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Federal Railroad Administration

INFLUENCE OF CONTACT PATCH RESISTANCE ON LOSS OF SHUNT AT HIGHWAY-RAILROAD GRADE CROSSING

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Final Report

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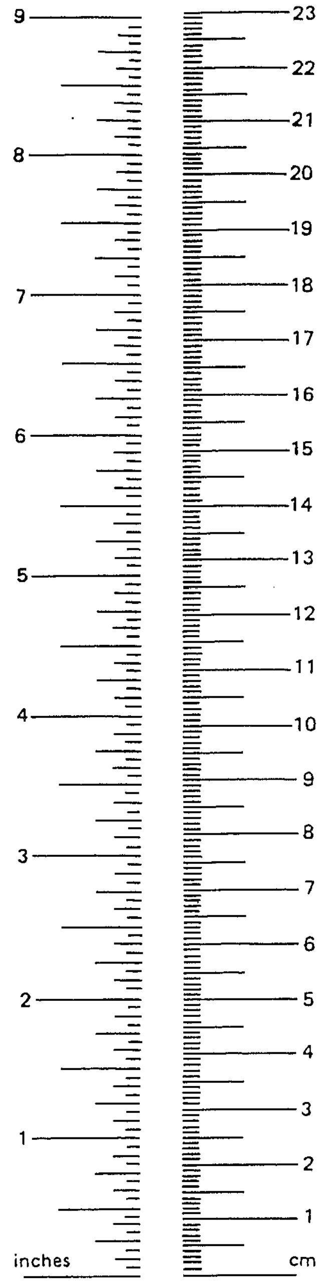
DISCLAIMER

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

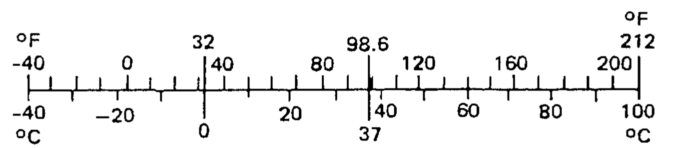
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 cm (exactly)



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius° temperature	9/5 (then add 32	Fahrenheit temperature	°F



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16. Abstract

Results of testing completed to date have revealed no promising mitigation techniques to reduce or eliminate loss of shunt on highway/rail grade crossing island circuits. During the course of this test program, results have shown that resistive films that develop on the running surfaces of wheels and rails are a major contributor to loss of shunt. Some untested mitigation techniques, however, have been developed recently and may offer an effective long-term solution for removing these resistive films.

This phase of testing was based on results of the field monitoring effort performed at eight field locations throughout North America by the Association of American Railroads, Transportation Technology Center, Pueblo, Colorado, to document statistical occurrences of loss of shunt (interim report titled "Influence of Contact Patch Resistance on Loss of Shunt,"August, 1993).

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EXECUTIVE SUMMARY

Results of testing completed to date by the Association of American Railroads (AAR), at the Transportation Technology Center, Pueblo, Colorado, have revealed no promising mitigation techniques that can be recommended to reduce or eliminate loss of shunt on highway/rail grade crossing island circuits. Loss of shunt is a temporary lack of electrical continuity between train wheels and rails, evidenced by a brief deactivation of flashers or gate arms, while passing trains are still occupying highway grade crossings. During the course of this test program, results have shown that resistive films that develop on the running surfaces of wheels and rails are a major contributor to loss of shunt. Some untested mitigation techniques, however, have been developed recently and may offer an effective long-term solution for removing these resistive films.

Chemical analysis of resistive films taken from revenue service shows that both rail and wheel film samples exhibit similar trends in chemical makeup. The two major components of the films are silicon in oxide (Si) and iron as oxide (Fe). Rail samples show a higher iron as oxide content and a lower silicon in oxide content than the wheel samples. This is most likely due to the differences in environmental exposure — rails being stationary and wheels rolling.

Dynamic contact patch resistance testing, performed on the AAR's railroad wheel dynamometer, shows that sporadic loss of shunt occurrences can be created in a laboratory environment. However, these occurrences were difficult to control, sustain, or repeat. Film samples taken from the laboratory test were different than those collected from numerous field site locations, both physically and in degree of chemical composition. The highest level and most frequent shunt loss occurred with a non-conformal brake shoe (where the brake shoe wear surface did not fully conform to the wheel tread profile

surface). Although films that are representative of what exists in revenue service were not able to be developed during the initial testing, it is felt that with extended running, films more like those seen in the field could be developed.

In limited testing, a whetting current reduced the number of loss of shunt occurrences. However, limited data and a short test duration prevents strong conclusions being drawn as to the overall effectiveness of a whetting current being a long term solution.

Data results from the wheel/axle/wheel resistance study indicates that resistance through a solid axle is not a significant contributor to loss of shunt. As a result of this study, the AAR C&S Division has proposed a recommendation for maximum allowable wheel to wheel resistance that applies to solid and split axle railroad cars.

For determining the pressure/resistance relationship, attempts were made at developing a small portable device for measuring resistive films on rail and wheels in the field. The attemps were unsuccessful in that field measurements obtained using this device were unstable and inconsistent. However, a full scale device set up in a laboratory showed a distinct relationship between pressure and resistance. The higher the pressure, the lower the resistance. In support of these findings, it was shown during field site monitoring that heavier railroad cars tend to provide a better shunt.

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1.0 INTRODUCTION

Both the railroad signal community and the grade crossing equipment suppliers have reported an increase in the occurrence of loss of shunt (LOS) on railroad grade crossing island circuits. Loss of shunt is a temporary lack of electrical continuity between train wheels and rails, evidenced by a brief deactivation of flashers or gate arms, while passing trains are still occupying highway grade crossings. A preliminary evaluation and monitoring at eight field locations throughout North America was conducted by the Association of American Railroads (AAR), Transportation Technology Center (TTC), Pueblo, Colorado, to document statistical occurrences of LOS. This was reported in the interim report titled "Influence of Contact Patch Resistance on Loss of Shunt," as part of FRA Task Order 106, issued in August, 1993.

Data from the field monitoring phase of this program indicated that occurrences of LOS severe enough to cause release of the island relay were very rare. Monitoring over six months at the eight field locations resulted in 46 trains out of over 10,000 exhibiting a LOS leading to island relay release. Release of the island relay could, in certain cases, result in gate bob or intermittent operation of warning devices, even if the train is still occupying the crossing. A number of field conditions were also monitored during this period, such as evaluations of films, rail condition, and other environmental concerns.

Technical direction for this task order was provided by the AAR Cmmunications and Signal Section (C&S), Committee D, Highway Grade Crossing Warning Systems, Track Circuit Parameters Task Force. Based on results of the field monitoring data, a number of follow-on evaluations and tests were recommended by the Task Force. These evaluations were intended to provide better understanding of conditions leading up to or increasing the tendency for rail equipment to lose shunt within island limits.

2.0 OBJECTIVES

The objectives of this phase of the task order were based on results of the field monitoring effort. The objectives were focused on obtaining a better understanding of causes of LOS and to investigating possible solutions.

The objectives were as follows:

- Evaluate effectiveness of a "whetting current" in reducing or eliminating LOS.
- Determine if portable measurement systems could be designed to allow field evaluation of wheel and rail conditions leading up to LOS.
- Perform full scale laboratory wheel/rail dynamic contact patch simulations to determine contribution of brake shoes, brake application cycles, and various contaminants that might contribute to conditions leading up to LOS.
- Evaluate films created in various laboratory simulations of the wheel/rail contact system, and compare these films to those collected at field sites.

3.0 PROCEDURES

This final report addresses follow-on action items suggested in the conclusions and recommendations stated in the interim report, which reported on field monitoring efforts. Loss of shunt data from field monitoring was used to specify the following:

- Locations where films were to be collected
- Location where the whetting current should be evaluated
- Determine contaminants to be used in the laboratory test

Each of the objectives was monitored and conducted separately; however, in some cases two or three objectives were addressed concurrently. For example, field sites were evaluated for film resistance at the same time film samples were taken for laboratory tests.

A major delay occurred in the brake shoe testing due to unavailability of the test fixture. For this reason, the next phase of this task order, which was to evaluate alternative detection technologies, has already been started. Although the follow-on efforts are funded under the same task order and there is an overlap in scheduling, the alternative detection system program is under technical direction of a different industry task force and has different objectives. Therefore, this report will not include results of the alternative detection technology test phase.

4.0 EVALUATION OF WHETTING CURRENT

Results of the extended field monitoring period performed in the initial field site investigation (documented in an interim report) indicated that the Sterling, Nebraska, sites had a relatively high incidence of LOS. At the recommendation of the Task Force, this site was selected for long-term monitoring to determine the effectiveness of a whetting current.

A whetting current is a circuit that overlays the existing island circuit and is designed to enhance shunting performance of wheels entering the island. The whetting current was activated only after the island relay became deactivated. It was not designed to increase shunting performance of the wheels prior to entering the island limit. Once activated, however, the whetting current performance was intended to prevent shunt loss of the island control current by providing a path through contamination or other surface films. Its intent is to reduce or eliminate electrical obstructions in the island control current flow path.

Restart of monitoring efforts at Sterling was delayed due to flooding which occurred earlier in the year. As films leading to LOS might have had seasonal variations, the intent was to monitor the site for an extended period of time, periodically activating and then deactivating the whetting current operation.

Analysis included statistical comparisons of LOS history between periods when the whetting current was active or not, as well as comparisons of a nearby (1 mile) site on the same track that was not equipped with any enhancements.

4.1 STERLING SITE LAYOUT

The Sterling sites remained the same as that reported in the interim report, a single track railroad, with bi-directional traffic. Coal loads travel eastbound, while occasional unit grain trains travel westbound. Some mixed freight traffic is also present.

Two actual road crossings were selected for monitoring:

- Site H (east end of Sterling)
- Site G (west end of Sterling)

In addition, an auxiliary island circuit, site R, was installed adjacent to site H, just east of the island limits. Site R was selected during the extended monitoring phase to determine if LOS performance was different adjacent to the crossing (where no road traffic was present) than at the crossing itself. Note that rail shape and profile was also different between site R and sites G and H. Standard production grinding machines usually cannot grind though road crossings. Rail through road crossings is thus often not ground unless the use of a spot (switch) grinder is made. The Task Force requested that rail through the crossing not be ground for the duration of this test to allow for evaluation of varying profile.

4.2 RESULTS

Table 1 and Figure 1 summarize results of the limited monitoring period. The test was suspended due to the limited budget for this task and because the site was selected for future evaluation of alterative detection systems, which would also include a whetting current technology.

Table 1. Summary of LOS Occurrences at Sterling, Nebraska

	Before			During			After		
	Total	Occur.	Percent	Total	Occur.	Percent	Total	Occur.	Percent
Site G	454	28	6.2%	389	31	8.0%	302	16	5.3%
Site H	449	22	4.9%	389	0	0.0%	302	1	0.3%
Site R	N/A	N/A	N/A	389	23	5.9%	302	25	8.3%

The whetting current test was performed between July 20 and September 24. During the period when the whetting current was activated, no occurrences of LOS were recorded. During the period immediately after the whetting current was deactivated, the same island (site H) reported only one occurrence of LOS. This should be compared to over 20 occurrences of LOS for a similar number of trains during the period just before the whetting current was activated. The site located 1 mile away (site G), where no whetting current was ever installed, performed about the same during all three periods. Note that site R indicates N/A for first monitoring period, due to an equipment malfunction.

Field data did not contain indications explaining why the primary monitoring site (site H) behaved so differently immediately after deactivation of the whetting current. There did not appear to be any significant "micro seasonal" effects during the period; that is, LOS occurrences at the other sites (G and R) were relatively evenly spaced throughout the test period.

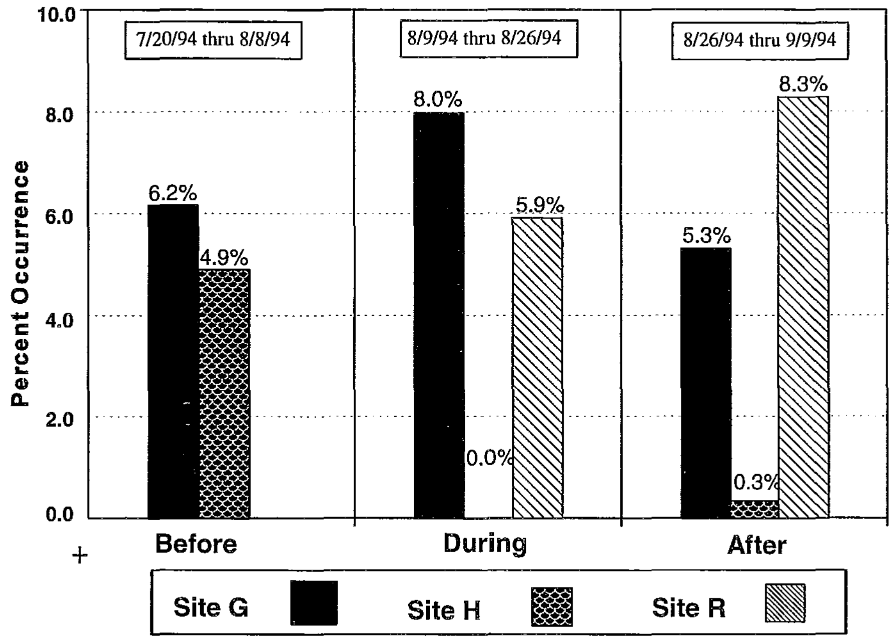


Figure 1. Percentage of LOS Occurrences

4.3 OBSERVATIONS

Based on the limited test period, the following observations are drawn from the test data:

- No LOS occurrences were recorded while the whetting current was active.
- Limited data and test duration prevents strong conclusions.
- Extended monitoring to eliminate seasonal changes and short term influences is suggested.
- Lack of site H returning to anywhere near its pre-whetting current performance makes results of this limited test questionable; although , it may be that application of the whetting current modified the oxide layer to form a better conductor

5.0 ELECTRICAL SHUNT PATH ENVIRONMENT

In order to better understand the total shunt environment, as well as determine if specific locations along the shunt path contributed significantly to LOS, a series of measurements were made to determine:

- Wheel-to-wheel resistance through the axle
- Electrical resistance of the film at various locations across the top running surface of the rail
- Durability of the film/change in electrical resistance under various contact pressures

5.1 WHEEL/AXLE/WHEEL RESISTANCE

The Task Force requested wheel/axle/wheel resistance information to determine typical ranges of resistances from one wheel, through the axle, to the other wheel. As wheel mounting procedures have changed with time (for example, the use of lead as a lubricant to assist in the wheel pressing process has been eliminated), there was a concern that some wheel sets might have higher than desirable resistances.

