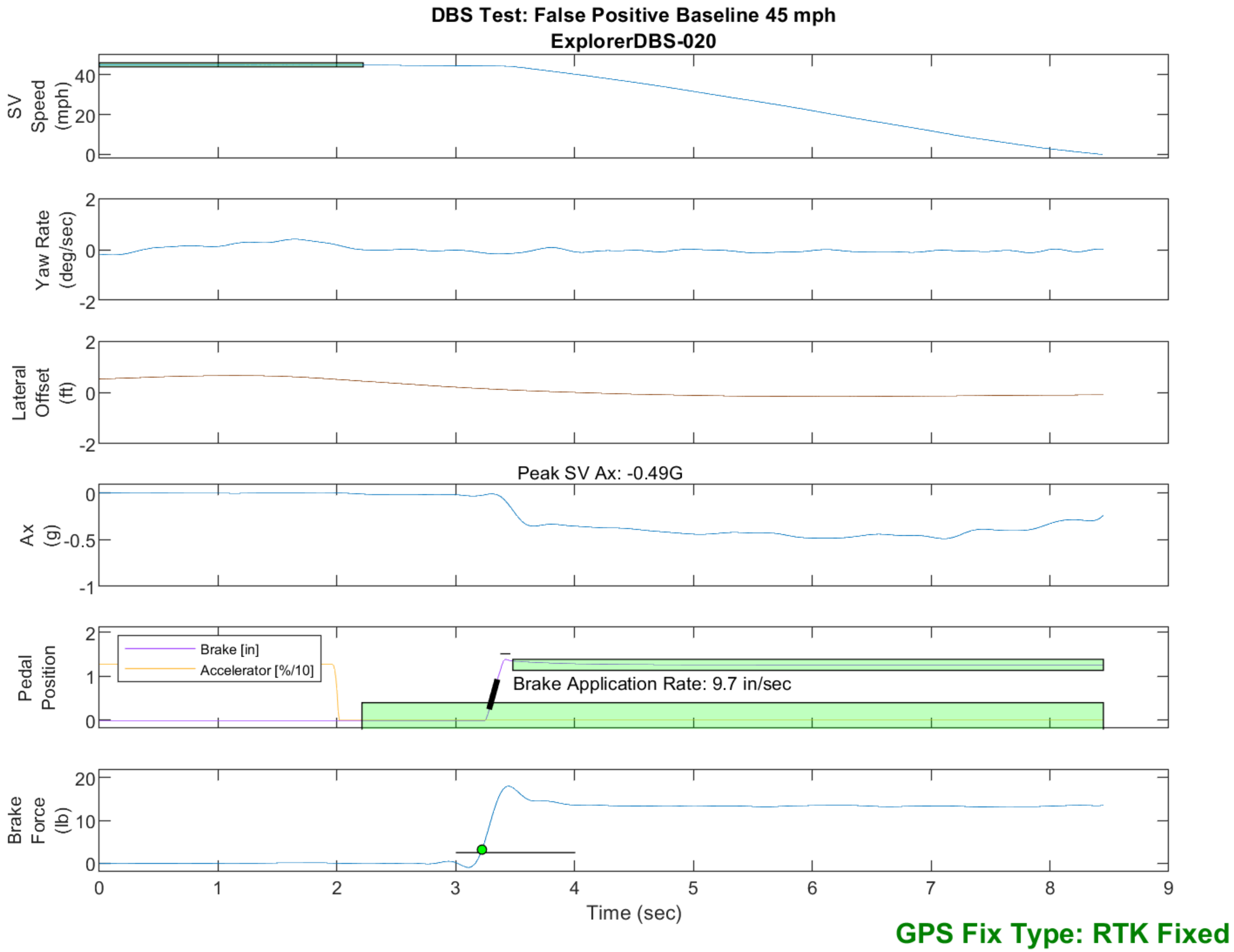


Figure E50. Time History for DBS Run 20, False Positive Baseline, SV 45 mph

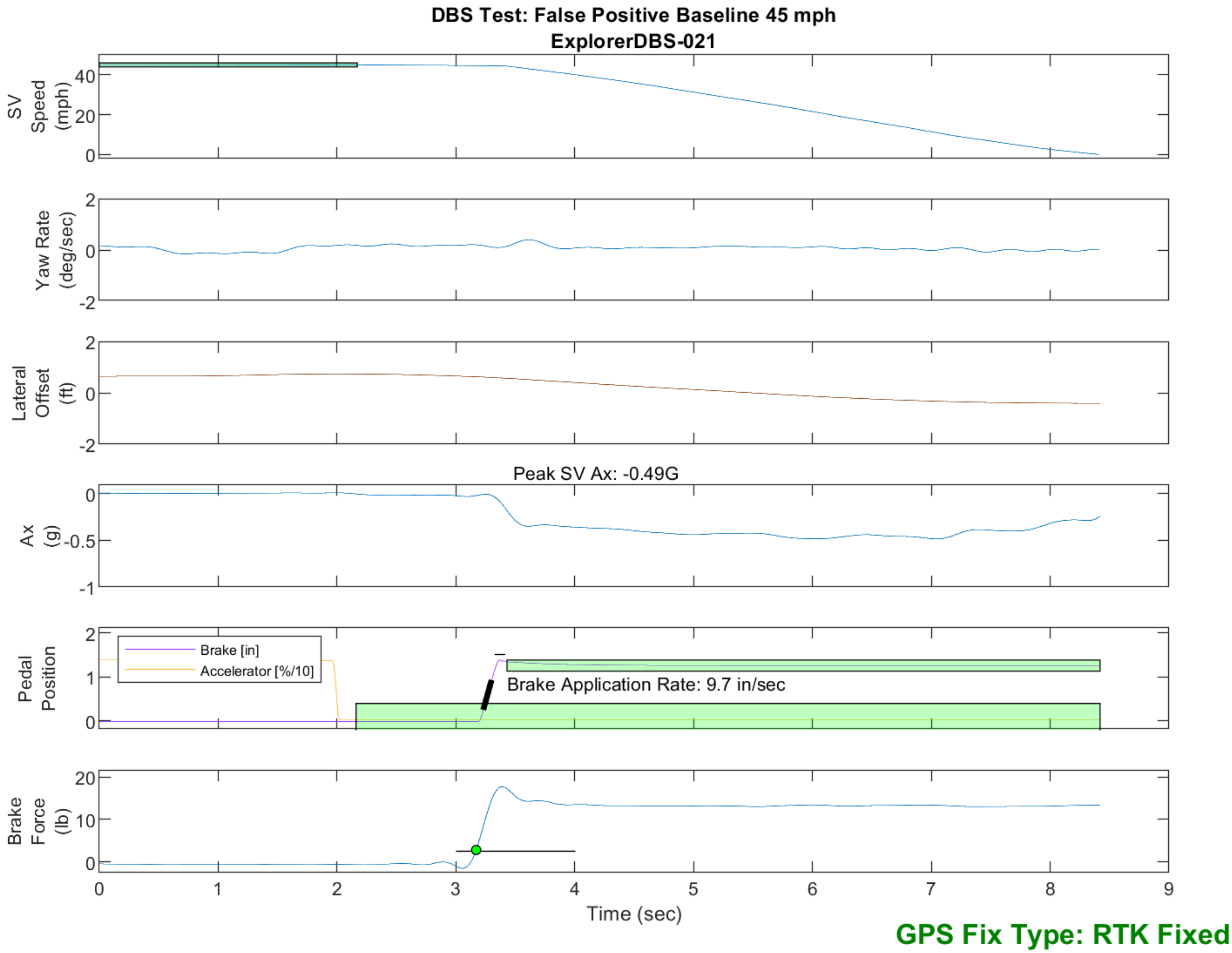


Figure E51. Time History for DBS Run 21, False Positive Baseline, SV 45 mph

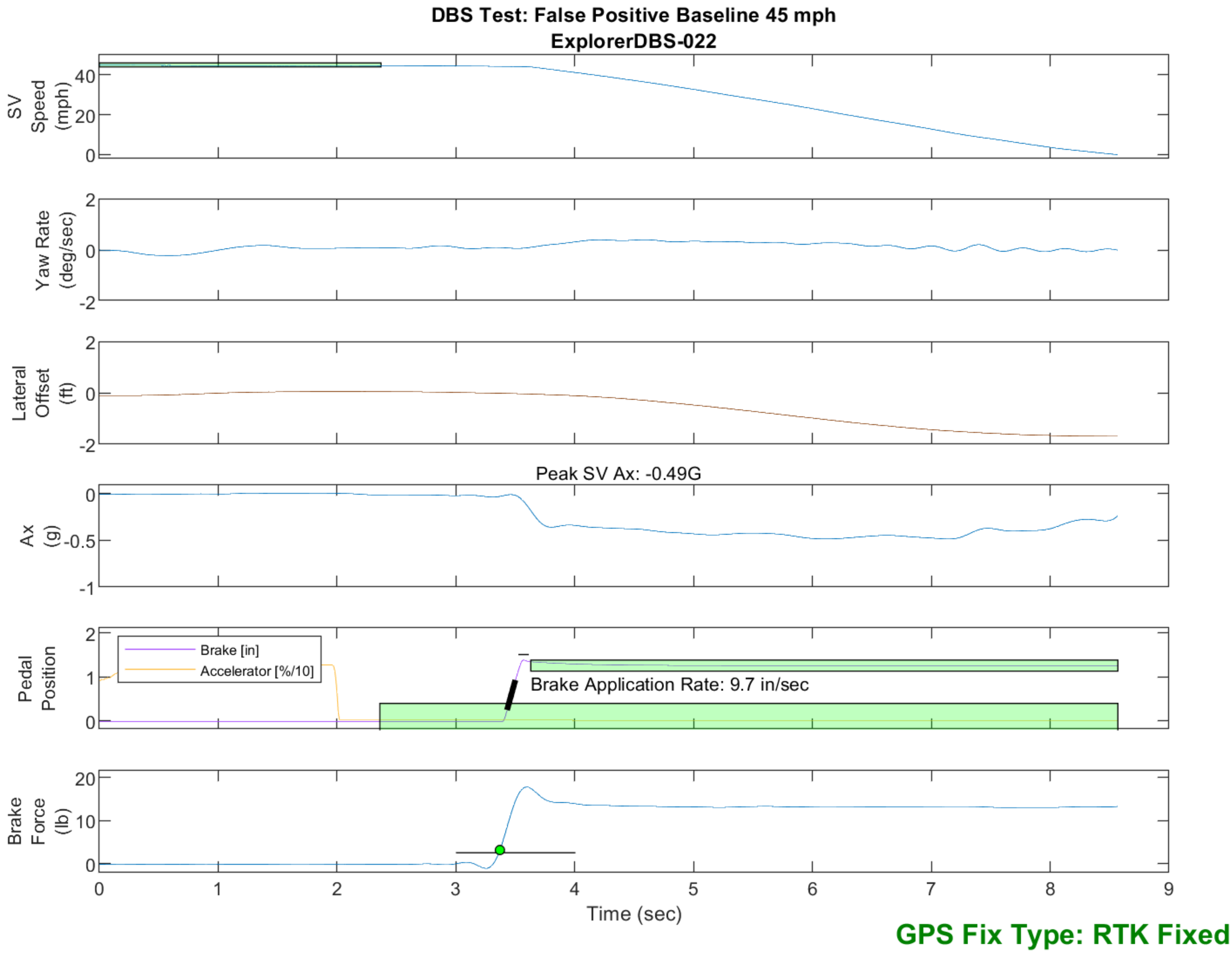


Figure E52. Time History for DBS Run 22, False Positive Baseline, SV 45 mph

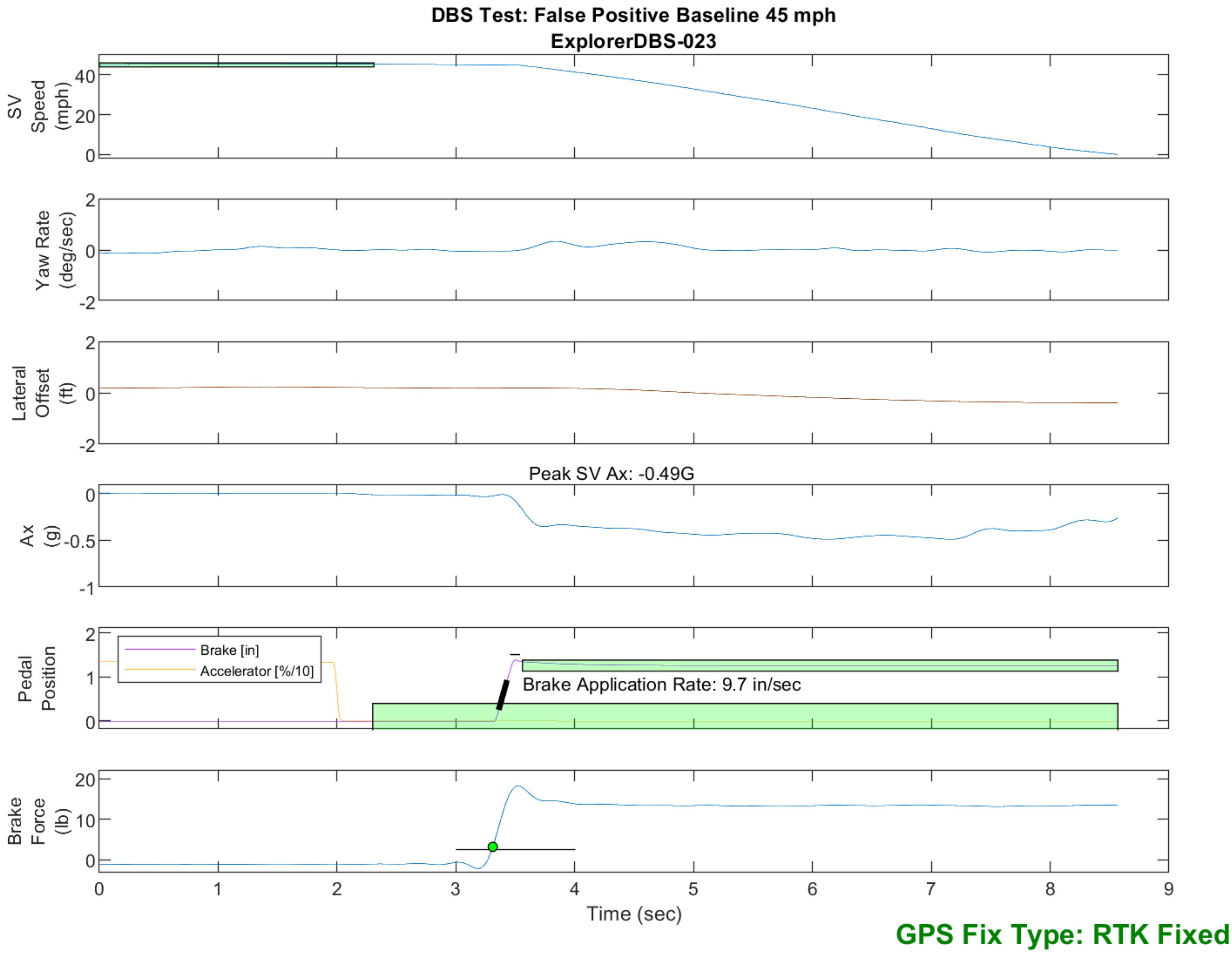