Also, such data could be used to provide "target" wheel-to-wheel resistances for new equipment being considered. For example, some equipment with independently rotating wheels is being evaluated for introduction into revenue service; because that equipment does not use a solid axle, wheel-to-wheel resistance might be significantly higher with no direct electrical path being provided. This data could also be used for proposed track circuit models that might simulate various components within the shunting path. A total of 140 wheel sets were measured for this task.

5.1.1 Measurement Apparatus

The TTC Instrumentation Calibration Laboratory provided a precision Kelvin bridge resistance meter that is suitable for making low-value resistance measurements. The Kelvin bridge device uses four input terminals which nullifies wire lead and contact resistances. The particular device used in this study was the Biddle model 72-439 portable Kelvin bridge with a measurement range of 0.01 micro-ohm to 1111.1 ohms in seven ranges. The error limits, as specified by the manufacturer, are +/-0.03 percent of reading +0.03 micro-ohm.

Two special C-clamps were fabricated so that they would attach between the back rim and field face of each wheel. Each clamp was electrically isolated in halves so that each area of contact was separate. The isolation was provided by a nylon bushing between the threaded drive and the pressure plate (see Figure 2).

The Kelvin bridge device was calibrated with the fabricated cables and modified clamps to assure accurate measurements.

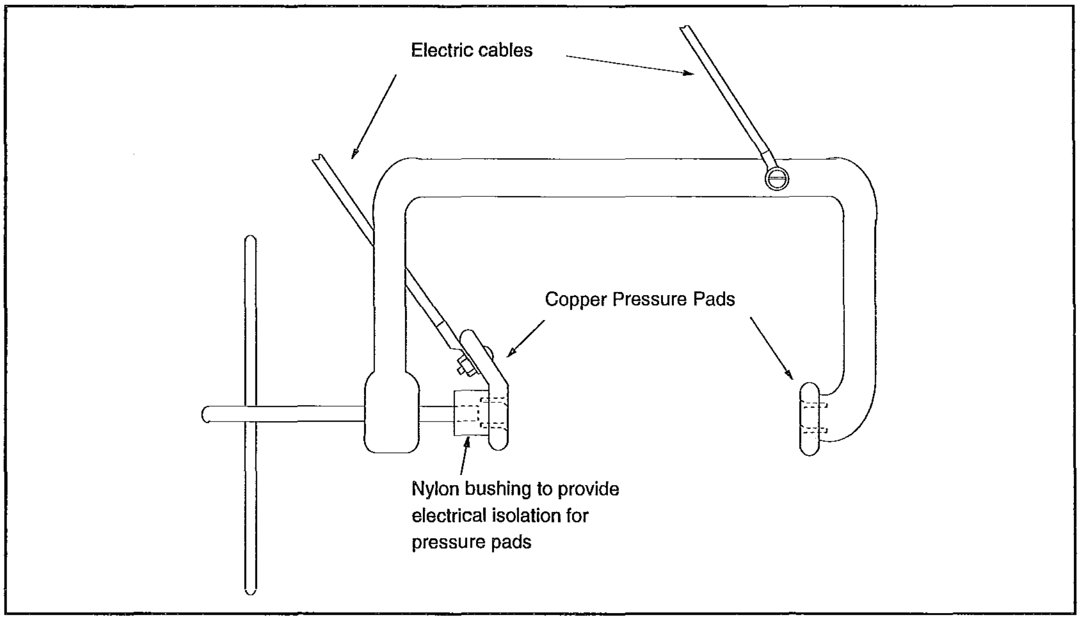


Figure 2. Modified C-clamp

5.1.2 Data Acquisition

During the latter part of May, 1993, measurements were taken of 126 varying wheel sets captive at TTC. It is important to note that these wheel sets *may* or *may not* have run in revenue service. All wheel sets measured were removed from trucks and isolated from any external shunting effects. This was achieved by resting both wheels on insulating rubber pads. Each wheel set was prepared for measurement by grinding the area of surface contact with an electric grinder on both sides of each wheel. This was necessary to warrant against surface contaminants, namely rust (Figure 3).

The Biddle meter has the capability of reversing polarity when obtaining measurements. Data was taken of both positive and negative applied voltage stimulus of each wheel set measured.

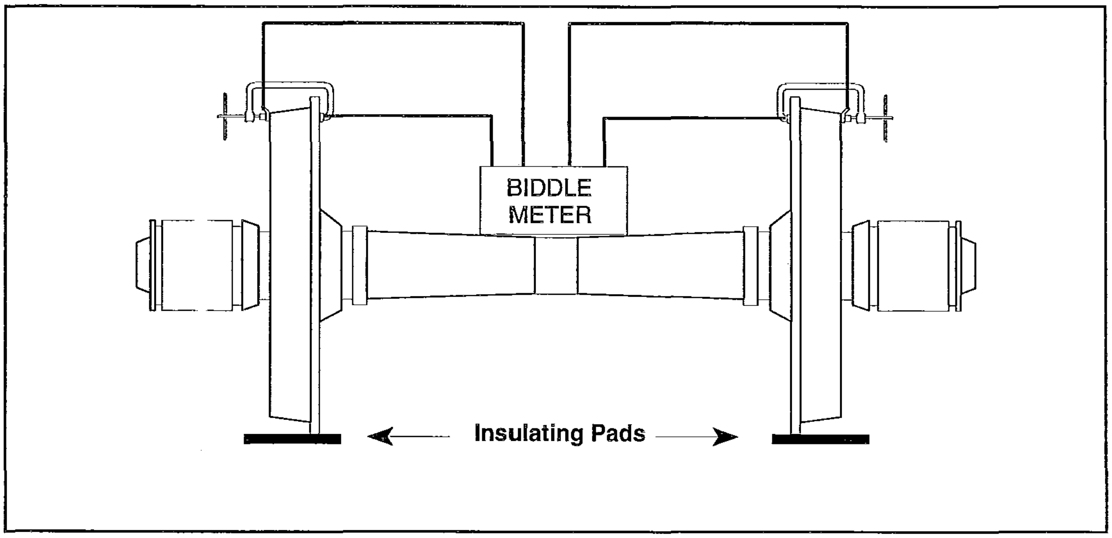


Figure 3. Wheel/Axle/Wheel Measurement

The remaining 14 wheel set measurements were obtained from revenue service. The same procedures of isolating the wheel sets and surface grinding were followed as those mentioned above.

5.1.3 Results

Data results of this study indicate that the resistance of a typical wheel set, as measured from wheel through axle to wheel falls in the micro-ohm range (Figure 4).

The frequency distribution of the data shows that all measured wheel sets fell within the 14 to 20 micro-ohm range, with the exception of one wheel set which measured in the 8 micro-ohm range.

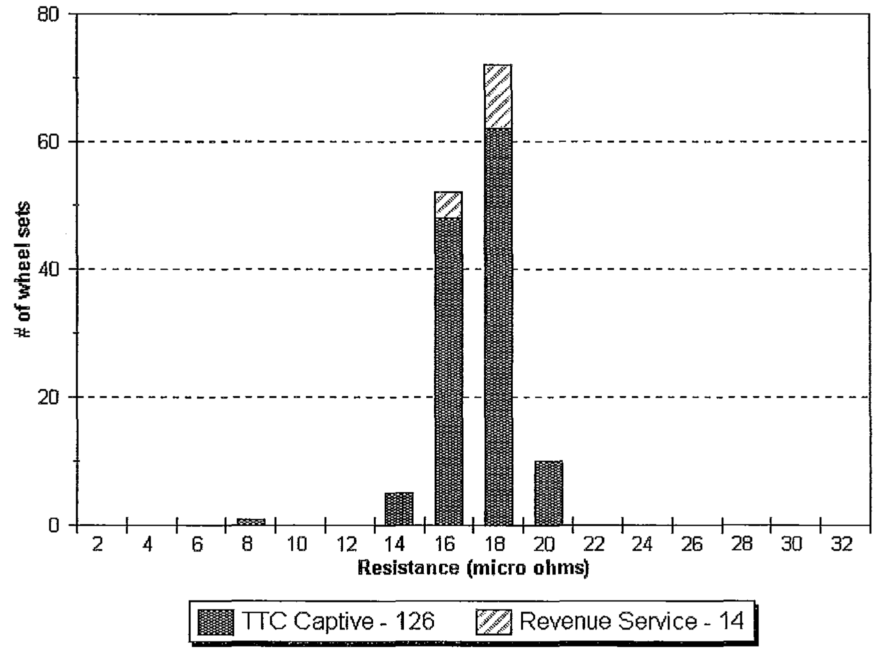


Figure 4. Wheel/Axle/Wheel Resistance Measurements

5.1.4 Conclusions

Data results from this study indicate that the resistance of wheel sets, as measured from wheel through axle to wheel, does not appear to contribute to LOS. This is based on solid axle wheel sets measured from typical freight railroad service and does not include independent rolling wheel configurations.

The measured resistances measured are well below values needed to cause intermittent shunt loss on AC track circuits.

As a result of this study, the AAR C&S Division has proposed a recommendation for maximum allowable wheel to wheel resistance (refer to Appendix A).

5.2 FILM RESISTANCE

During the extended field monitoring period, occurrences of LOS appeared to be significantly higher when light or empty car trains were passing. This was especially noted at the Sterling and Gothenburg, Nebraska, sites, where empty coal trains could be occasionally identified by special car tracking efforts. Car weights for unit train service have been reduced (by use of aluminum bodies, for example) during the past few years. A means of determining at what contact pressure rail films on the top running surface would breakdown their electrical resistance was desired.

The location on the rail of the highest resistance was desirable. Although some films were visible as a dark black or grey band, some were virtually transparent. A means of mapping where the film was most resistive would help determine what wheel/rail profile combination might lead to LOS. This could provide information as to remedial rail grinding shapes that would inhibit LOS.

Two measurement devices were designed and fabricated, one for measuring resistance under varying contact pressure, the other for determining resistance across the top running surface of the rail. These devices were evaluated at the TTC, and limited field data was subsequently collected; however, results were insufficiently repeatable to allow use in subsequent tests.

5.2.1 Rail Film Electrical Resistance Meter

To determine the location on the railhead of highest resistance, a rail film electrical resistance meter (RFERM) was designed and fabricated by Safetran, a member of the Task Force. The RFERM allows measurements of resistance, calculated from voltage and current measurements, to be made with a multiple pin fixture. Pins applying a light pressure are arranged across the top of rail, spaced at approximately 0.25-inch intervals (Figure 5).

Resistance is measured between each pin and the rail material. Each pin is measured separately, with an automatic control system designed by Safetran engineering staff to sequence across the railhead.

5.2.1.1 Results

Multiple readings at the same point (without moving the clamp) were very repeatable; however, multiple readings in the same vicinity on the top of rail using the RFERM were not repeatable. A wide range of resistances was recorded during repeated readings along a short distance of the rail. The RFERM appears to be adequate for indicating whether a resistive film is present, but the value may not represent true resistance.

The RFERM provided insufficient resolution between different locations to allow data to be useful. One problem may have been that the pins disturbed the film (by micro scratching), thus altering the data. Ensuring that all pins were clean for each measurement was also difficult.