Figure E53. Time History for DBS Run 23, False Positive Baseline, SV 45 mph

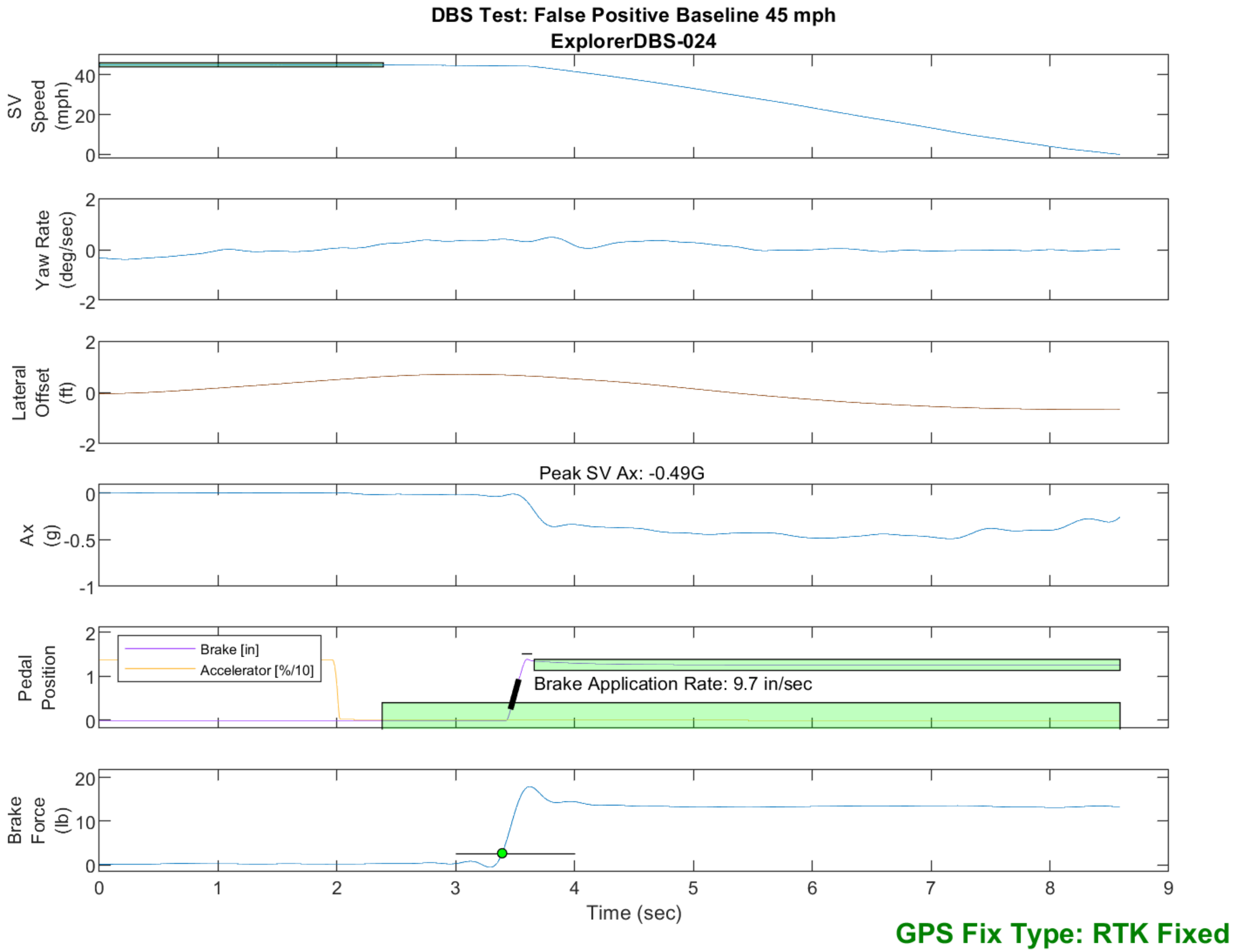


Figure E54. Time History for DBS Run 24, False Positive Baseline, SV 45 mph

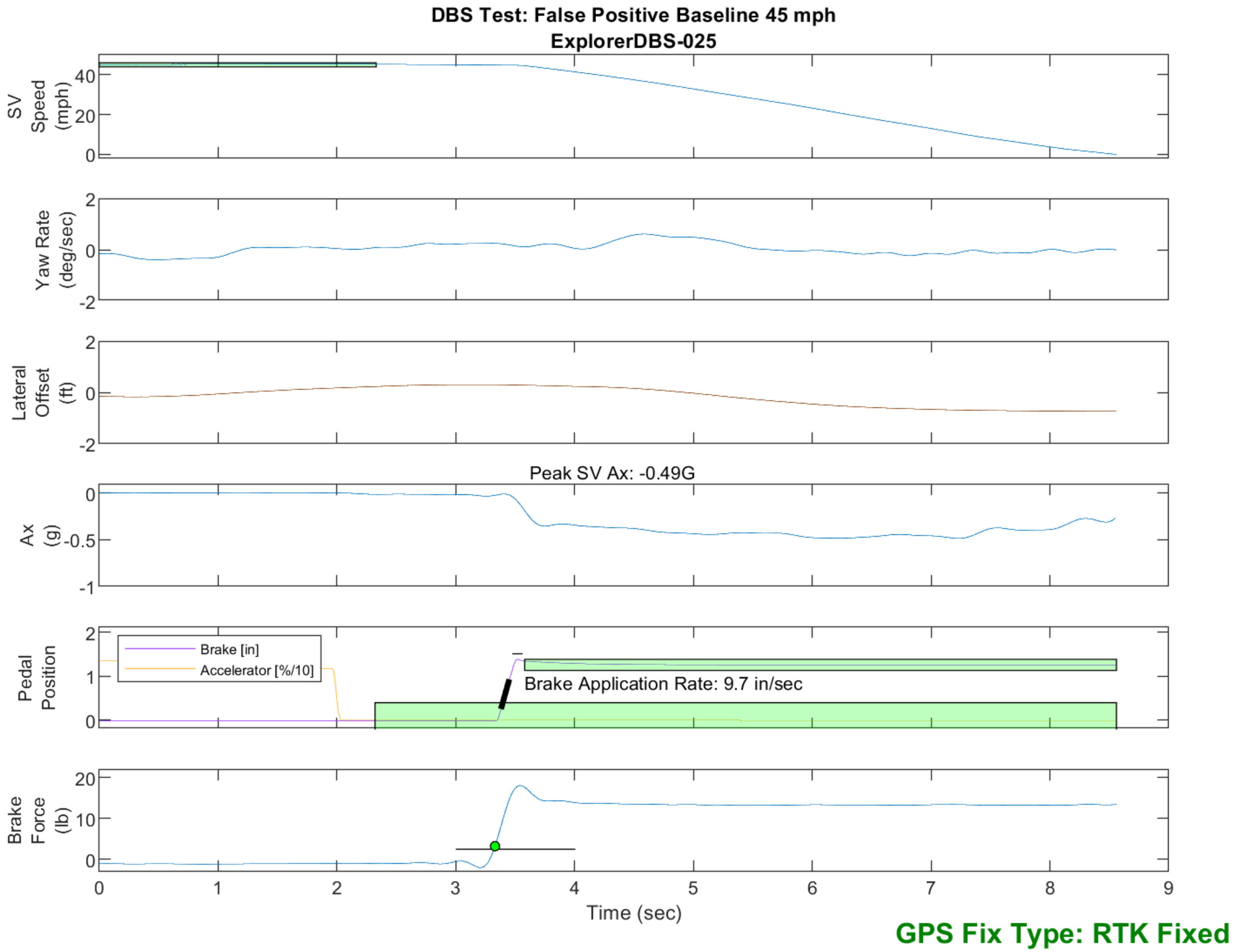


Figure E55. Time History for DBS Run 25, False Positive Baseline, SV 45 mph

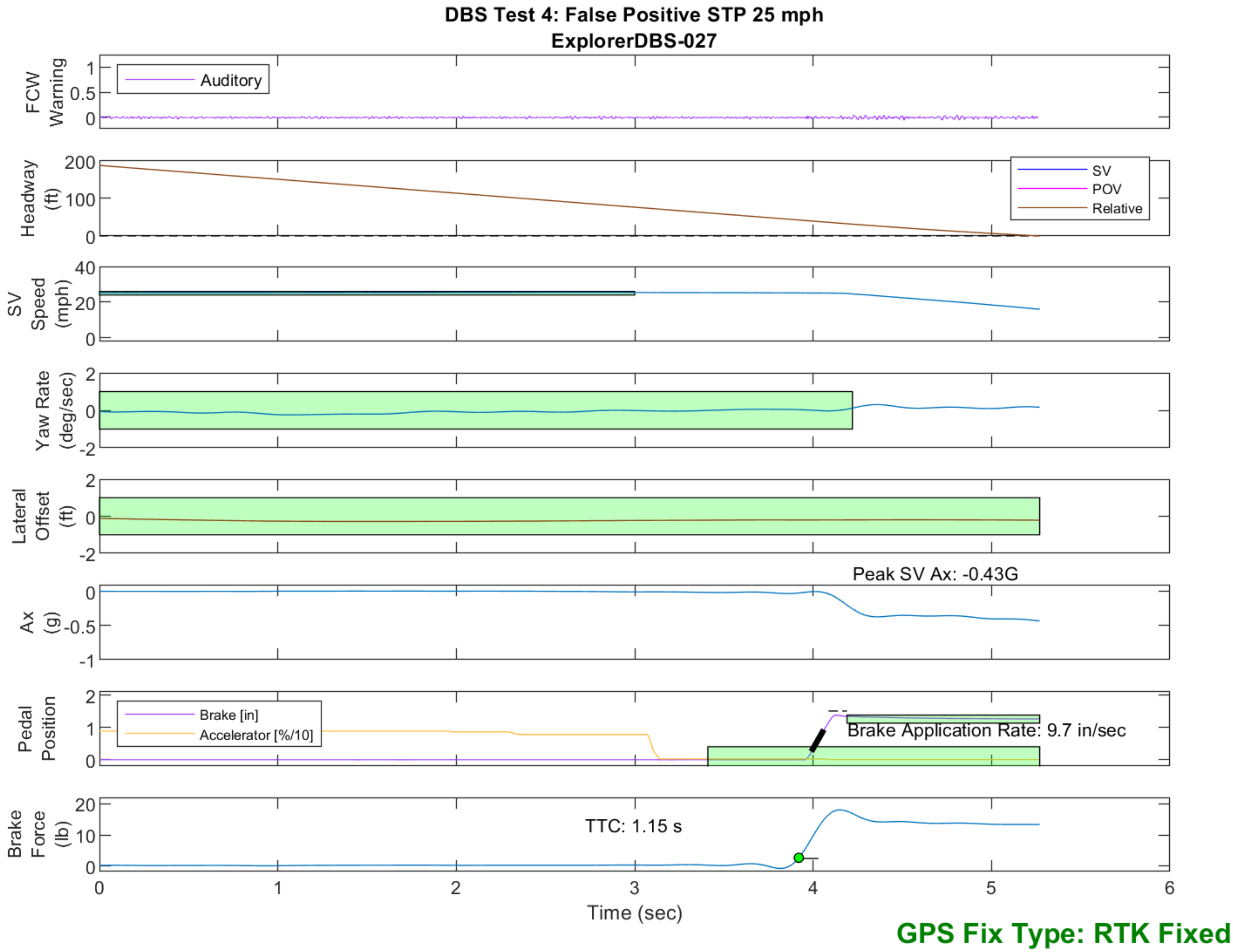


Figure E56. Time History for DBS Run 27, Test 4 - False Positive STP 25 mph