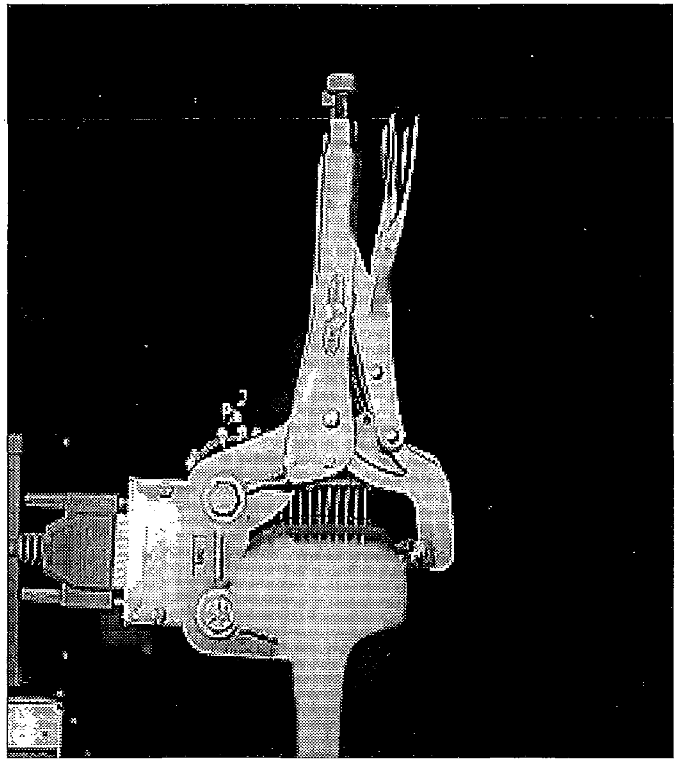


Figure 5. RFERM

5.2.2 Variable Pressure Electrical Resistance Meter

TTC designed and developed a variable pressure electrical resistance meter (VPERM) to permit measurements of rail film resistance as a function of varying pressure (see Figure 6). The VPERM clamps on the head of the rail and allows the test head to be lowered on the top of the rail. The test head is made from cut sections of cylindrical shaped steel bars. Three test heads were fabricated, each with a different radius (½", ¾", 1"), such that they could be interchanged easily.

The concept of the VPERM was to have the test head serve as a positive lead or probe which contacts the film while the negative lead is attached to the rail by a magnet on a surface that had been cleaned using an electric grinder to assure a good grounding surface contact. Measurements were taken using a Philips RCL meter. This particular meter is a four wire device that can measure both resistance

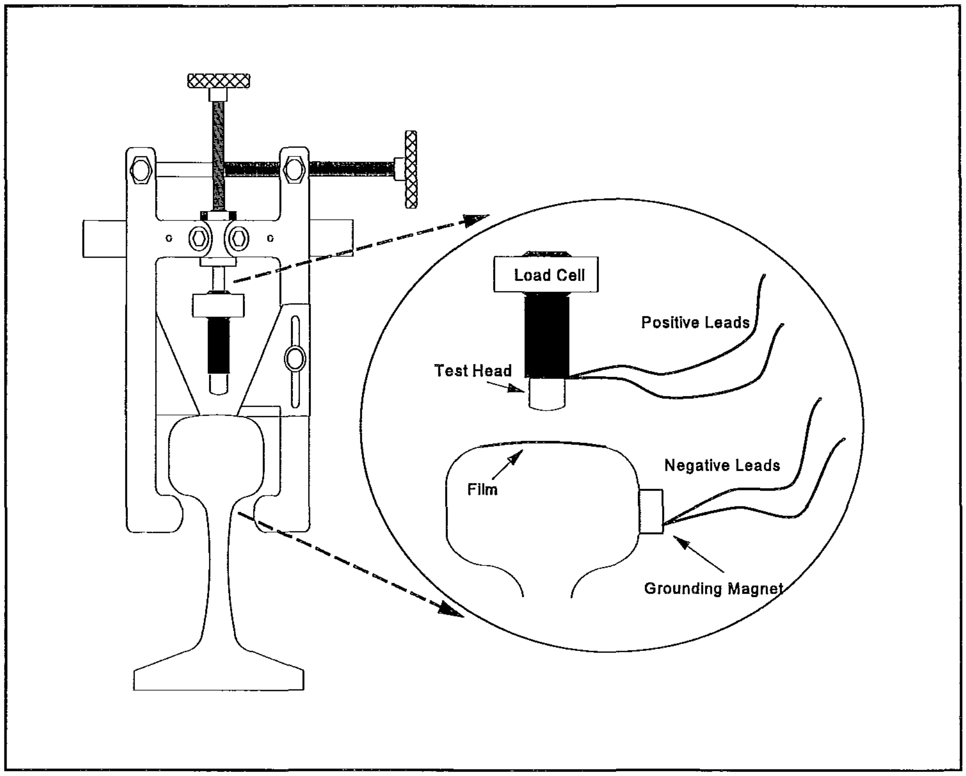


Figure 6. Portable VPERM Fixture

and reactance in DC and AC modes respectively. Resistance measurements for this test were taken using the DC mode. The Philips RCL meter also has a trim feature which allows for open and short circuit testing for the purpose of nullifying lead resistances.

Initial results indicated some variability of resistances. Concern was raised about the VPERM being able to accurately replicate the wheel/rail contact patch conditions. An audit with a previously utilized test fixture designed by Canadian National Railway was proposed.

5.2.2.1 Canadian National Audit

On July 5, 1994, Transportation Technology Center (TTC) personnel traveled to Montreal, Quebec, in an effort to audit the ability of VPERM to measure rail film resistance. This audit was based on the comparison of the VPERM against the results of a full-scale apparatus designed by Canadian National Railroad

(CN), which also measures the resistance of the film between the wheel and rail.

The results of this comparison showed that the VPERM device, in its current configuration, does not provide accurate nor consistent results in measuring film resistance due to the size of the test head probe. The CN device does, however, give consistent results and indicates a linear relationship between pressure and film resistance. CN conducted its own test, allowing observation by TTC personnel. CN provided TTC with its test data for the purpose of establishing a relationship with the VPERM results. Figure 7 shows the test circuit of the CN full scale setup.

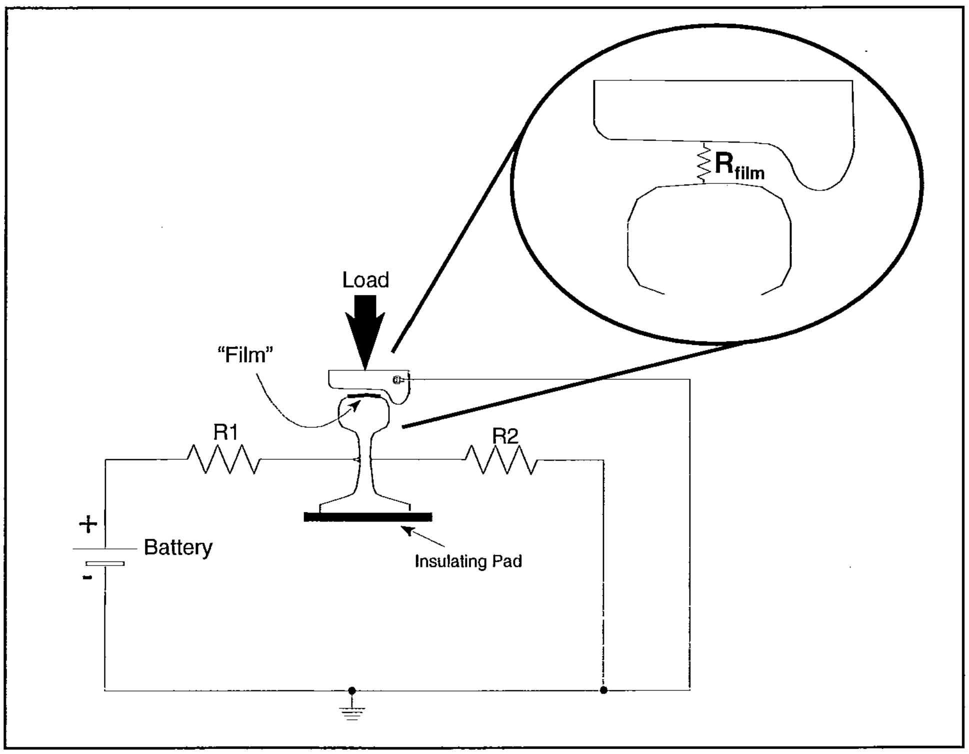


Figure 7. CN Full Scale VPERM Setup

Measurements were taken of voltage across resistors R1 and R2 (Figure 7). From basic electronic principles, current, voltage and resistance of the film were calculated. The test was conducted using a single cell and a double cell Ni-Cad battery. Three different rail samples were examined (1) an extremely rusty rail, which had been exposed to weather for about 2 years, (2) a 6-month rusty rail, and (3) a new rail. Three readings were taken from each rail at different locations to ensure there had not been any perforation of the film of the previous reading. Each rail was tested for loads of 2,000, 5,000, 10,000, and 20,000 pounds.

5.2.2.2 Results

Measurements obtained using the portable VPERM fixture were unstable and inconsistent. Numerous attempts were made to establish consistent readings at different locations of each rail; however, these attempts were unsuccessful (see Table 2). This may be due to the size of the test head. The actual contact area between the VPERM test head and the rail is so small (.0031 square inches - calculated at approx. 1/80 of 33" wheel) that surface roughness of the rail is causing inconsistent and unreliable readings.

In the case of the heavy rust film in Table 2, substantial fluctuations are seen throughout the load spectrum as well as between measurements 1 and 2. The attempted results to measure the 6-month rusty rail show the inability to maintain consistent readings. Numerous attempts were made to establish a consistent load/resistance relationship; however, the above data indicates the typical performance of the VPERM. Figures 8 and 9 show a strong inverse relationship between pressure and resistance using the CN device. In all cases, as pressure was increased, the resistance of the rust film decreased.

Table 2. Summary of VPERM Audit Data

Applied Load (lbs)	Heavy rust film		6 month rust film (Ω)
	*Measurement 1 (Ω)	*Measurement 2 (Ω)	
25	40500	233000	0.27
50	1400	82000	0.44
75	710	56000	0.33
100	750	3.2	0.72
130	1150	400	----
150	2700	438	----
170	3300	345	----

* Measurements 1 & 2 were taken on the same rail at the same location.

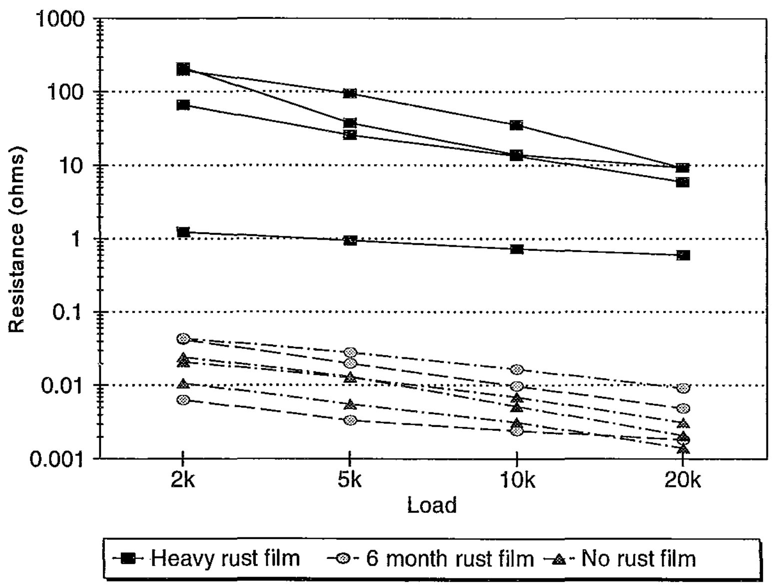


Figure 8. Film Resistance of Double Cell Test

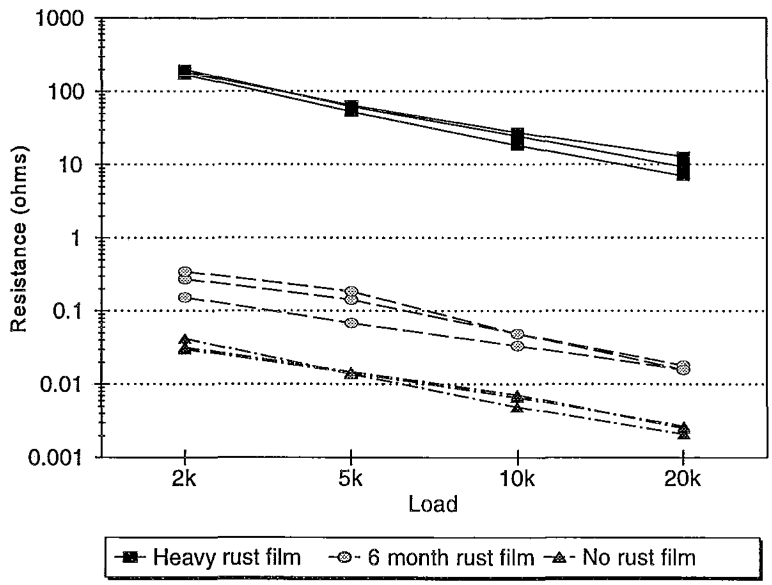


Figure 9. Film Resistance of Single Cell Test

5.2.2.3 Conclusions

Although no correlation could be established, the difference between the two devices indicate that not only pressure, but also contact area may have a significant effect on film resistance. There is no concrete evidence linking contact area and film resistance, but the results of the CN test could indicate a need for further investigation.

5.3 CHEMICAL FILM ANALYSIS

Chemical content and makeup of films were determined from samples collected at various field locations to address where and how mitigation techniques might be applied for reducing or eliminating LOS. Also, laboratory tests, conducted using the full scale wheel rail dynamometer, attempted to replicate these films to create LOS conditions by applying various amounts of contaminants. The resulting films were analyzed and compared to films collected in the field.

Samples from rails were collected from virtually all field sites where LOS long-term monitoring had been conducted. Specific details of these sites may be found in the interim report and will not be repeated here. In addition, samples collected during the training phase (on how to collect films samples) conducted by Oregon Graduate Institute (OGI) near Portland, Oregon, are also included in the database. In all but one case, rail samples were collected along the center top running surface at or near the location where the majority of the wheels appeared to be operating.

A field location at Washougal, Washington, was near a wayside lubricator. Samples were taken from the top running surface (Washougal 2) and from the field edge of the top of rail (Washougal 1). The material collected from Washougal 1 was not heavily worked and required considerably less effort to remove compared with other sites.

Film samples were collected from wheels located in three car shops. One was the Burlington Northern (BN) one-spot repair shop at Vancouver, Washington, (near Portland, OR), the others were in the Union Pacific car shops in North Platte, Nebraska, and the BN car shops in Lincoln, Nebraska. Wheels that had been removed recently were selected to avoid biasing the data with films containing large amounts of rust from time in storage.

5.3.1 Collection Method

Scrapings of films from top of rail (primarily the running surface) and from wheel tread surfaces were collected and sent to the OGI for analysis. Samples were collected by using a clean, sharp single-edge razor blade, scraping the rail or wheel surface at a very low angle 6 to 24 inches. When a sufficient amount of material was collected, it and the razor blade were carefully placed in clean plastic vials, sealed and labeled.

In many cases the film was very hard and strongly bonded to the rail. Significant force was required during the scraping process to remove an adequate amount of the film for laboratory analysis. The sample collection procedure was developed by OGI. Their representatives trained TTC engineering staff. Virtually all samples were collected by the same TTC engineering group to ensure that a uniform process was followed.

5.3.2 Analysis

Samples sent to OGI were analyzed using a number of laboratory techniques. These included scanning electron microscope/energy dispersive x-ray analysis. This permitted qualitative as well as quantitative microanalysis of the small sample available from each site.

OGI provided a data analysis of each site sampled, indicating the amount of carbon, iron oxide, silicon in oxide, aluminum in oxide, calcium in oxide, and oxygen present. This is shown as a percentage of the entire sample. A more detailed description of the analyses is shown in Appendix B.

5.3.3 Results

Figures 10 through 12 summarize results of film samples collected from the rails and wheels. Figure 10 shows percentage of major film components from all wheel samples collected. Figure 11 shows film sample results from all field sites except Washougal 1. Figure 12 shows only the results from the Washougal 1 site, which is the area sampled outside of the running surface.

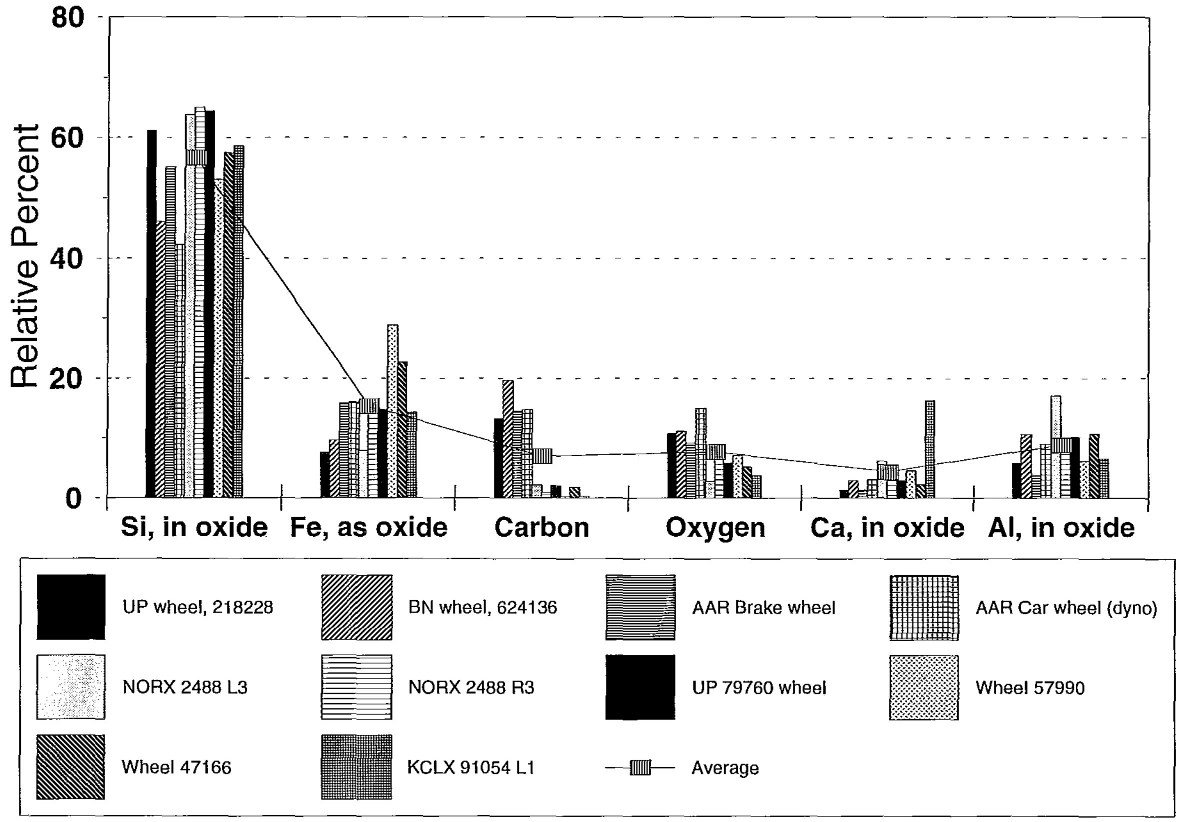


Figure 10. Film Samples Taken from Wheels in Revenue Service

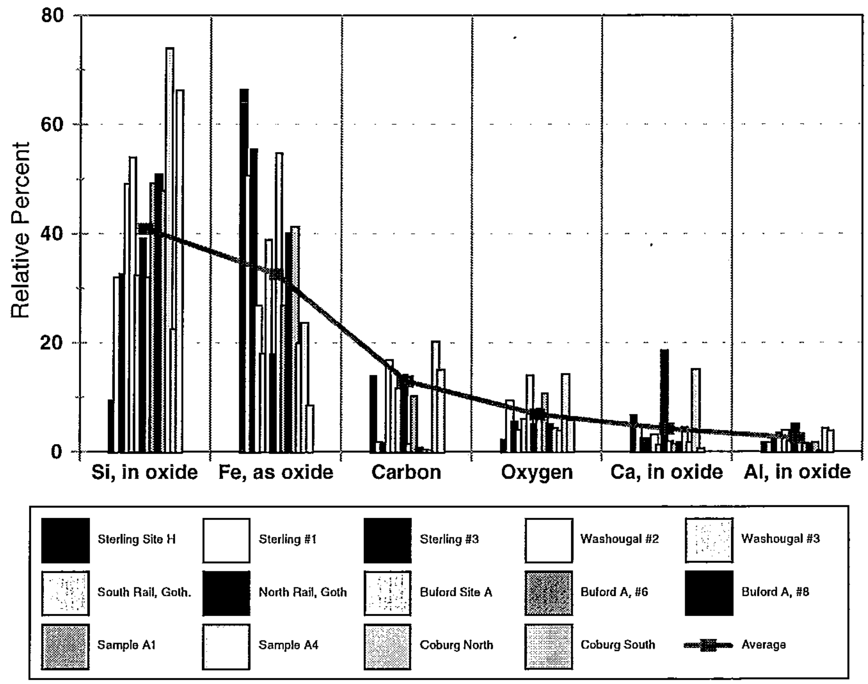


Figure 11. Film Samples taken from Rails in Revenue Service

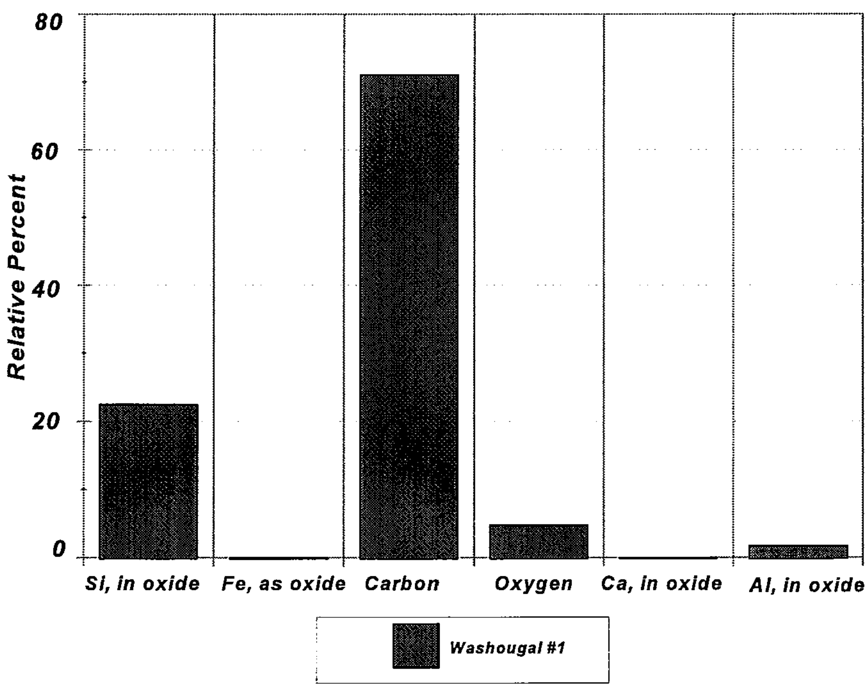


Figure 12. Film Sample Taken from Washougal 1 Site

As can be seen, the rails show a higher variability between sites than the wheels. Between different field sites, the highest variability is between content of carbon, silicon in oxide, and iron as oxide. Data showed a higher percentage of silicon in oxide from the wheel samples than from the rail sites; the rail data showed a higher percentage of iron as oxide than the wheels. The other components of film from both rails and wheels (carbon, oxygen, calcium in oxide, and aluminum in oxide) were similar in both locations (Figure 13).

Figure 14 shows the average of all rail sites compared to the one site that was heavily lubricated (Washougal 1). There are notable differences of silica in oxide, carbon, and iron as oxide. The high carbon content of the Washougal 1 site is likely due from track grease, while the low (almost 0%) iron as oxide may be due to lack of rust forming as a result of the protective layer of grease.

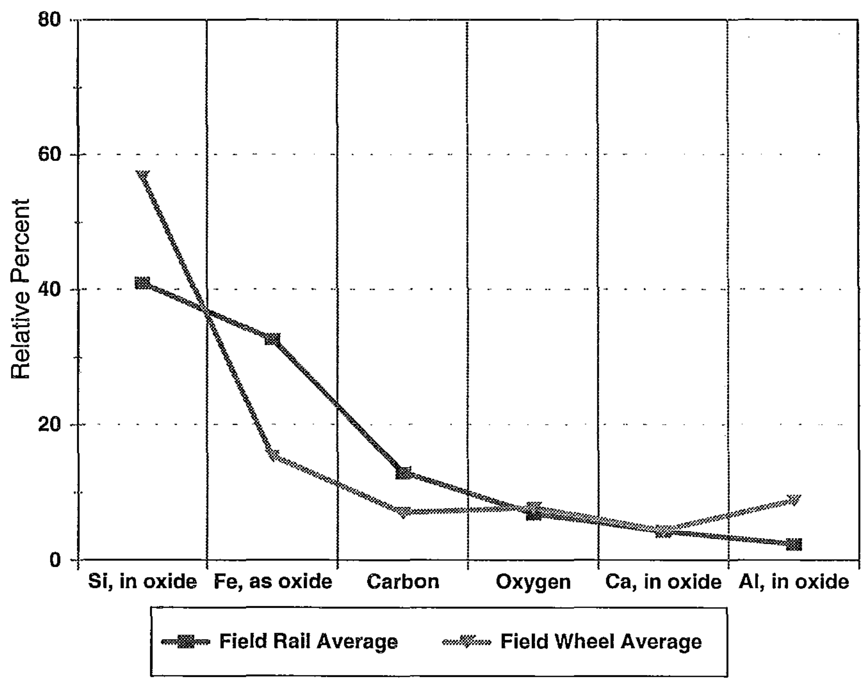


Figure 13. Average Wheel and Rail Film Composition

Additional analysis and observations of film results will be discussed in Section 6, after dynamic contact patch testing procedures have been described.