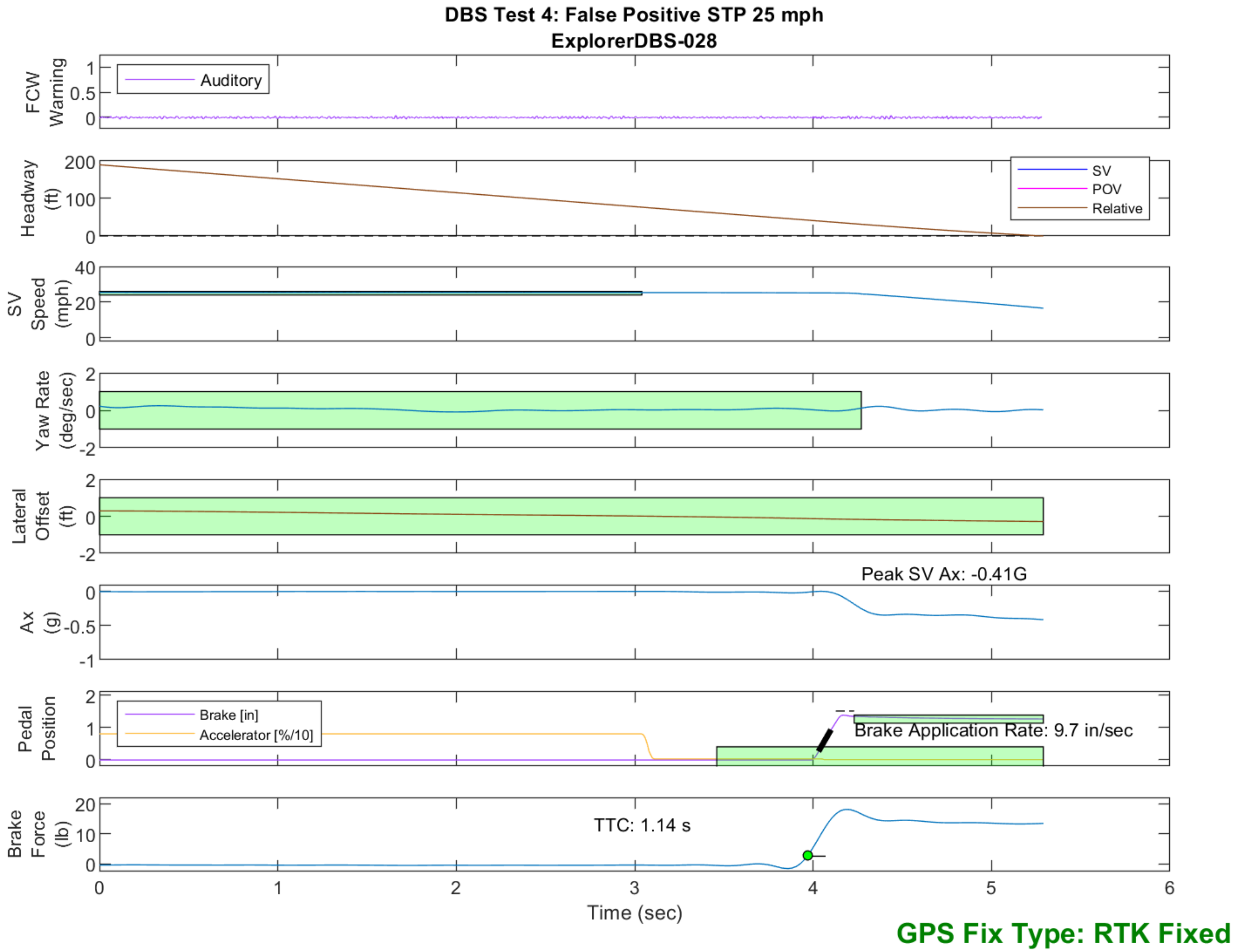


Figure E57. Time History for DBS Run 28, Test 4 - False Positive STP 25 mph

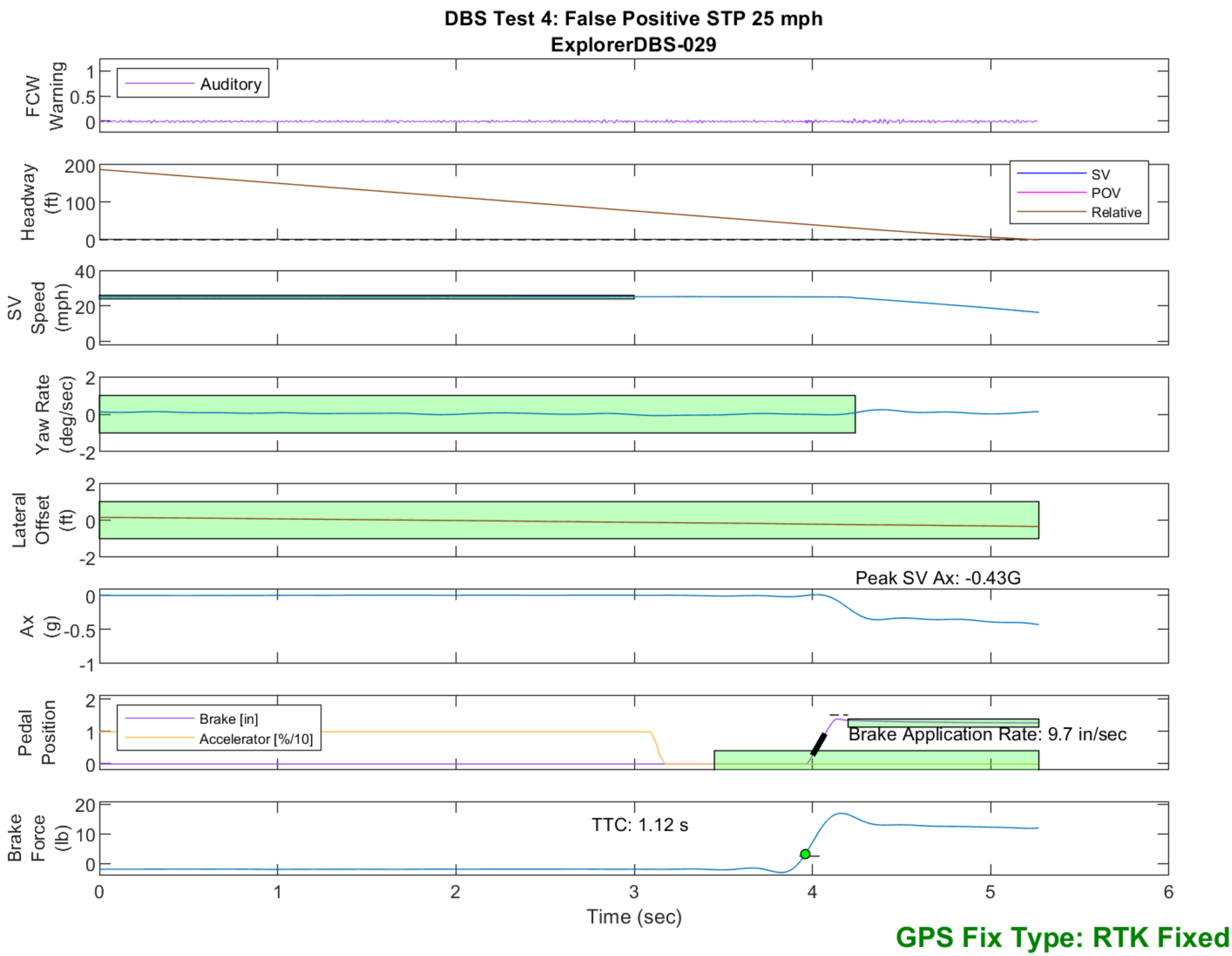


Figure E58. Time History for DBS Run 29, Test 4 - False Positive STP 25 mph

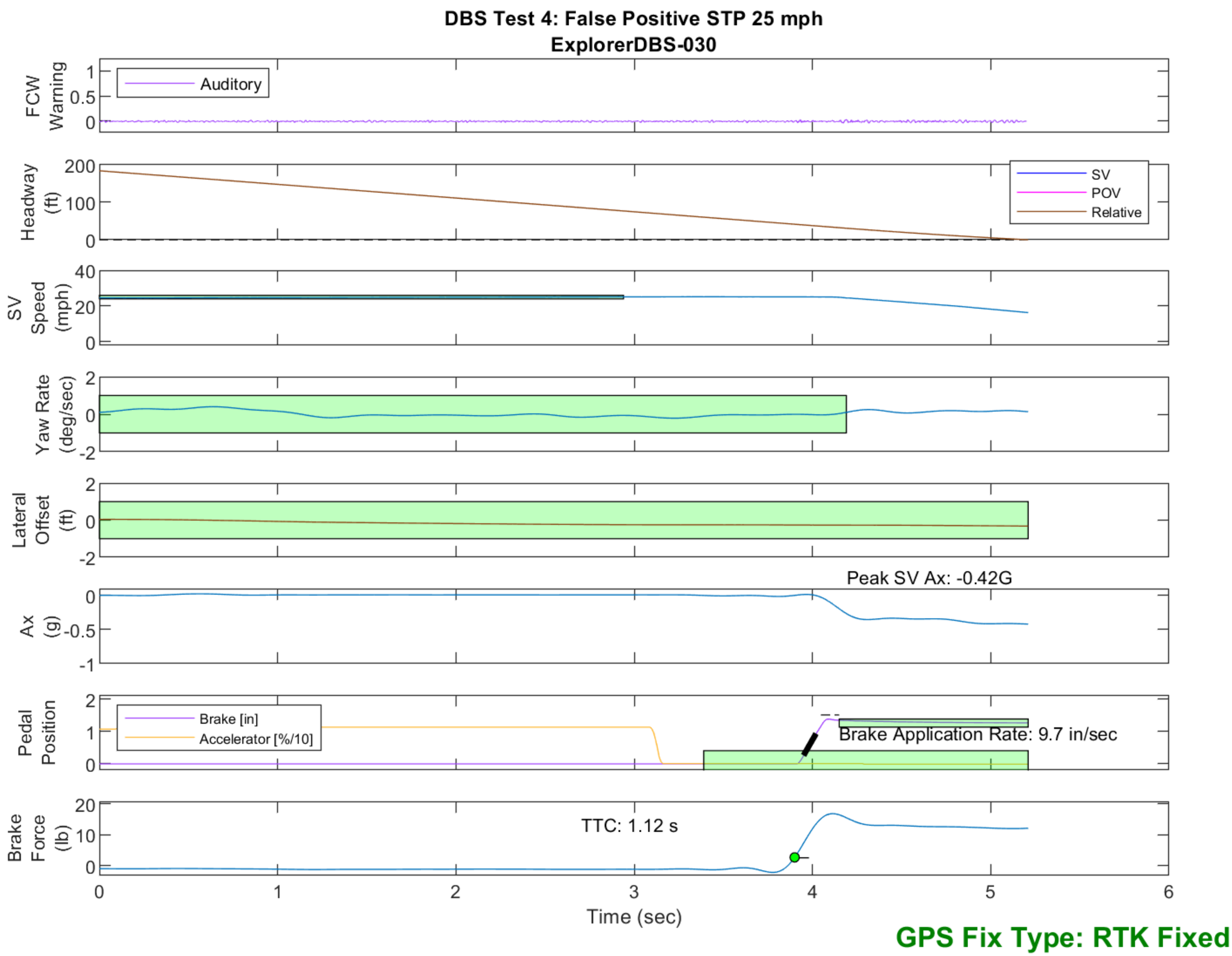


Figure E59. Time History for DBS Run 30, Test 4 - False Positive STP 25 mph

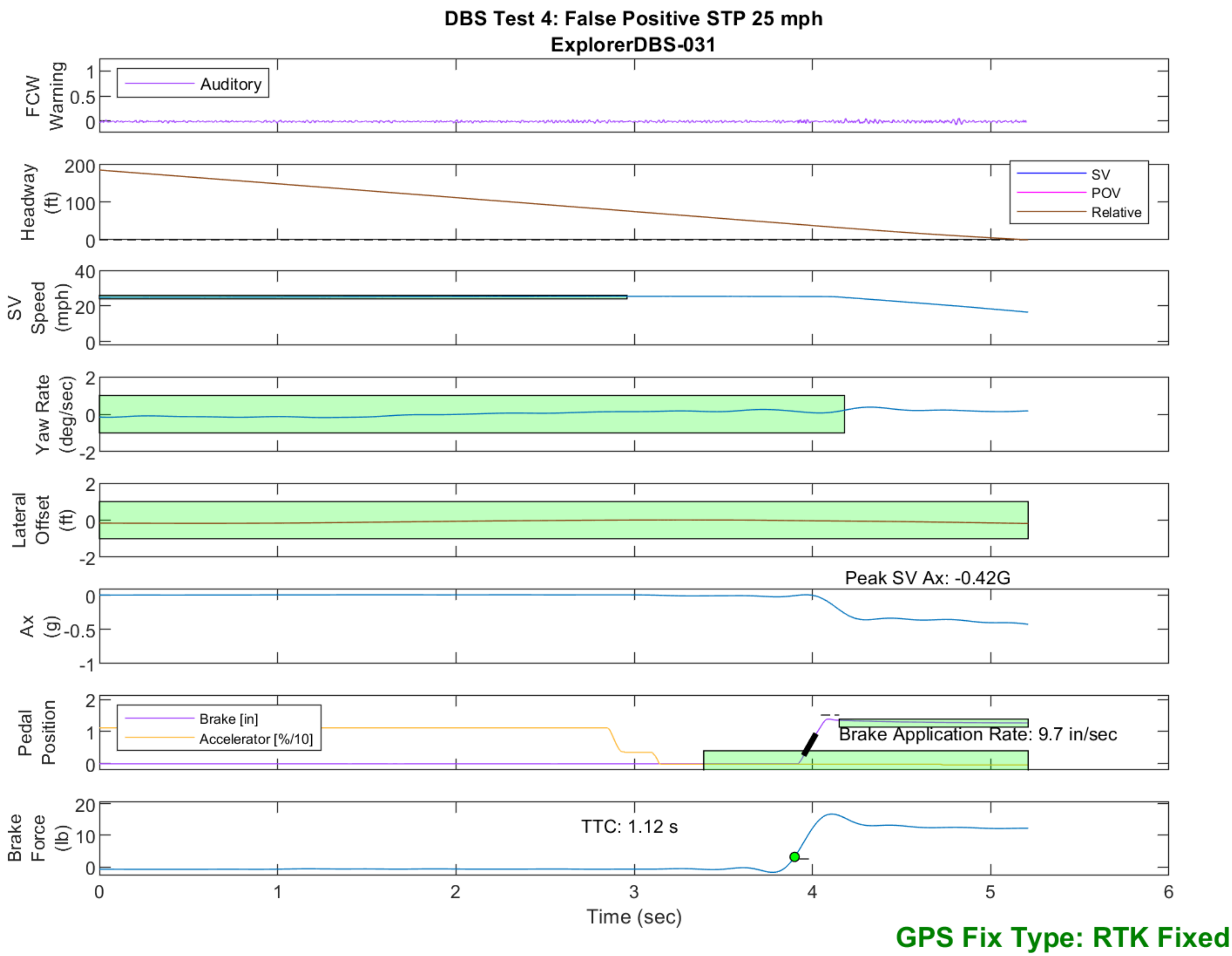