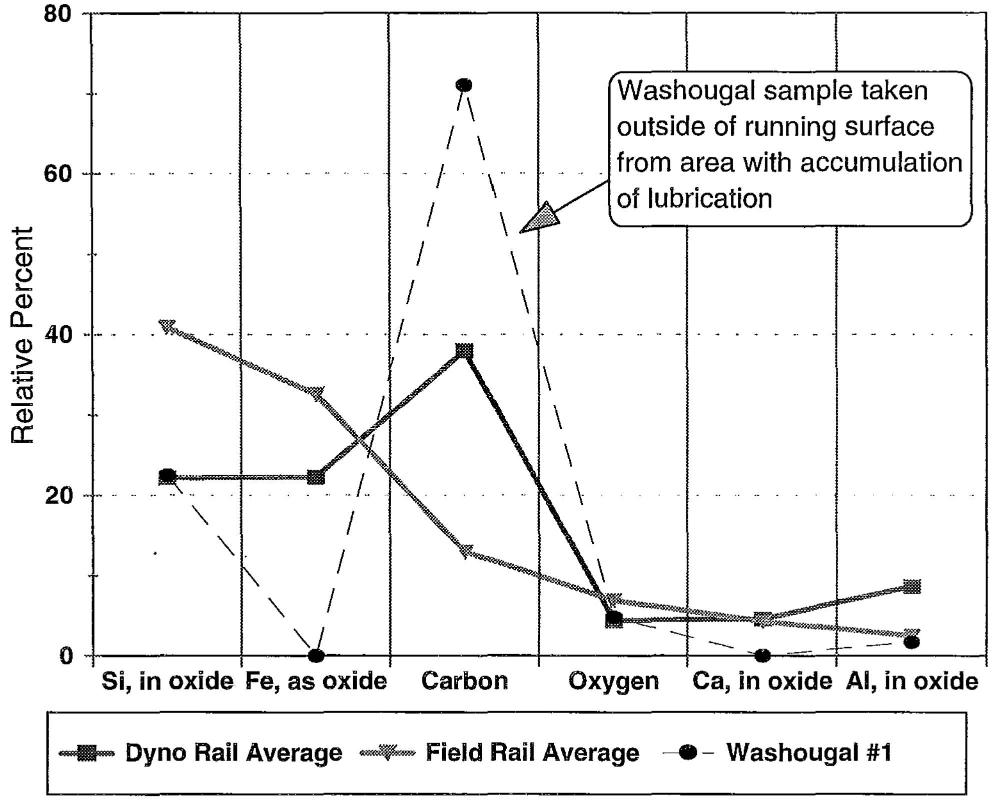


Figure 14. Field Rail Averages Compared to Washougal 1

5.3.4 Conclusions

Both rail and wheel film samples exhibited similar trends in chemical makeup, with silicon in oxide and iron as oxide being the two major components of the film composition. Rail samples had a higher iron as oxide content and a lower silicon in oxide content than the wheel samples. This is most likely due to the differences in the types of environmental exposure — rails being stationary and wheels rolling.

There were significant differences in carbon and iron as oxide in rail samples collected at a heavily lubricated area located well away from the running surface (Washougal 1). Rail samples did exhibit higher variations in individual material makeup than the wheel samples but remain relatively consistent in their makeup.

6.0 DYNAMIC CONTACT PATCH RESISTANCE

The source of the materials that makeup the composition of films was investigated to determine if mitigation techniques to reduce or eliminate LOS were feasible. By identifying a portion of the railroad operating procedures that is controllable and is also contributing to the LOS film, a mitigation technique or procedure could then be proposed.

These operating procedures can include brake shoe materials, braking procedures, rail lubrication, use of locomotive sand, leaking car lading or other controllable conditions. Environmental factors such as blowing dust and dirt, leaves, moisture, and oxidation were also considered; however, it would not be feasible to try and control all these factors.

Efforts were made to replicate films, as identified by field testing, in a controlled laboratory environment by independently varying parameters such as contact pressure (force), brake shoe type, braking activity (cycle, force), speed, lubrication (conventional calcium based 11% graphite track grease), and contaminants commonly found in the field. Film samples were taken after selected runs to compare with samples previously obtained in the field to determine if the same type of films were being developed.

The test was conducted at the former Chicago Technical Center (CTC) on the Railroad Wheel Dynamometer. The testing was performed during three separate visits immediately following AAR certification testing of three different manufactured brake shoe products from May, 1995 through June, 1995. For the purpose of this test, brake shoe manufacturers and materials are proprietary and are therefore not identified. Two to three days were allowed for each test.

6.1 INSTRUMENTATION

a special insulating sleeve was fabricated for the dynamometers car wheel axle for the purpose of electrically isolating the signal between the car wheel and rail wheel. The material was 0.030-inch Teflon sheeting (Figure 15). The sheeting was ordered with one side acid-etched so that it could be bonded to the axle using a high strength adhesive. The car wheel was also "sandwiched" between two BAKELITE rings to insulate the car wheel at the hub.

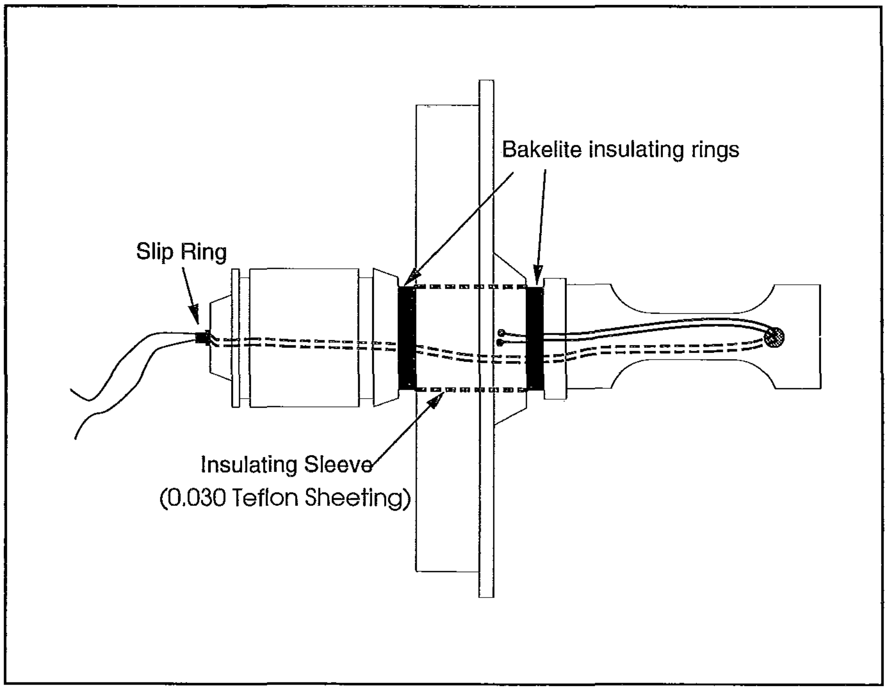


Figure 15. Car Wheel Setup

A locking key was also fabricated from BAKELITE material. This key (not shown in the figure) was positioned within the axle and locks through the wheel to keep the wheel from slipping as it rotates. Two wire leads were attached to the hub of the wheel and routed through the inside of the axle to the multi-channel slip ring. a Kelvin bridge four-wire measurement method was used (Figure 16). This measurement method is designed to negate lead resistance in order to accurately measure the expected low resistance of the contact patch.

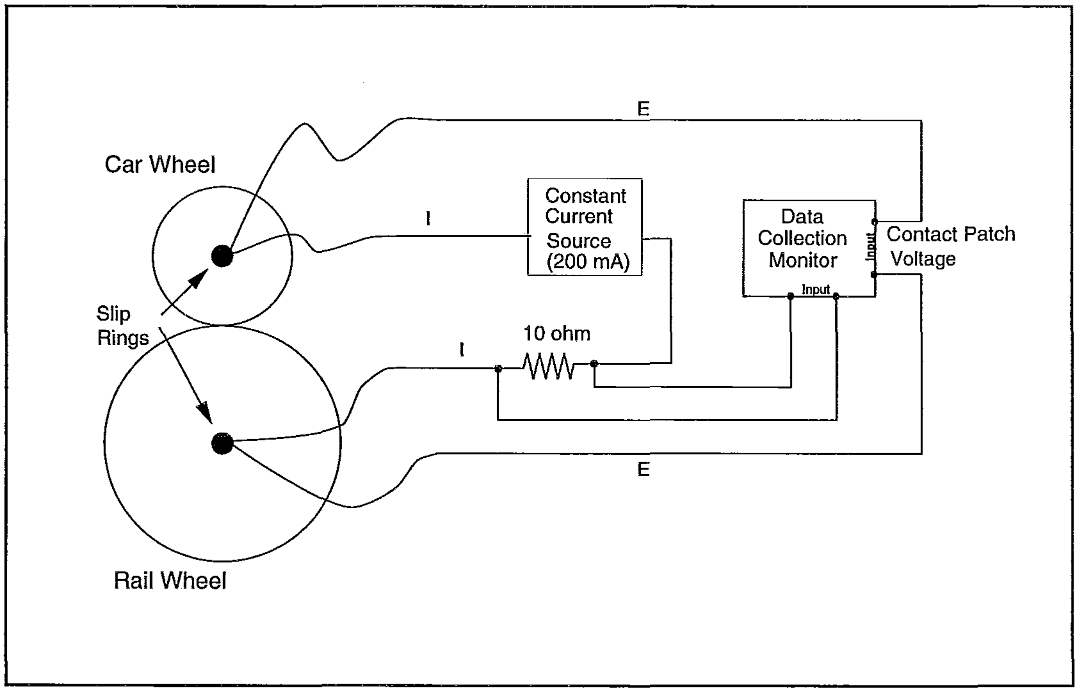


Figure 16. Kelvin Bridge/Data Collection System

Figure 17 shows both the car wheel and track wheel. Bond wires were welded at various locations from the rail to the rim, and from the rim to the stub axle to assure a good electrical conductivity path. Two wire leads were also connected from the slip ring mounted on the track wheel to complete the other half of the Kelvin bridge used for obtaining low potential resistance measurements. The desired measurement of the test was the contact patch resistance between the two surfaces of the car wheel and the rail of the track wheel. The current (I) and contact patch voltage drop (V) was measured. The contact patch resistance (R) was calculated as R = V/I.

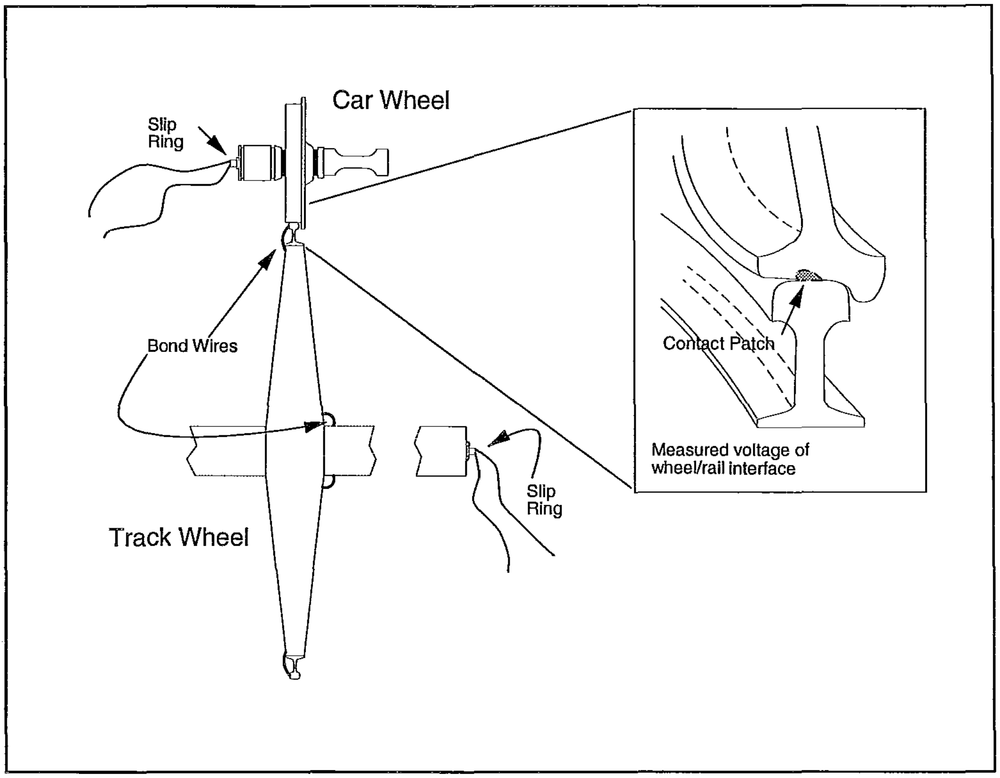


Figure 17. Railroad Wheel Dynamometer Test Setup

6.2 DATA ACQUISITION

The data collection system was set up to allow for real time viewing of the data, both measured voltage drop across the contact patch and calculated contact patch resistance (refer to Figure 16). This allowed the personnel conducting the test to make timely decisions as to when a resistive film was being developed, when film samples should be taken, and when test sequences should be discontinued. Along with voltage and current, other measurements monitored were brake force, wheel tread temperature, speed, and wheel load. Data was collected on a Toshiba 5300/386 laptop computer using Snap-Master Version 3.0 1991-1994 HEM Data Corporation acquisition software. The data was collected at 10 samples per second (10 Hz).

6.3 TEST CONDUCT

Because of the unknowns involved in this type of testing, namely, the method of developing and replicating resistive films, many of the decisions about the timing, degree and frequency of measurements, and amount of contaminants were made during each run. A full matrix of test runs was performed only for the first brake shoe test (Test A). Observations made during the first test sequence helped dictate the test procedures followed in the subsequent test series (Test B and Test C).