Figure E60. Time History for DBS Run 31, Test 4 - False Positive STP 25 mph

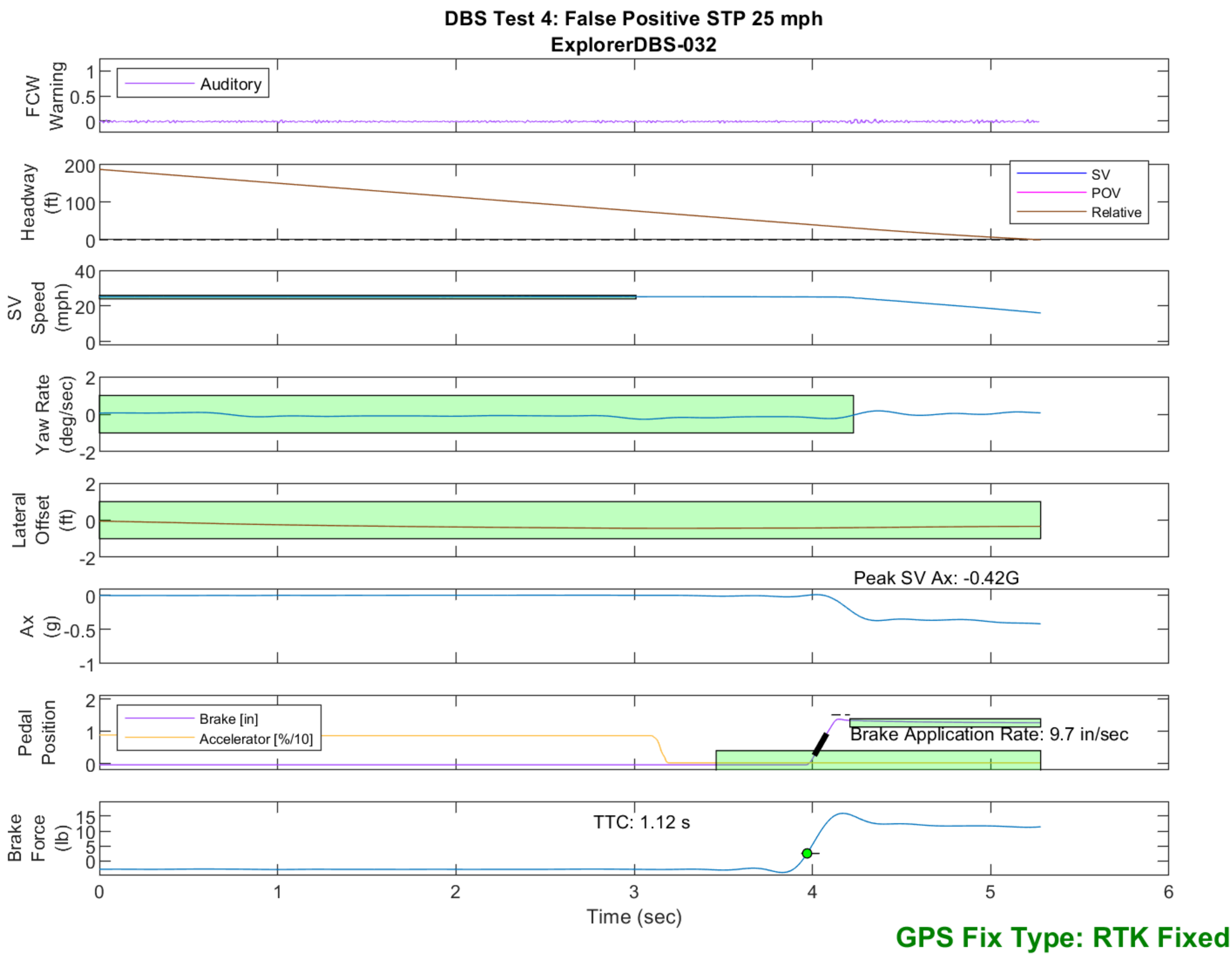


Figure E61. Time History for DBS Run 32, Test 4 - False Positive STP 25 mph

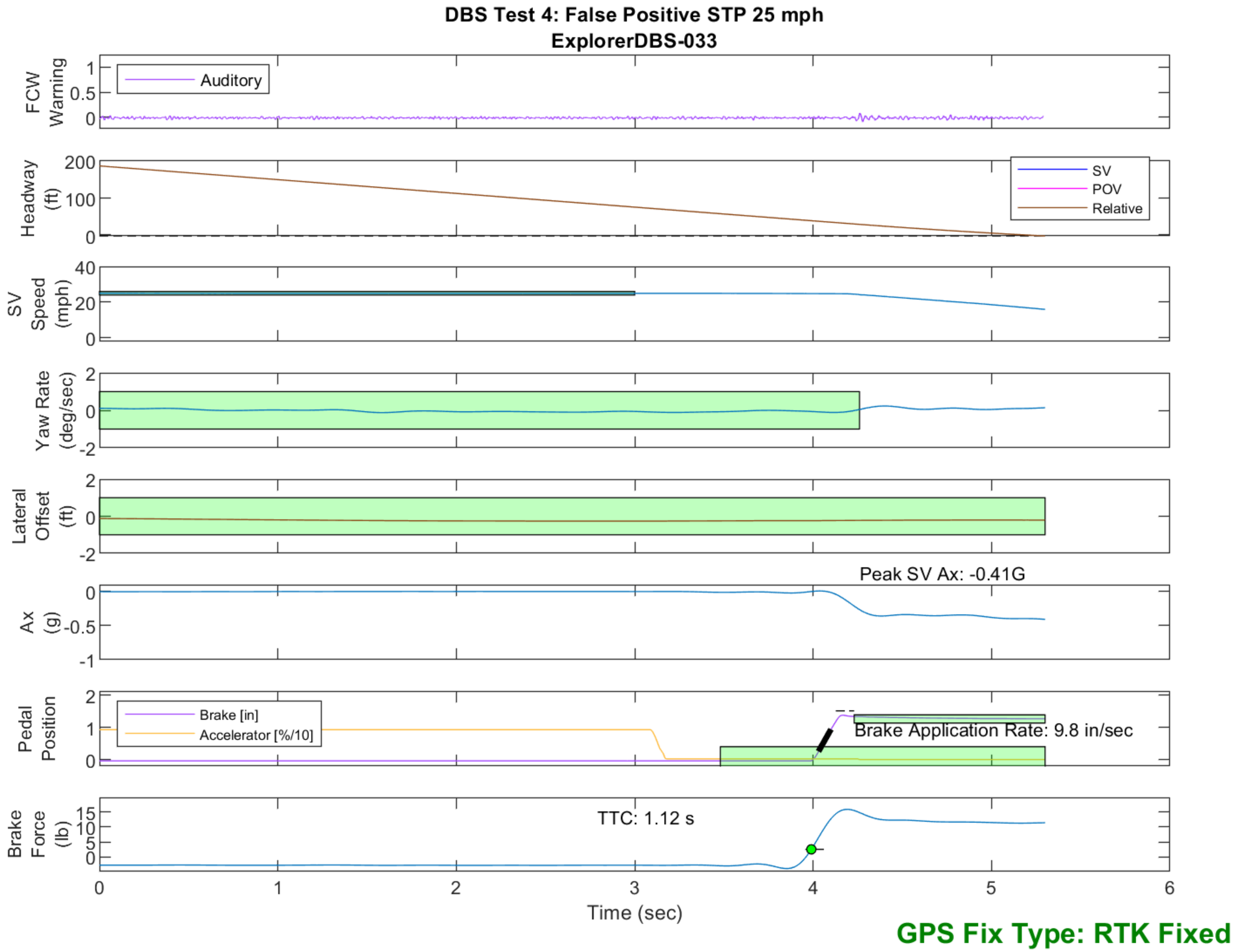


Figure E62. Time History for DBS Run 33, Test 4 - False Positive STP 25 mph

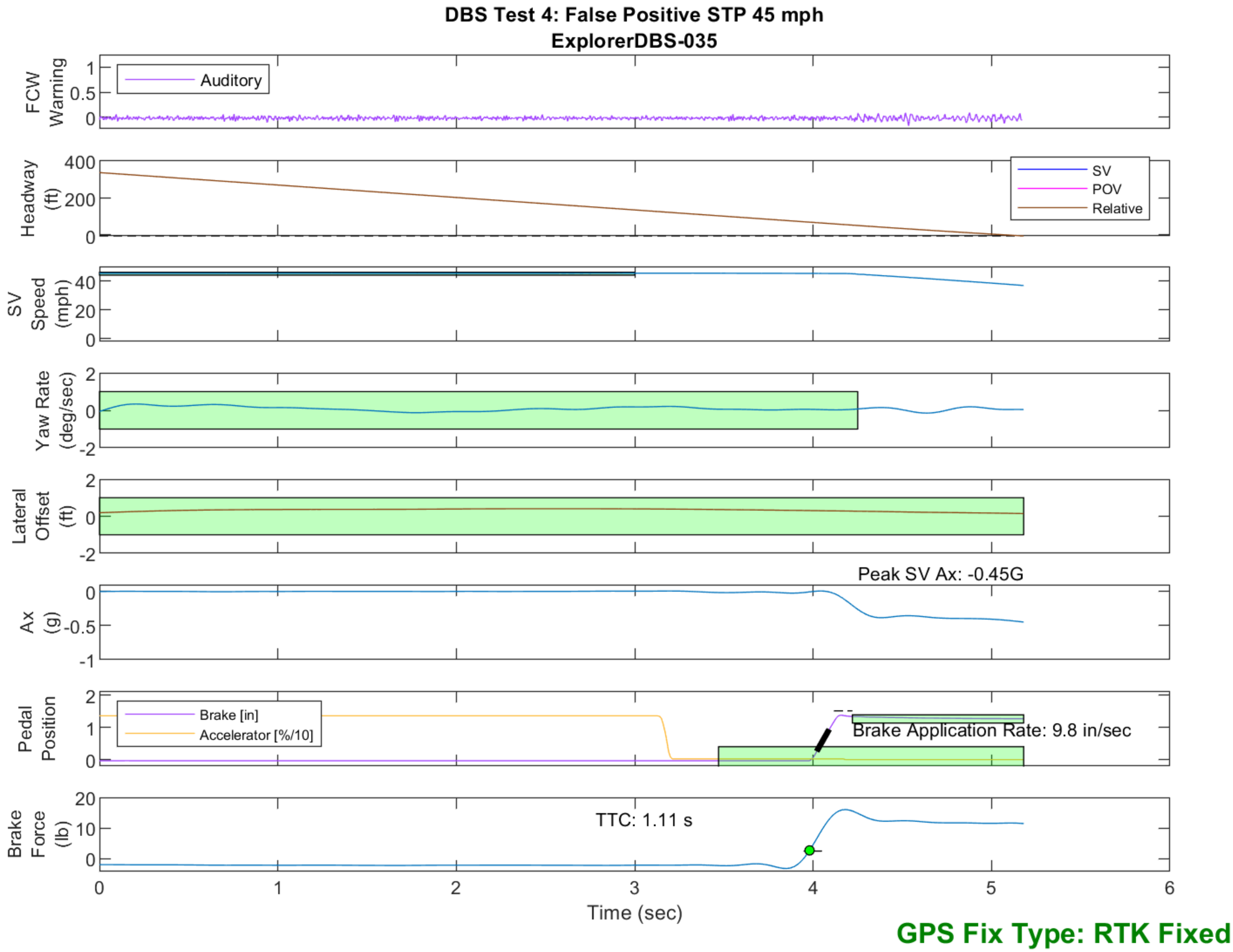


Figure E63. Time History for DBS Run 35, Test 4 - False Positive STP 45 mph

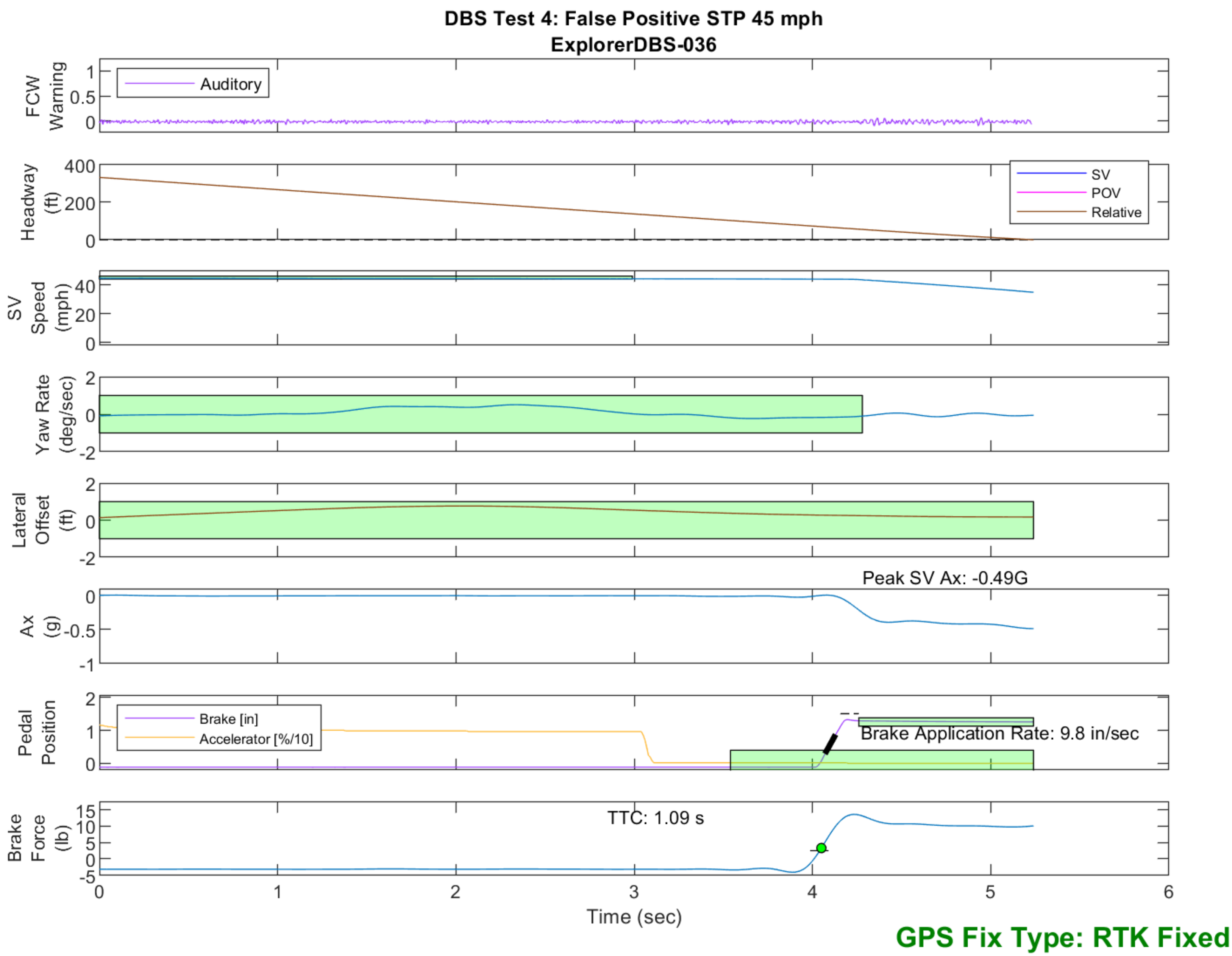


Figure E64. Time History for DBS Run 36, Test 4 - False Positive STP 45 mph

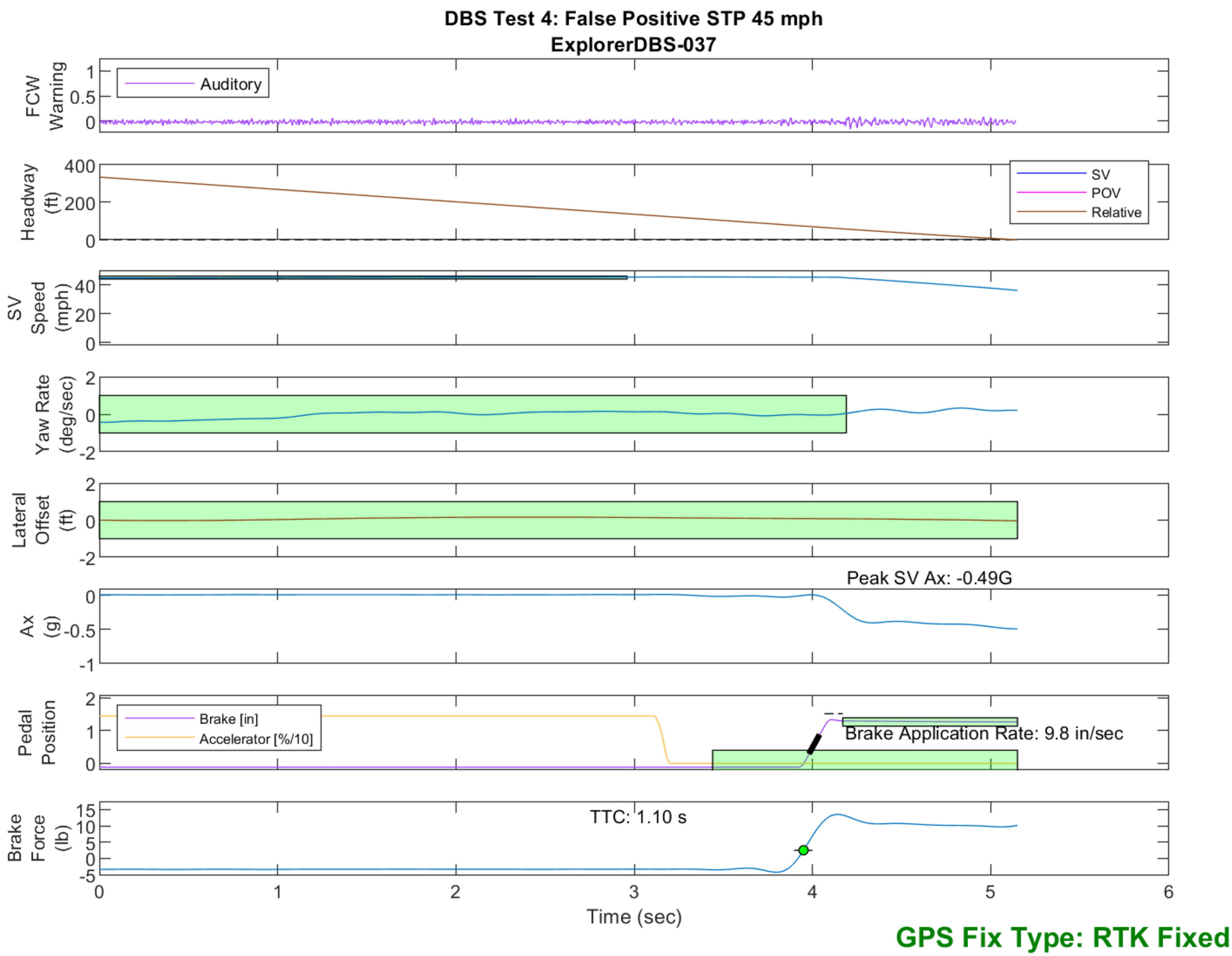


Figure E65. Time History for DBS Run 37, Test 4 - False Positive STP 45 mph

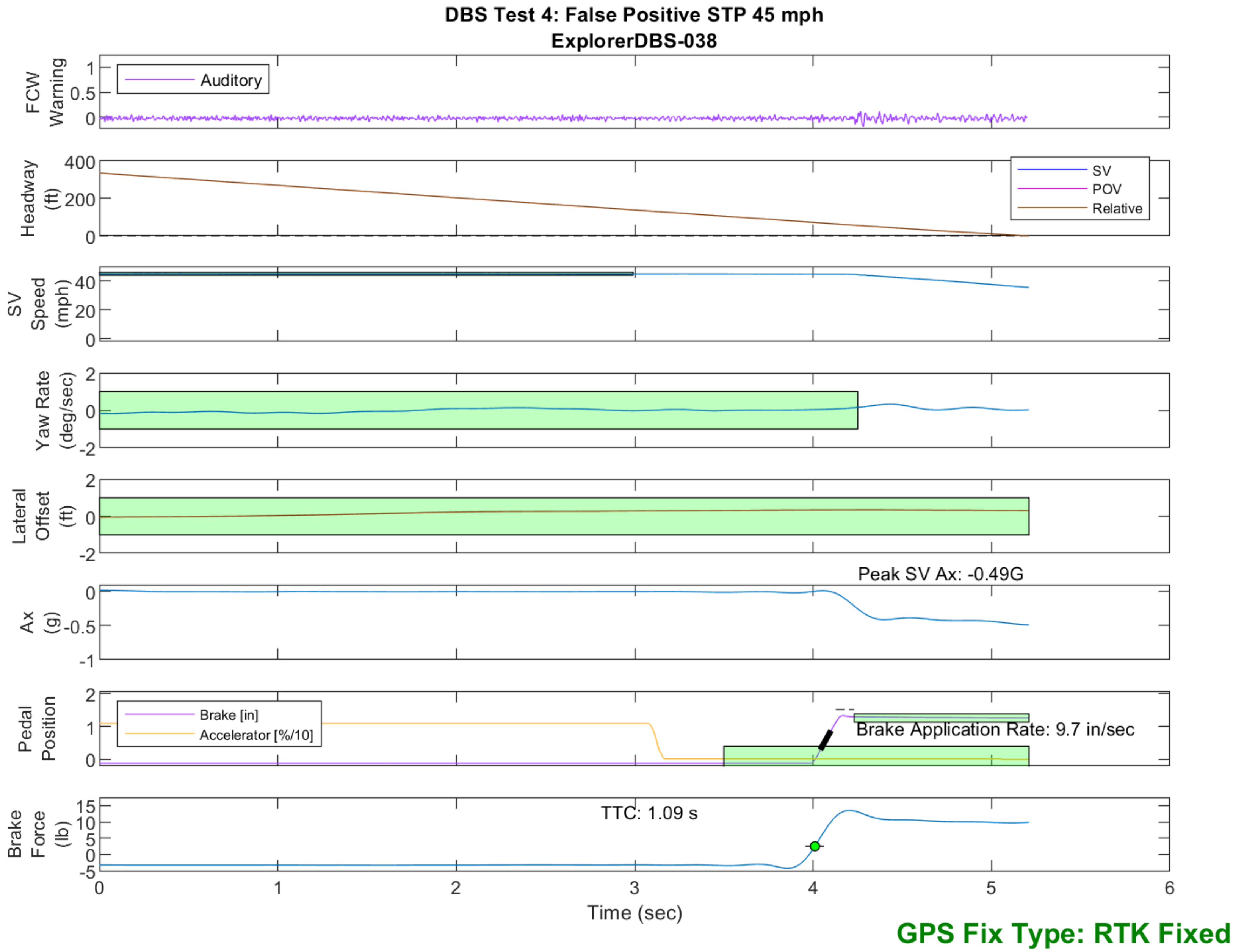


Figure E66. Time History for DBS Run 38, Test 4 - False Positive STP 45 mph

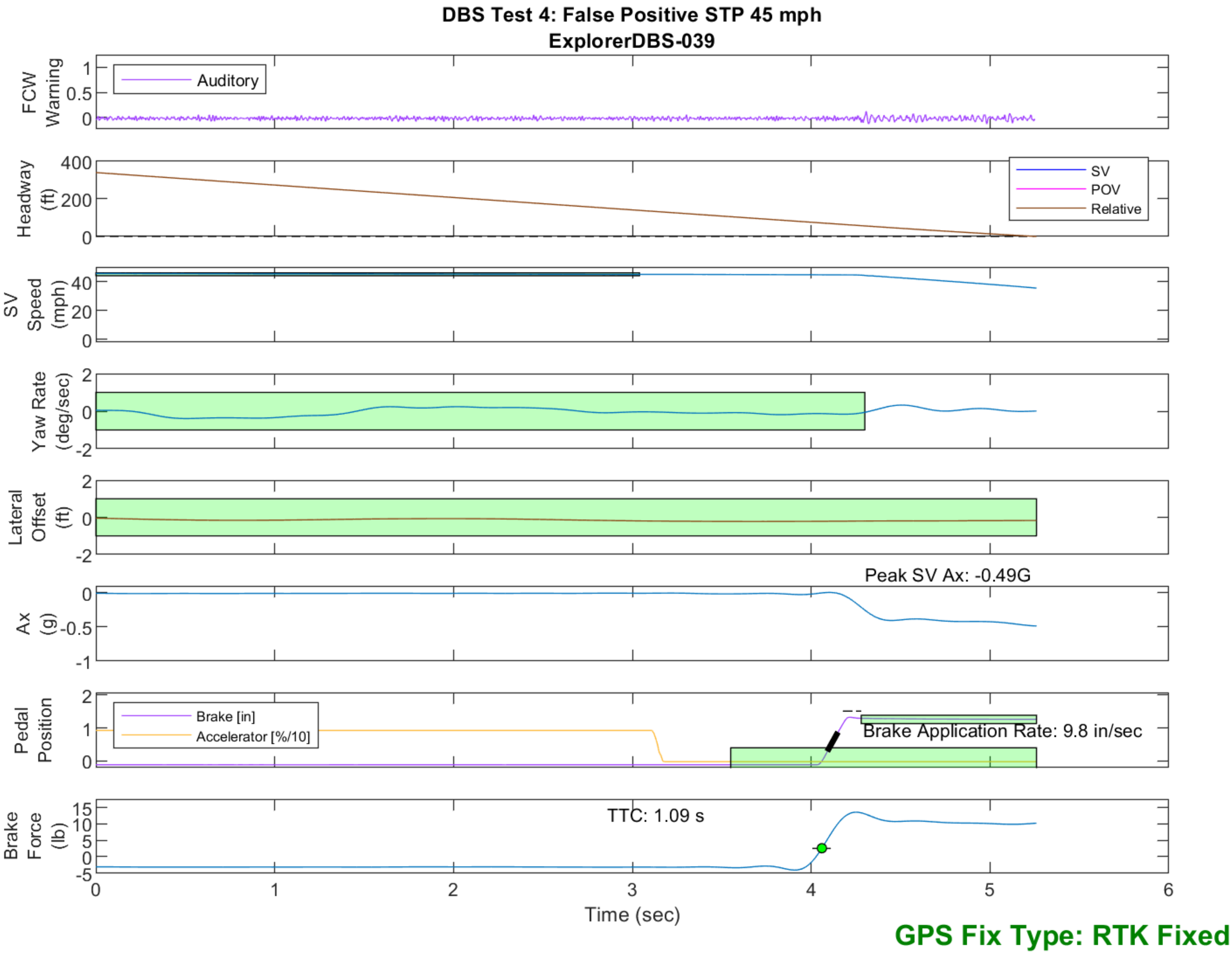