It is also important to note that only two of the brake shoe types were available for "full conformal contact" testing, due to a scheduled move of the dynamometer to TTC. The shoe used in the first test (Test A) was new and had not yet been worn to the point of full conformal contact. Figure 18 is an exaggerated illustration of the difference between conformal versus non-conformal contact of the brake shoe on the running surface of the car wheel.

6.3.1 Test A / Brake Shoe No. 1

Test A was performed from May 1 through May 4, 1995. Immediately following the data collection and instrumentation setup, the first test run was performed before cleaning the track or car wheels. The surface of the rail was extremely contaminated as a result of approximately 1½ years of inactivity (of the track wheel ONLY). It had been approximately that long since the track wheel had been engaged with the car wheel. During brake shoe certification tests, the track wheel is not engaged. Consequently, a fair amount of debris from the previous 1½ years of dynamometer operation had deposited on the track wheel from above. In addition to the accumulation of debris, rust had developed on the track wheel as a result of water which is used to help cool the car wheel during certain test operations.

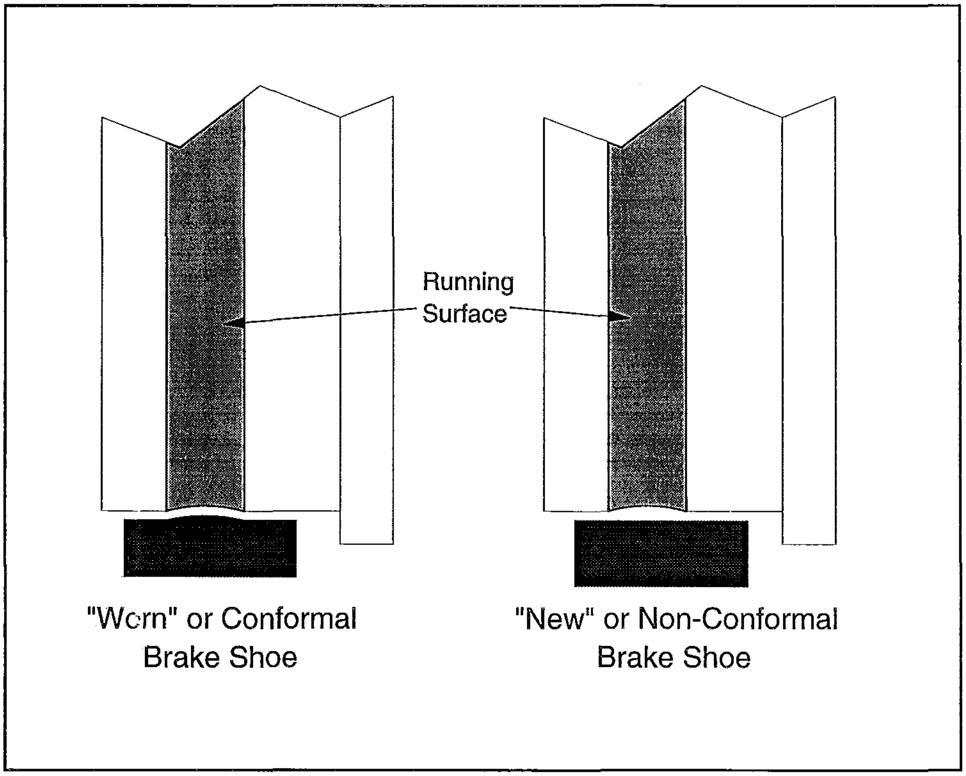


Figure 18. Conformal vs. Non-Conformal

Mechanical cleaning of the track wheel was performed using a hand held grinder with a heavy wire brush. This was necessary to remove the heavy build-up of rust and debris previously described. Both wheels were then cleaned with an acetone cleaning solvent. Initial test runs were made of clean/dry car and track wheel of various speeds and wheel loads.

Following the "clean" runs, each of the parameters and contaminants was added individually to examine each effect independently. The following is a list of the parameters and contaminants evaluated:

Wheel Load (6,300 lbs. - 32,000 lbs.)

- Speed
- Braking Pressure/Cycle
- Lubrication
- Locomotive Sand
- Other Contaminants (soil, leaves, water, etc.)

Lubrication was added to the track wheel with a paint brush directly to the top of rail as the track wheel was being operated at slow speeds. A couple of applications were also performed at higher speeds. The method of adding locomotive sand, and other contaminants, was done by using a make-shift funnel with a hose positioned as close to the wheel/rail interface as possible. Film samples were taken following select runs. A detailed log of all runs and description of conditions is included in Appendix C. Certain run sequences are missing. These numbers were skipped when computer failure and other anomalies required a test run to be aborted. They are not part of the database.

Again, it should be noted that the brake shoe used for this first test series was a new shoe and had not yet worn conformally to the profile of the car wheel. Figure 19 shows visible evidence of the non-conformal band. This photograph was taken following Run 25 as described in the appendix.

6.3.2 Test B / Brake Shoe No. 2

Test B was performed on May 26, 1995. This test was conducted following AAR certification test of brake shoe No. 2. Preliminary test condition decisions were made based upon observations derived from Test A of runs where there was a measurable resistance. The conditions where there was notable resistance measured were used as guidelines in an attempt to re-create similar results in subsequent tests. However, these observations and decisions were based strictly on observations of the real time data of the first test, as results of the film analysis had not yet been provided.

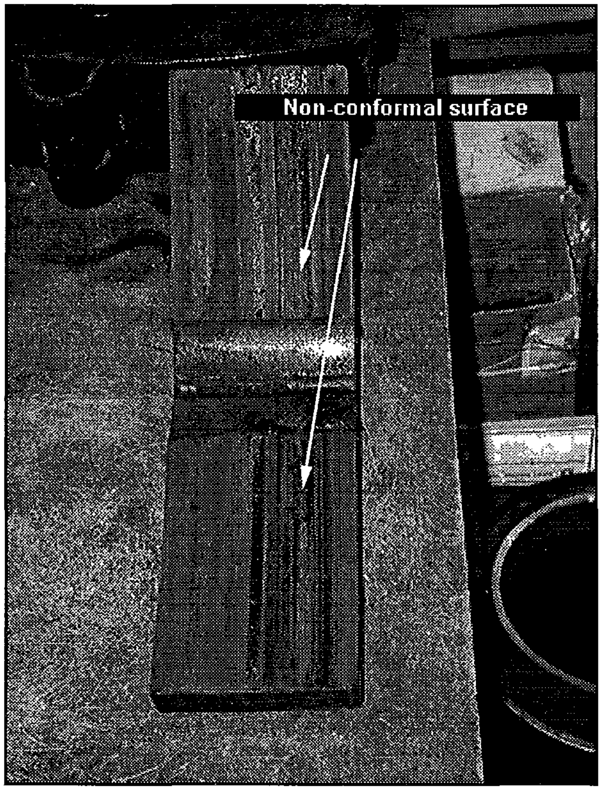


Figure 19. Brake Shoe No. 1

Results of Test A were not able to be repeated during this second test series. Contrary to the first test, brake shoe No. 2 was a worn (conformal) brake shoe (refer to Figure 18) and had previously completed AAR certification testing and was worn to the profile of the car wheel. An effort was made to duplicate a non-conformal contact of the brake shoe during latter runs with the car wheel running surface. This was physically done by grinding a groove on the brake shoe in alignment where the running surface of the car wheel was positioned.

The contaminants were added in a different manner in tests series B and C. Sand, dirt, leaves and other debris were mixed with lubrication. The lubrication served as a binder to assure that the contaminants were being worked into the interface of the wheel and rail. The mixture was then applied to the track wheel rail surface using a paint brush.

6.3.3 Test C / Brake Shoe No. 3

The procedures and test sequences run of Test C were similar to those performed during Test B. Again, a groove was ground into the brake shoe to simulate a non-conformal contact. And again, results of Test A could not be repeated during the third test series.

6.4 ANALYSIS

a method of evaluating and interpreting the data was established based on criteria set by the Ad-Hoc Track Circuit Parameter Task Force Committee. In order for a resistance measurement to be considered as LOS, one or both of the following conditions must have existed (Note: Data was collected at 10 samples per second):

- Continuous resistance greater than 0.06 ohms for 10 or more consecutive samples.
- Any time 0.06 ohms is exceeded for five samples within 1 second for each second during a moving 2-second window. The 2-second window is evaluated every 0.1 seconds, then incremented for 0.1 seconds, then re-evaluated. This process is repeated for the entire run.

Data plots of each run from all three tests is included in Appendix D. Each run includes data plots of the calculated resistance measured between the wheel and rail. A 0.06 ohm threshold line is drawn. The second plot is the criteria signal showing a LOS (signal level 1) or no LOS (signal level 0), based on the committee guidelines stated above. The final two plots are of the measured wheel/rail velocity and braking activity. The evaluation routine does not care what the level of resistance is, only if it exceeds the 0.06 ohm threshold of the conditions previously stated. Figures 20 and 21 are a sample of Runs 19A and 23A, respectively (the subscript A denotes results from Test A).

Figure 20 shows an example of a run with no LOS as established by the previously stated criteria. Although there is intermittent values of resistance that exceed the 0.06 ohm threshold, based on the evaluating criteria, the criteria signal stays "low" for the duration of the run. The conditions of this particular run were added lubrication, no braking activity, accelerate to 40 mph and coast with a wheel load of 24,000 pounds.

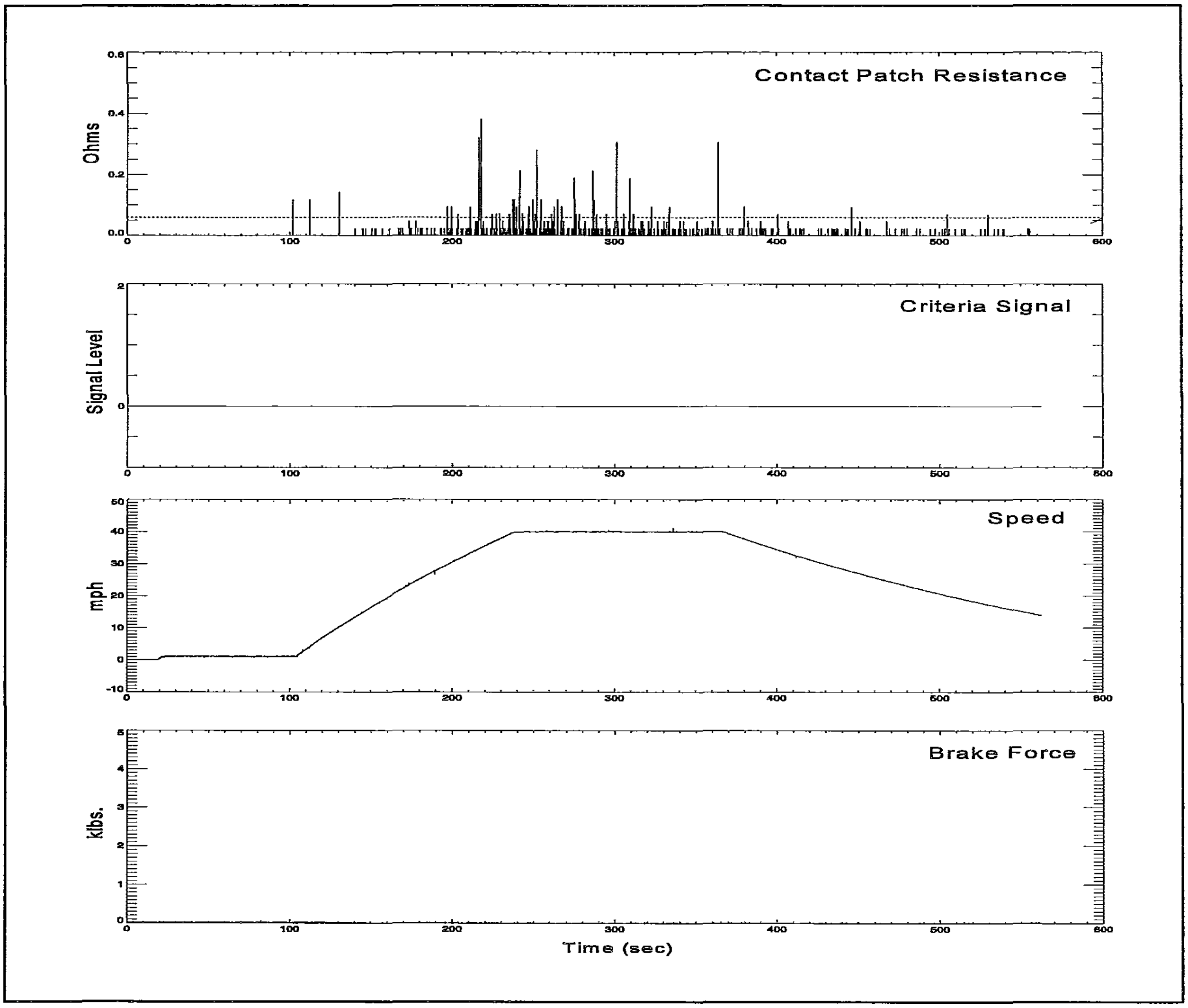


Figure 20. Run 19A / Example of No Loss of Shunt

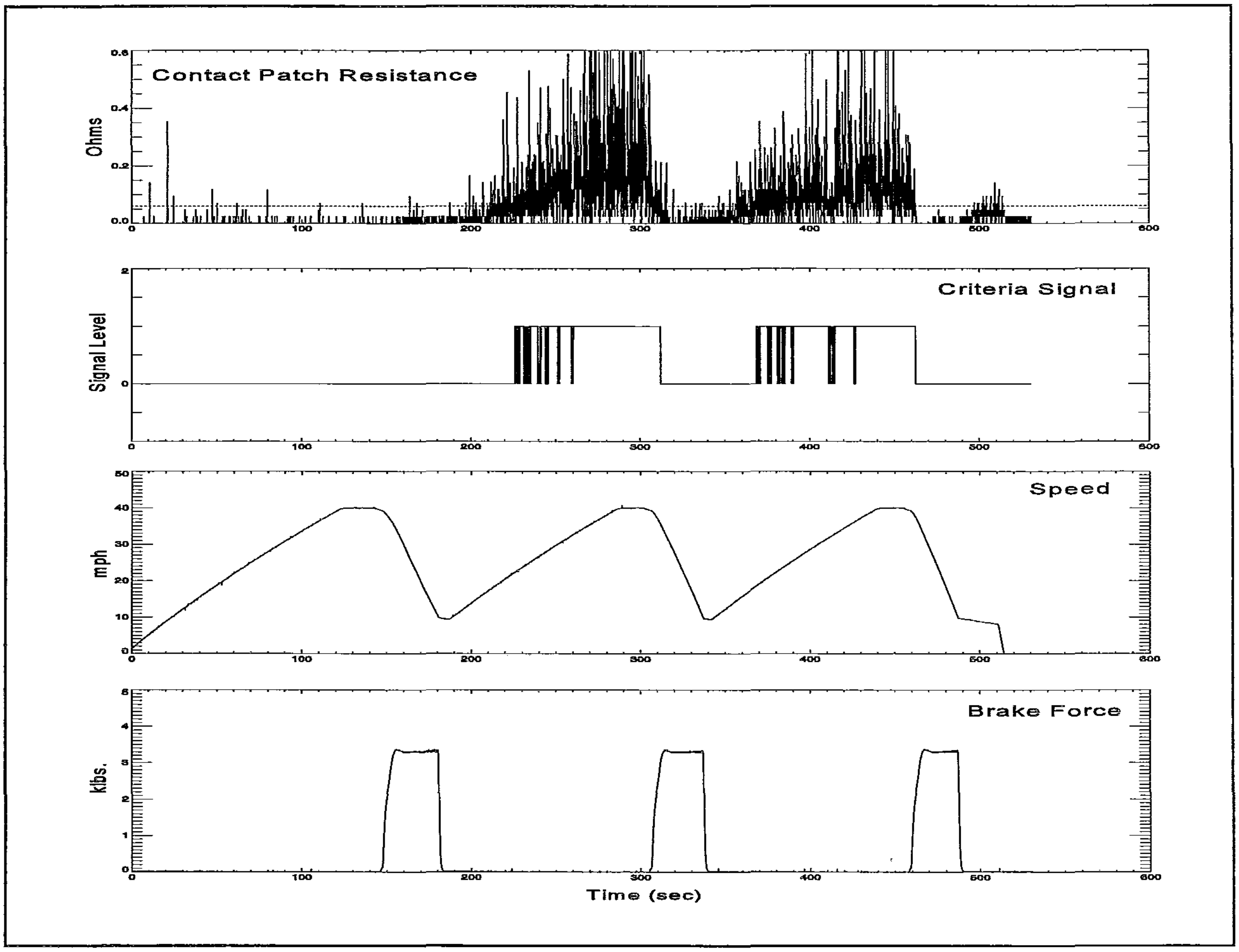


Figure 21. Run 23A / Example of Loss of Shunt

Figure 21 shows an example of LOS, both intermittent and sustained. The track wheel had a presence of lubrication from previous runs. Excess lubrication of the track wheel was hand wiped with a clean cloth. The run was then conducted by cycling from 5 mph to 40 mph using a 3,300-pound brake application. The criteria signal goes "high" during the second and third acceleration cycles, which is where the threshold of 0.6 ohms is exceeded.

6.5 RESULTS/CONCLUSIONS

Select runs of the wheel dynamometer test exhibited LOS patterns resembling island voltage time history plots that were previously seen in the revenue service environment. These occurrences of LOS were difficult to control, sustain, or repeat. Film samples taken from the laboratory test were different than those collected from numerous field site locations, both physically and in degree of chemical composition. The highest level and most frequent shunt loss occurred during the first test series utilizing a non-conformal brake shoe (Test A). Efforts to duplicate these same LOS occurrences in the subsequent test series of B and C were unsuccessful.

The runs in test series A where LOS was observed were repeated in test series B and C. Although there were similar LOS patterns during test series B and C, the test conditions were different. The only variables that changed between the running of test series A, B, and C were:

- Test series A was run with a non-conformal brake shoe where test series A and B were run with conformal brake shoe.
- The method of adding contaminants from series A to series B and C.

Test series A was performed with a new brake shoe prior to the AAR Brake Certification tests and therefore had not been fully "broken in" and was non-conformal to the car wheel. Test series B and C were performed with worn brake shoes after brake shoe certification and were fully conformal with the track wheel when shunting tests were performed.

Contaminants were applied to the track wheel by an unconventional method. In test series A, lubrication was applied to the track wheel with a paint brush while the other contaminants were introduced near the car wheel/track wheel interface. This method made it difficult to control the amount of contaminants being introduced. During test series B and C, the contaminants were mixed in with the lubrication and applied directly to the track wheel with a paint brush.

Analysis and comparison of film samples taken in the field and during the dynamometer testing suggests that films developed in the lab are both physically and chemically different than those obtained in the field. The results of the film samples collected during the dynamometer test show no instances where all components can be correlated with any given field samples, with the exception of lower percentages of oxygen, calcium in oxide, and aluminum in oxide. There was a large variability of the major components of silicon in oxide, iron as oxide, and carbon (Figures 22 and 23).

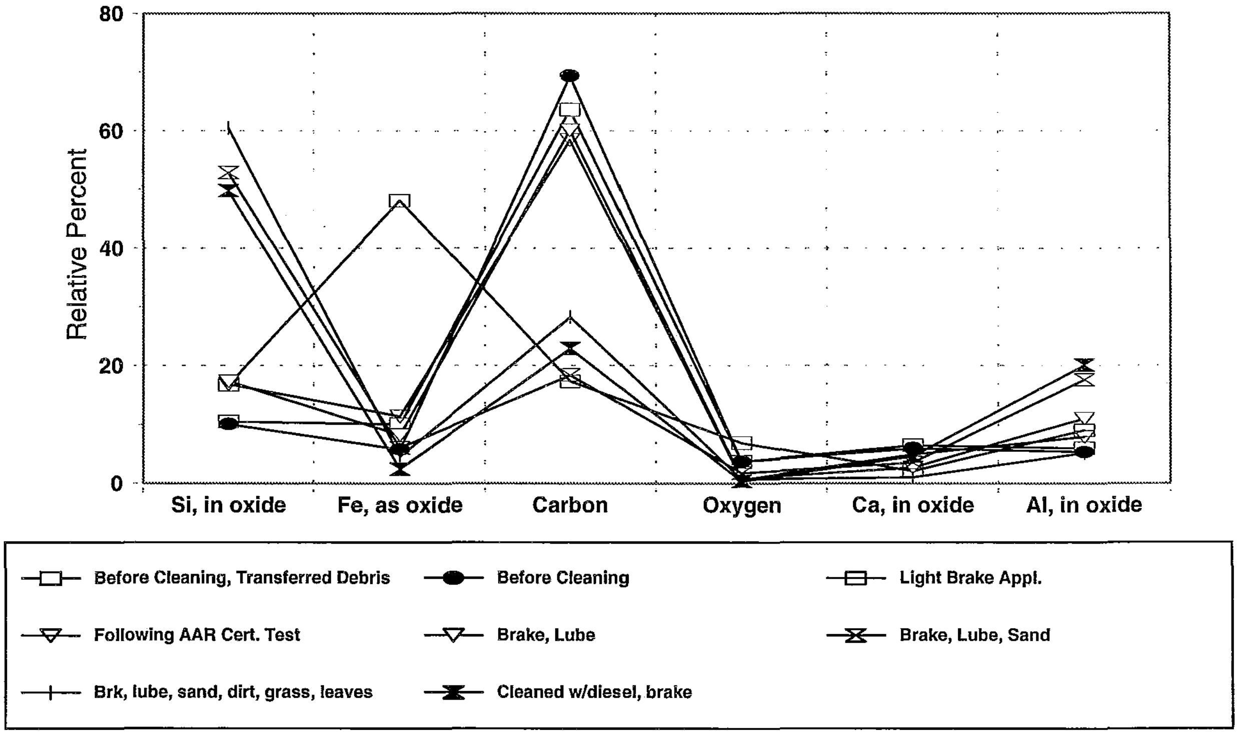


Figure 22. Dynamometer Car Wheel Film Sample Results

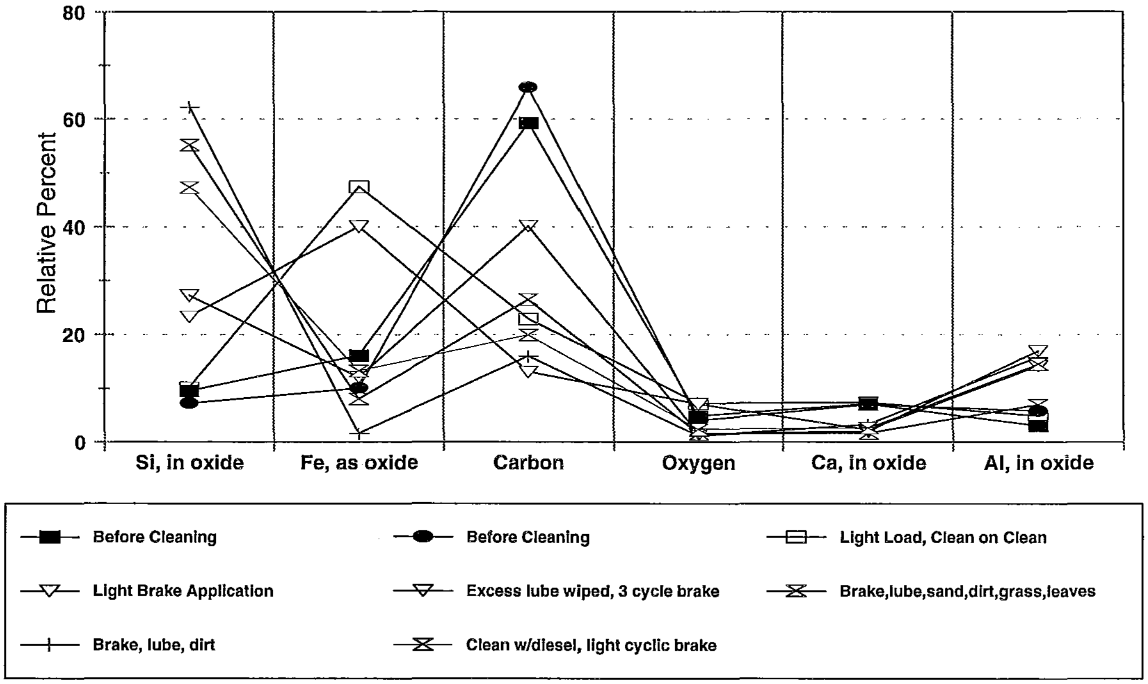


Figure 23. Dynamometer Track Wheel Film Sample Results

In addition, the physical characteristics of films, as noted by engineering personnel gathering the samples, were significantly different between field and laboratory. This was noted by a contrast of effort required to "scrape" the samples from the surface. The samples collected in the field required more effort and were, at times, extremely difficult to remove from the rail surface than those collected in the lab. The field samples collected were dry powdery substance whereas the lab samples were more tacky, likely due to the amounts of lubrication applied, difference in operating environment, and dwell-time between train passes.

It is important to note that an excessive amount of any of the applied contaminants, either separate or in combination, can cause immediate or temporary LOS.

The differences may be due to the effects of extended operational (lubrication practice, locomotive sanding, braking, and time between trains) and environmental exposure (wind blown contaminants, sun, cold, and oxidization) on the development of these films. In the field, contamination of the wheel and rail occur in random amounts and at random intervals and were difficult to simulate, particularly environmental, in a laboratory environment given the time and budget constraints on this test.

Although conditions were created in a laboratory environment that reduced shunting performance, the LOS mechanism in the laboratory could be different from that in the field. And while LOS conditions did occur as a result various combinations of speed, braking, wheel/rail pressure and added contamination, the physical and chemical differences of the films do not allow recommendations for effective mitigation techniques to be offered at this time based on the results of this test.

7.0 RECOMMENDATIONS

7.1 CONTACT PRESSURE/RESISTANCE RELATIONSHIP

There is an inverse relationship between film resistance and contact pressure (refer to Section 5.2.2.1). The AAR recommends further research in this area to gain a better understanding of this relationship in a laboratory environment. If this relationship is determined to be significant, a different device for measuring film resistance in the field would need to be developed to determine the effectiveness of mitigation techniques resulting from the research.