Figure E67. Time History for DBS Run 39, Test 4 - False Positive STP 45 mph

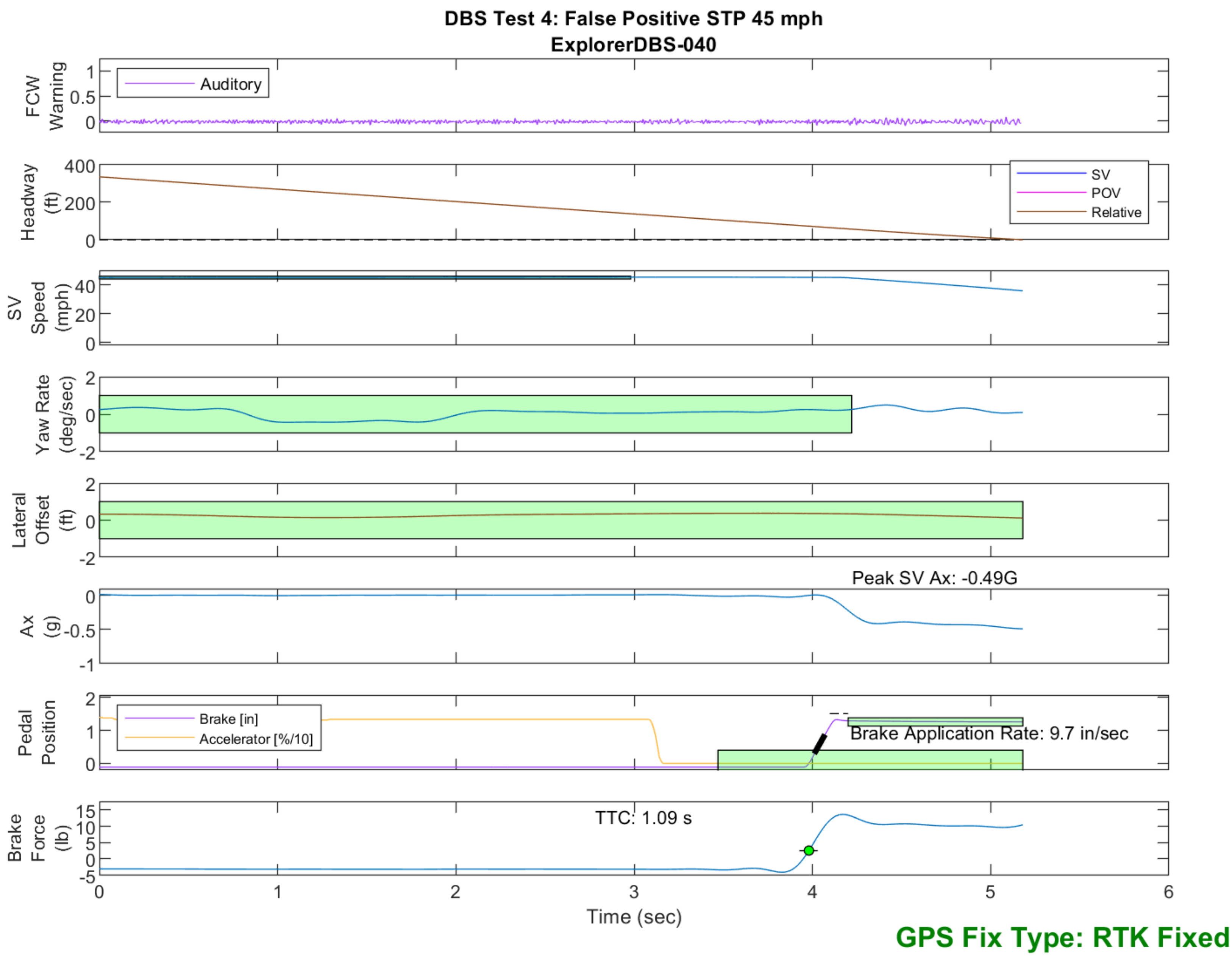


Figure E68. Time History for DBS Run 40, Test 4 - False Positive STP 45 mph

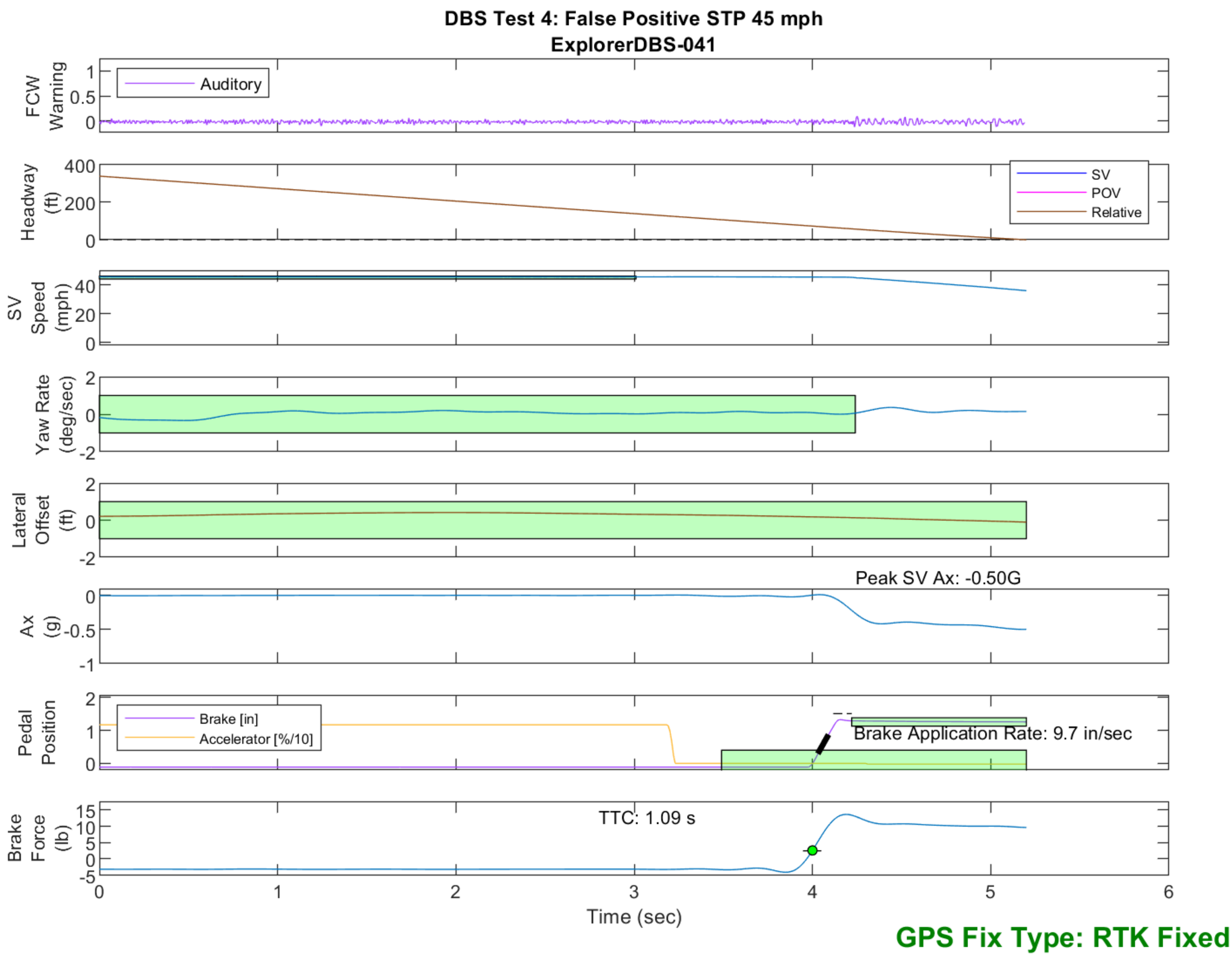


Figure E69. Time History for DBS Run 41, Test 4 - False Positive STP 45 mph

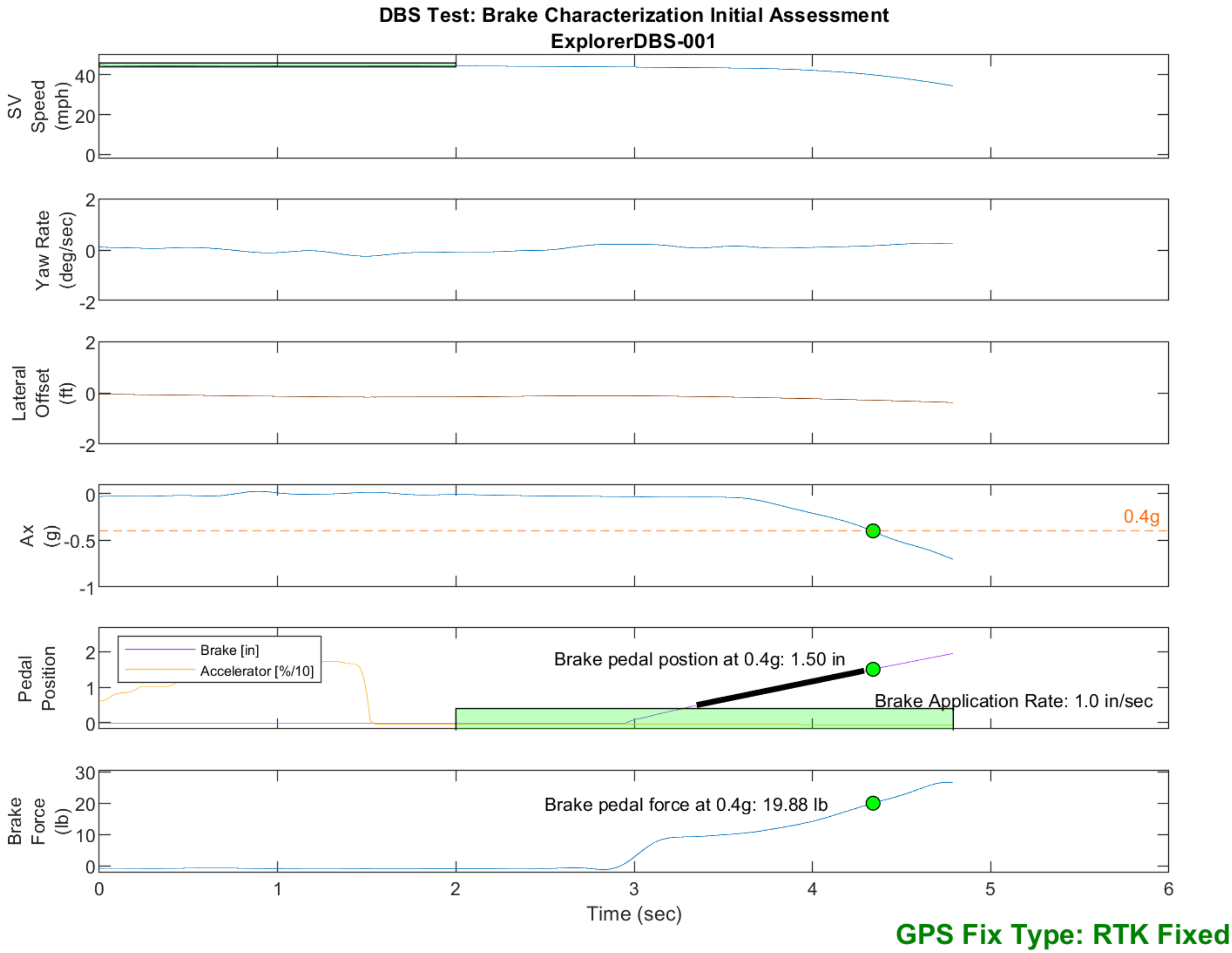


Figure E70. Time History for DBS Run 1, Brake Characterization Initial

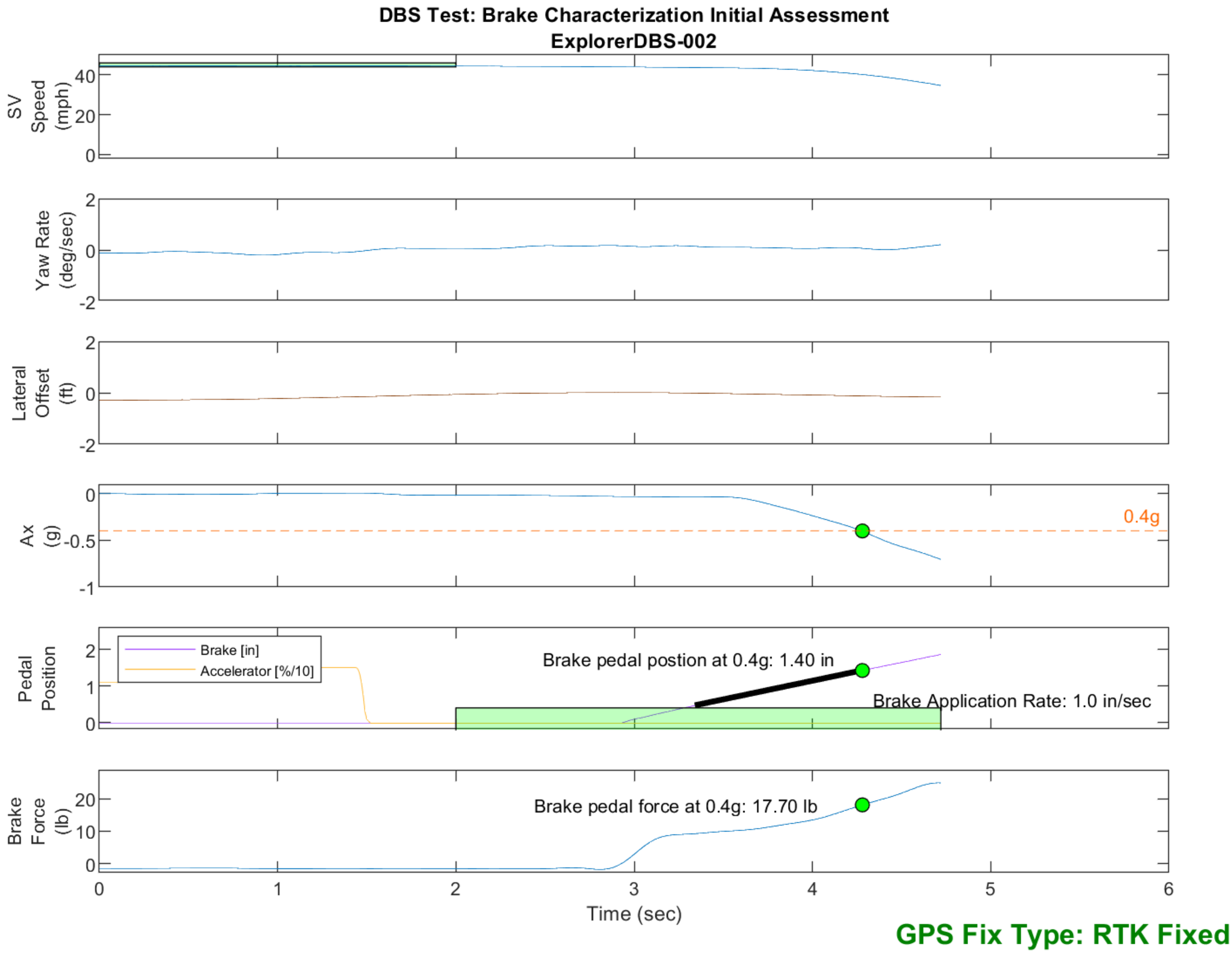


Figure E71. Time History for DBS Run 2, Brake Characterization Initial

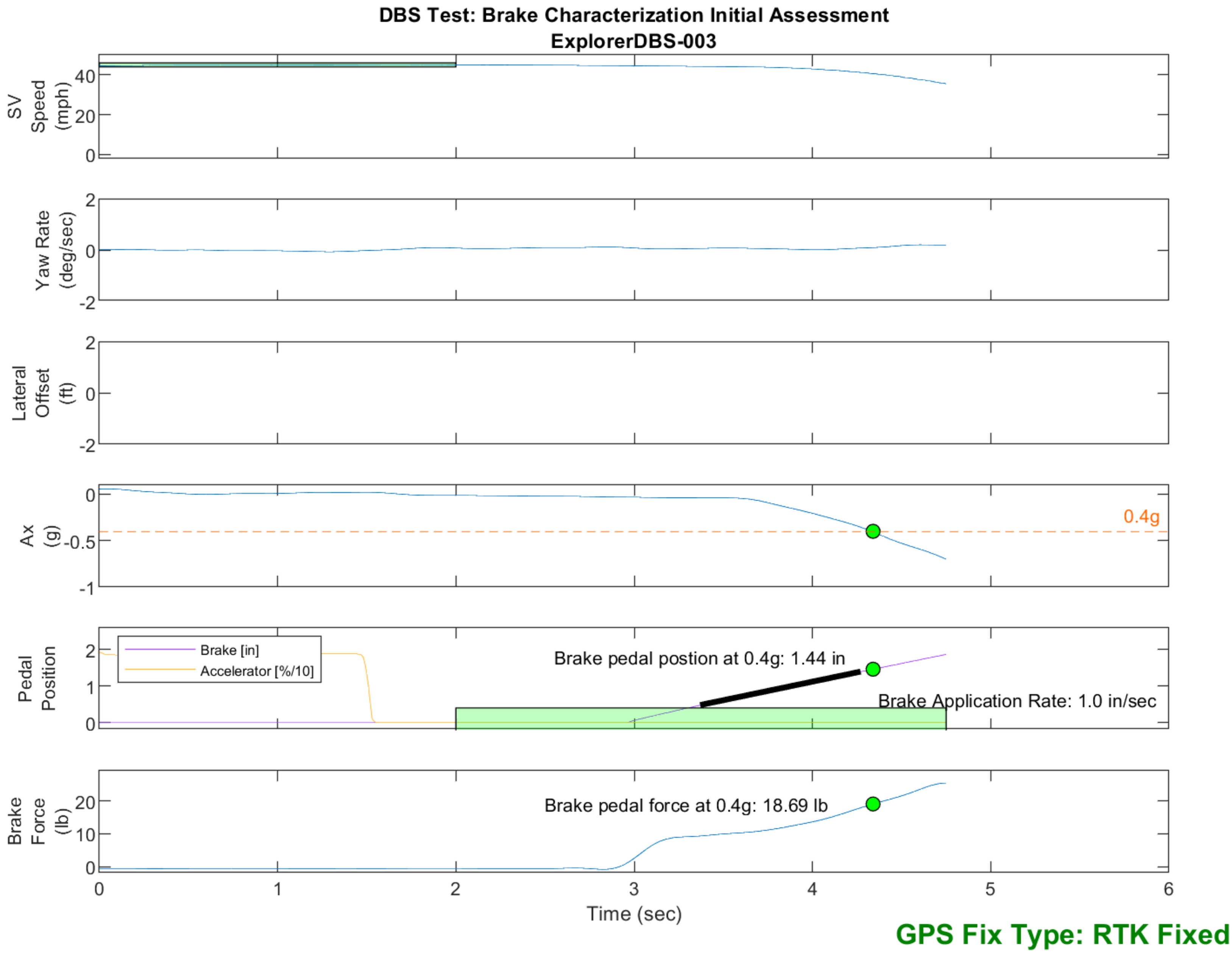


Figure E72. Time History for DBS Run 3, Brake Characterization Initial

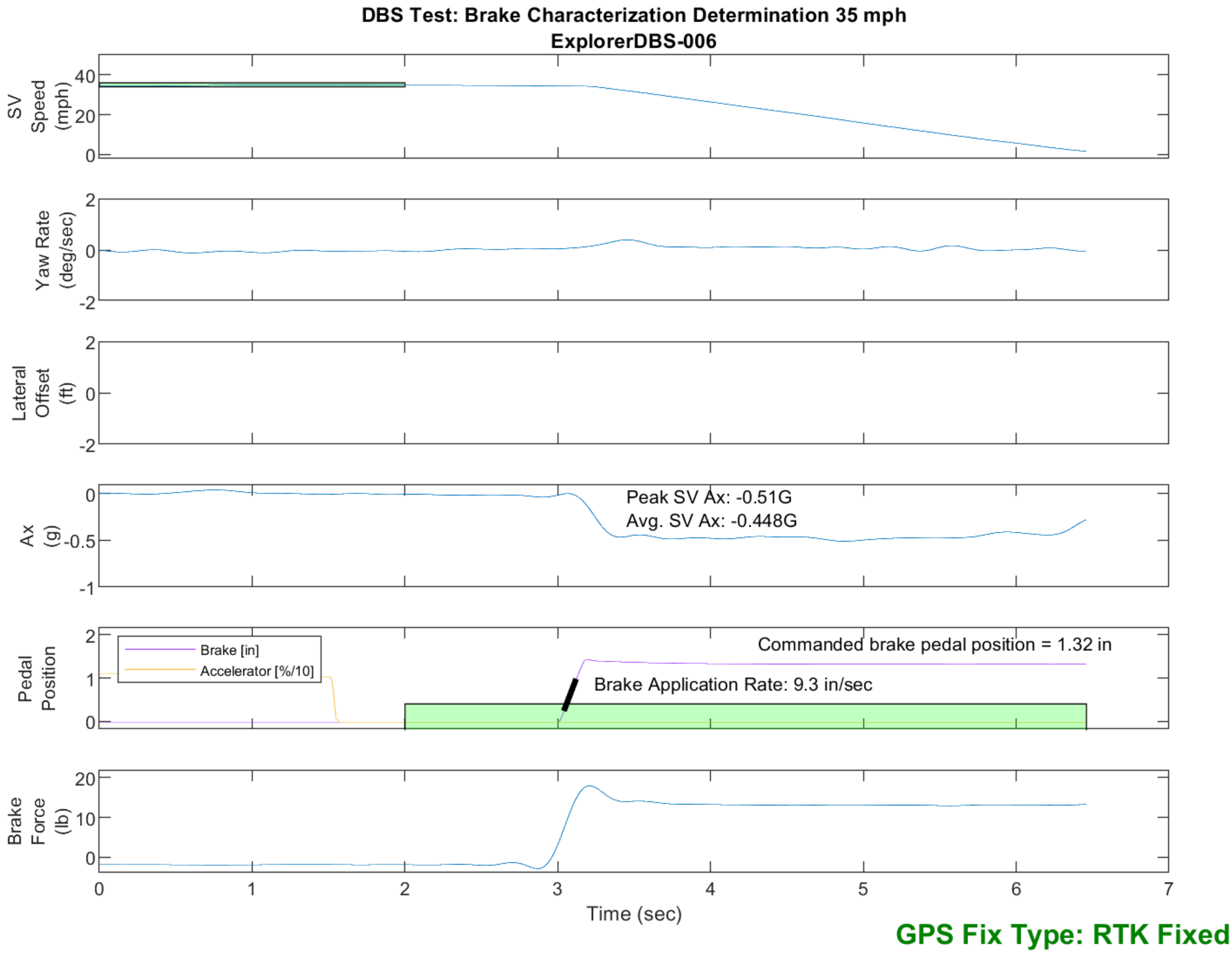


Figure E73. Time History for DBS Run 6, Brake Characterization Determination, Displacement Mode, 35 mph

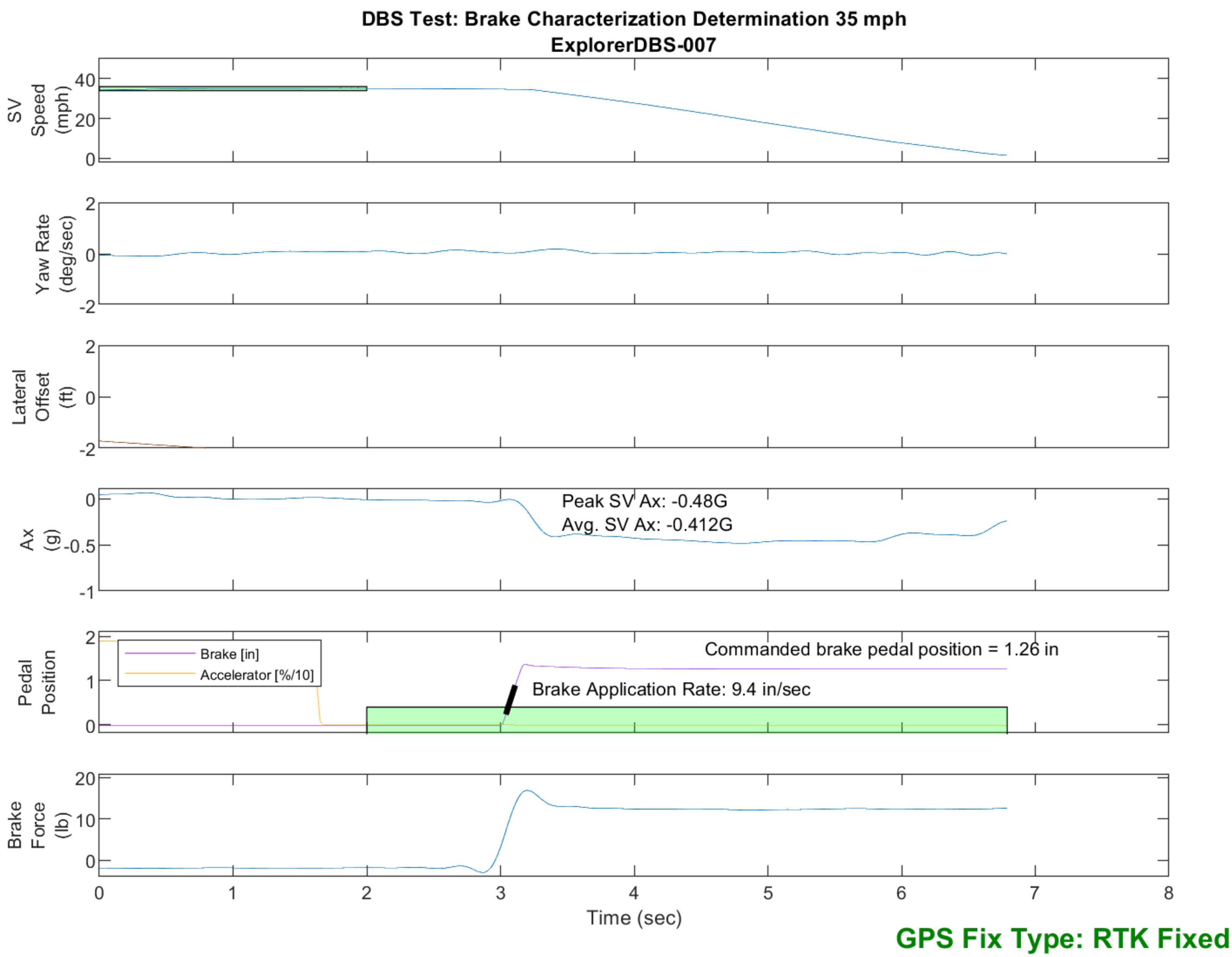


Figure E74. Time History for DBS Run 7, Brake Characterization Determination, Displacement Mode, 35 mph

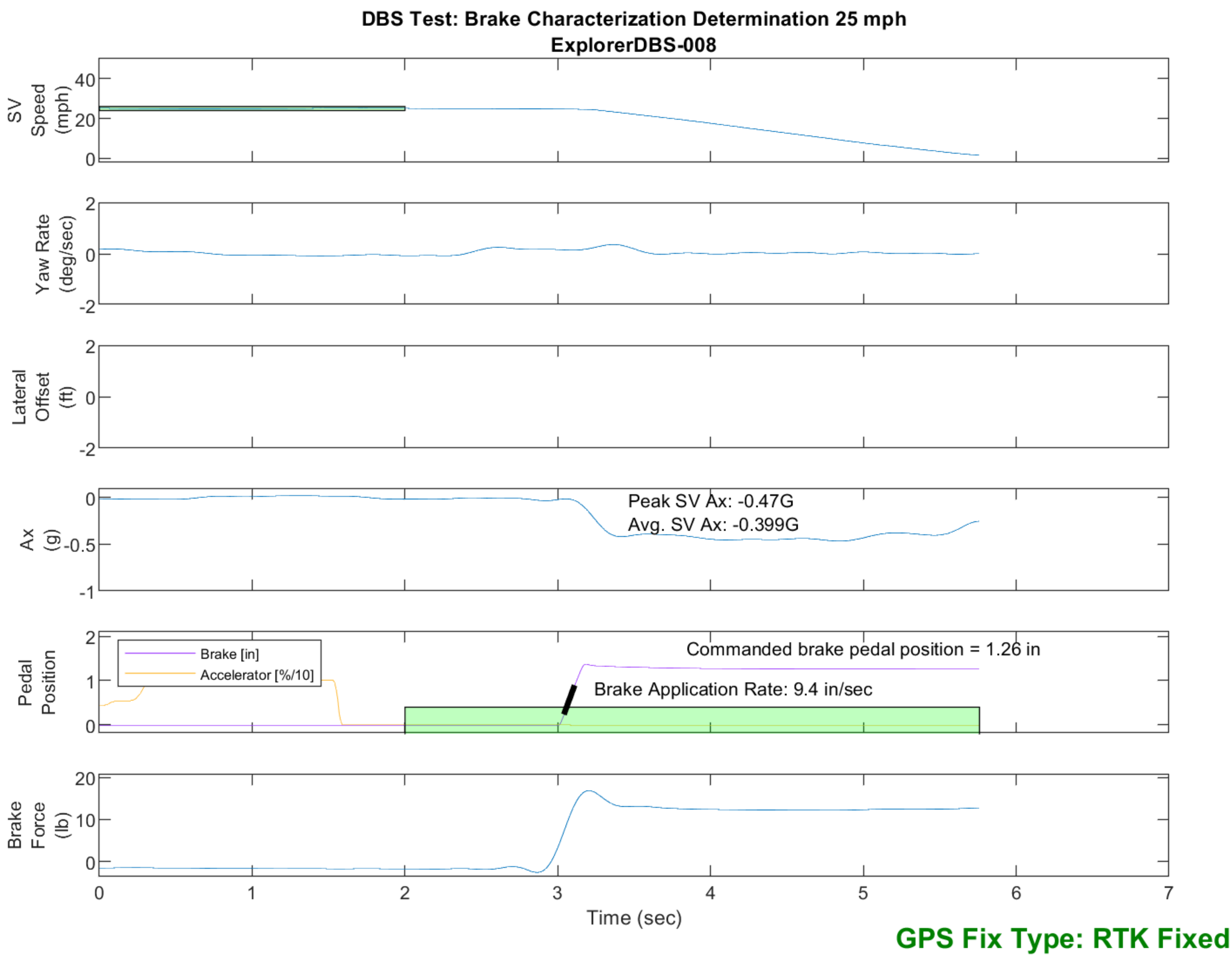


Figure E75. Time History for DBS Run 8, Brake Characterization Determination, Displacement Mode, 25 mph

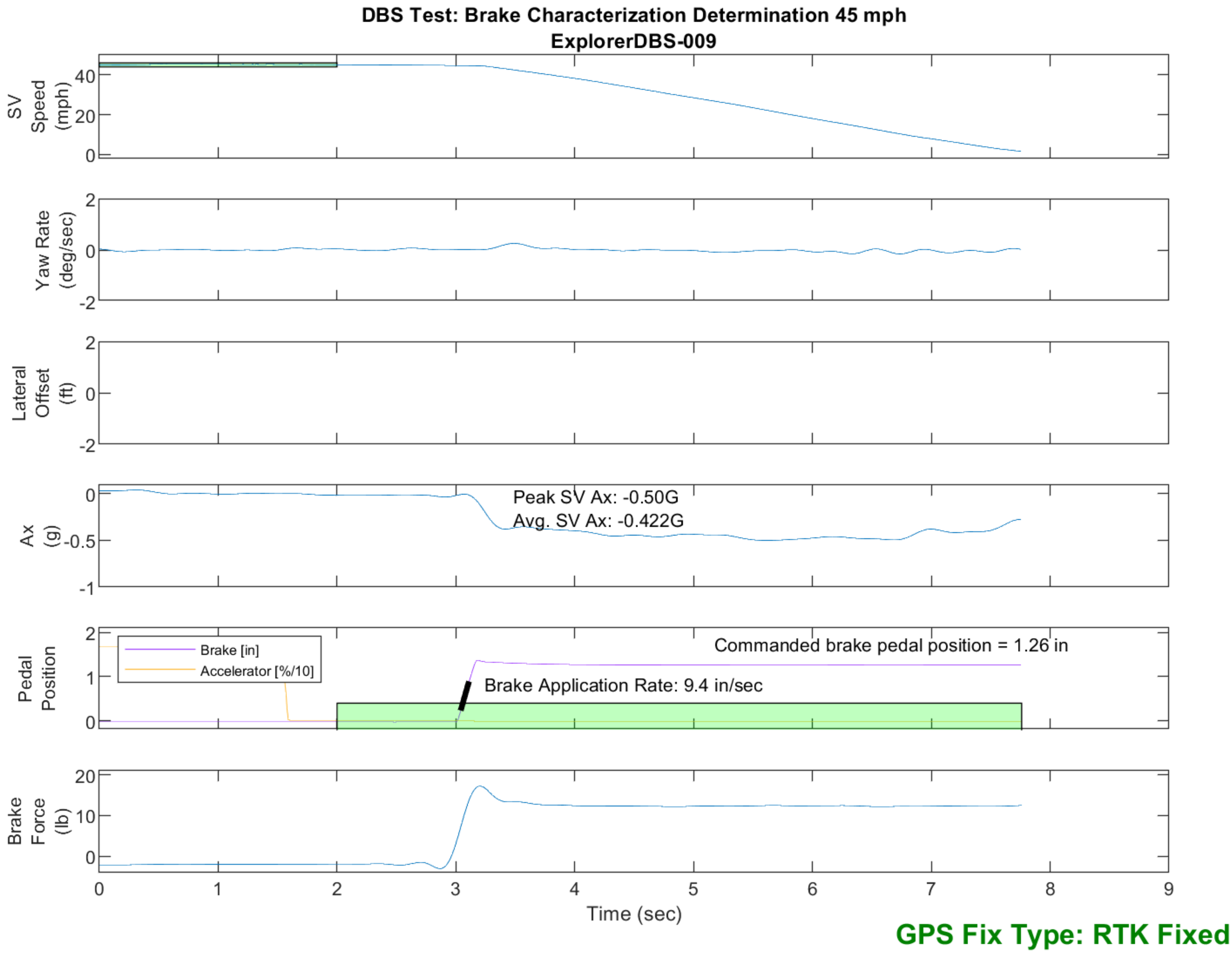


Figure E76. Time History for DBS Run 9, Brake Characterization Determination, Displacement Mode, 45 mph