7.2 DYNAMOMETER TESTING

Although films that are representative of what exists in revenue service were not able to be developed during the initial testing on the dynamometer, it is felt that with extended running, films more like those seen in the field could be developed. Additional testing to determine relationships between contaminants and resulting LOS, films, and subsequent mitigation techniques is recommended.

Comments from individual task force members of the wheel dynamometer test are included in a Appendix E.

ACKNOWLEDGMENTS

Technical direction and review of results for this program were performed by the Track Circuit Parameters Task Force. This group is comprised of railroad, supplier, FRA and AAR personnel. The Task Force was chaired by Mr. Jim Murphy of the Union Pacific Railroad. Task force members provided significant assistance during all phases of testing, including coordination of field support, data analysis, and review of final results.

Task Force Members

Jim Murphy	UP	Bill Bryce	Conrail
Manuel Galdo	FRA	Tom Rose	Amtrak
Jim LeVere	BNSF	Chuck Johnson	NS
Max French	BNSF	Jim Moe	Safetran
Terry Therion	CN	Forrest Ballinger	Harmon
Mel McNichols	CSXT	Wayne Etter	AAR
Phil Miller	NS		

Field support at each monitoring site was an important requirement during this test. Each railroad designated personnel to coordinate installation, calibration, and follow-up inspections. Special thanks go to the following people:

Butch Raczka	Conrail	Joe Miller	UP
Forest DeVries	BNSF	Darwin Glinsman	UP
Dean Cook	BNSF	Mike House	Safetran
Jack Witcher	NS		
Mike Manella	CN		

Data collection software for field sites was desgined by Salient Systems, dublin Ohio.

APPENDIX A

Wheel/Axle/Wheel Resistance Recommendations

Conclusions and Recommendations for Wheel to Wheel Resistance Operating Performance

Consideration was given to the maximum wheel-to-wheel resistance allowable in a new specification to be written to cover wheelsets of rail vehicles. In the past, there have been no requirements for this, as solid axle wheelsets always have exhibited such a low resistance that it was insignificant in the total shunting picture.

However, with the advent of split or stub axle wheelsets, it is necessary to specify a maximum allowable wheel-to-wheel resistance to assure that the wheelset will properly shunt the track. This obviously has to be less than the 0.06 ohms (60 miliohms) used as the standard for track circuit shunt sensitivity setup in North America.

Exactly how much less is open to question. It is virtually impossible to approach the problem on any other than empirical basis because the total shunting resistance of a wheelset includes the wheel-to-rail resistance which has proven to be highly variable. However, a number of resistance measurements have been made on conventional solid axle wheelsets and the values of wheel-to-rail shunting resistance under favorable conditions is generally known. Thus it is possible to develop a maximum wheel-to-wheel resistance figure that has some meaning in fact and precedents in experience if not in absolute quantitative terms.

In discussion, it was agreed that any resistance value which would likely satisfy the mechanical fraternity would be too high for the signal fraternity to accept. Using slip rings and brushes or metallic contact through the bearings would almost certainly result in a wheel-to-wheel resistance large with respect to the 0.060 ohm total shunt standard now used. Consequently, efforts were directed toward establishing a maximum allowable resistance value which would not adversely affect shunting using the current 0.060 ohm standard.

In the measurements made by in the course of the Track Circuit Parameter (TCP) working group activities, maximum wheel-to-wheel resistance for a solid axle wheelset were in the tens of microohms. Thus they were very small with respect to the 0.060 ohm shunting standard. Also, experience of the working group members was that wheel-to-rail resistance was well under 0.060 ohms under normal clean wheel-clean rail conditions. Values under 10 miliohms (total for both wheels) are typical. Thus, the .060 track circuit adjustment standard affords a degree of a safety factor for increased wheel-rail contact resistance due to dirt, rust or other semiconductive films.

It was the conclusion of the working group that this safety factor should not be significantly eroded by introducing a wheel-to-wheel resistance which was large with respect to the normal wheel-to-rail resistance. Also, it should be relatively insignificant with respect to the 0.060 ohm track circuit adjustment standard.

After considering a range of values from 1 to 50 miliohms, the group decided on a maximum of 6 miliohms (0.006 ohms). This is well in excess of the values measured for conventional solid axle wheelsets, so does not impose an unrealistic value that would be difficult to meet using current technology. This also is 10% of the track circuit adjustment standard so would be fairly insignificant in determining performance of a present track circuit/wheelset combination.

APPENDIX B

OGI Report

INVESTIGATION OF SURFACE FILMS ON RAILS AND WHEELS
for the
Association of American Railroads

by
Milt Scholl and Paul Clayton
Oregon Graduate Institute for Science and Technology

RAILS AND WHEELS EXAMINED:

Following received and examined in laboratory.

Buford Site A. Rail from TTC - D.C. resistance measurements made, sectioned, examined in SEM and by FTIR, also took scrapings for examination in TEM. Used to try methods of sample collection and for examination methods/techniques. (all done)

Sterling Site H. Rail from TTC, from revenue service. D.C. resistance measurements made, took scrapings for examination in TEM and in SEM . Used to try methods of sample collection and for examination methods/techniques. (all done)

Field rail samples, Burlington Northern revenue line, Washington. Took scrapings from rail when possible in areas identified by RCL meter and probe (Scott Gage, AAR). These examined in SEM and TEM.

From crossing east of Bonneville dam between two curves at Cooks Crossing. Samples **BN1**, **BN1-A**, and **BN4-A**. Samples poor due to high winds in area blowing away scrapings.

From crossing near Washougal on main line, tangent track. Samples **WA5-1**, **WA5-2**, **WA5-3**. Good samples, rail had very thick films. Field side had very thick, loose films. On gage and running surface there was very adherent films. Sample WA5-1 from the region of the thick film, while WA5-3 was from the center of the rail head.

Wheel samples from Burlington Northern Wheel Shop, Vancouver, WA. Samples taken from areas identified by RCL meter and probe (Scott Gage, AAR). Examination in SEM (done) and TEM.

> **UP Car Wheel**, UP218228, covered hopper car. Scrapings from wheels set already removed from car.
>
> **BN Car wheel**, BN624136, box car. Scrapings from wheel set already removed from car.

Wheel and brake block samples from AAR, Chicago. Examination in SEM (done) and TEM.

> **AAR Brake Wheel**, section from brake block rig test. Wheel re-machined flat for test. Scrapings taken from surface. This was wheel no. 65129, run under a continuous braking load of 60 HP at a speed of 40 mph.
>
> **AAR Brake Block, Surface**, scrapings taken from brake block used on the Brake Wheel. Samples taken from the surface contact region.
>
> **AAR Brake Block, Bulk**, scrapings taken from brake block used on the Brake Wheel. Samples from the un-affected bulk material.
>
> **AAR Car Wheel**, section from a wheel which had been in revenue service. Scrapings taken from surface.

Field wheel samples from North Platte, NE, Union Pacific wheel shop.

> **NORX 2488 L3**, auto transport car, scrapings from wheel already removed from car, axle 3, left wheel.
>
> **NORX 2488 R3**, auto transport car, scrapings from wheel already removed from car, axle 3, right wheel.
>
> **UP 79760**, unknown car type, scrapings from wheel already removed from car.

Wheel 57990, and Wheel **47166**, Wheelset from unknown car, scrapings from wheel already removed from car.

Field rail samples from Gothenburg, NE test site, areas identified by RCL meter and probe (Scott Gage, AAR)

North Rail, Goth., north rail of north trackset. Westbound traffic, many coal empties.

South Rail, Goth., south rail of south trackset. Eastbound traffic, many full coal trains.

Field wheel samples from Lincoln, NE, Burlington Northern rip shop in main yard. Primarily rolling stock repair with considerable traffic through shop of cars in immediate use.

KCLX 91054 L1, from aluminum 200t coal car, axle 1, left wheel. Car in for brake system work.

KCLX 91054 R1, from aluminum 200t coal car, axle 1, right wheel. Car in for brake system work.

BN 447453 L1, from covered hopper grain car, axle 1, left wheel. Car in for coupler replacement.

BN 447453 R1, from covered hopper grain car, axle 1, right wheel. Car in for coupler replacement.

Field rail samples from Sterling, NE test site, areas identified by RCL meter and probe and sent by Scott Gage, AAR.

Sterling #1, #2, #3, #4.

Field rail samples from Buford, Georgia. Sent by Scott Gage, AAR.

Buford #5, #6, #7, #8, #9.

Field rail samples sent by Scott Gage, from near a crossing, Santa Fe RR.

Sample A1, A2, A3, A4

EXPERIMENTAL PROCEDURE

OGI Resistance Measurements

Using high resolution d.c. multimeter (7 digit) with simple probe. Later modified a rail profile gage to hold a test lead (insulated from profile gage). The profile gage made it possible to advance the probe across the rail head in repeatable increments. The probe itself was a polished brass tip with a radius of about 0.05 inches. A 100 gram load was applied to the probe during measurement. The probe was lifted from the rail surface between measurements. It was found that sliding the probe on the surface between measurements left a layer of brass on the surface which affected the resistance measurement. Repeat traverses were made to yield an average resistance. A ground lead was attached to the rail web, about 6 to 12 inches away from the measurement area. The measurement area was carefully cleaned with ethanol and dried thoroughly before resistance measurements were made. Resistance was measured with respect location on the rail head and plotted respectively.

Scrapings from Rail

Initial exploratory work was performed on rails from Sterling Site H and Buford Site A. Samples were taken by sectioning the rail to obtain a small specimen with the film on it. Because of the impossibility of doing this in the field, a method for scraping a film sample from the rail head was developed. Basically a clean, sharp razor blade is used to scrap the rail head at a very low angle. The material scraped off tends to collect on the razor blade and rail or wheel surface. Some of this was collected on a sticky carbon dot for SEM/EDS analysis. Samples and the razor blade were then stored in clean plastic vials.

SEM/EDS work

The scrapings on the sticky carbon dots were sputtered with a few angstroms of Au-Pd to produce a conductive surface on the debris, to minimize specimen charging problems in the SEM. Samples were examined in the SEM at a 10 kv accelerating voltage. A Link EDS (energy dispersive x-ray) system was used to collect x-ray spectra produced due to beam interactions between the sample and electron beam. Analysis was at a constant beam voltage and beam diameter was adjusted to maintain count rate between samples. Due to the time involved to standardize the detector and peak analysis software for the sample configuration and the number of samples to examine; the EDS data was acquired and then a simple peak measurement/normalization done. Correction for atomic number, atomic weight, and fluorescence (ZAF) were not made to the data. Some samples will be analyzed with such corrections at a latter date. At least three diverse areas on each sample were examined to help account for possible chemical inhomogeneity.

TEM/Electron diffraction work

Since the samples were in the form of a very fine dust, the probability was high that particles thin enough for electron penetration in the transmission electron microscope could be found. Dust/debris which remained on the razor blade were placed on copper grid coated with a continuous carbon film and placed directly into the TEM. The small beam size of the TEM (300 Å) enabled composition measurements in extremely small areas of each particle. Composition variations were also mapped for some of the particles. Micro-diffraction of the electron beam was used in crystalline areas for analysis of structure, covering an area of about 1000 Å. Once the diffraction patterns were indexed, the indexed results were compared to a electron diffraction pattern database for identification of the phases or phases present.

RESULTS

SEM/EDS Analysis

The SEM/EDS results are shown in the accompanying table. It is assumed, and there is little evidence to doubt the assumption, that the elements listed in the table are in the form of oxides. Though the amount of oxygen appears minimal in the table, in actuality once all the corrections have been applied to the data, it is actually a substantial amount. Thus, 'free' iron or aluminum was not observed. Backscattered imaging of the samples, which images based on elemental composition, showed that the scraped material was fairly uniform, at least at magnifications of 1000 to 2000 times. The iron is most likely present in the form of an iron oxide, Fe_2O_3 or Fe_3O_4. The aluminum, calcium, and silicon are combined as an oxide, silicate, or a glass in the films. Silica and alumina, in either crystalline or glassy states possesses quite high resistance. Indeed, if the samples were not coated with a conductive layer (such as the gold-palladium) the imaging of the sample in the SEM would be almost impossible due to specimen charging. Electrons from the electron beam need a conductive layer/surface/bulk to be able to flow to ground, otherwise they build or "charge".

Several groups of samples are worth noting. A brake block and wheel were obtained from AAR. The brake had been run against a machined wheel surface while the wheel ran at a constant speed and load. The film on the wheel, the brake block surface, and unaffected material from the brake block bulk, were all examined. The film on the wheel showed a high amount of silicon, some aluminum, some calcium, and some iron, and little carbon (Figure 1). The surface of the brake block showed an equivalent composition with less iron and more aluminum. The brake bulk though, showed little iron and a very high amount of carbon. It is surmised that the brake material is bonder with a carbon based binder, which consequently shows in the EDS spectra. The surface of the brake block has essentially been baked, and much of the carbon compounds volatilized. The presence of the calcium in the wheel film was somewhat of a mystery though, until a closer look, and analysis, was made of the brake block material. The brake block is a composite of several materials bound together with a carbon-based binder. Among the individual materials found in this composite were pure silica particles (spectra showed only silicon and oxygen) and numerous glass fibers of a aluminum, silica, calcium glass (spectra only showed aluminum, silicon, calcium, and oxygen). Thus it is highly likely that the calcium, silicon, and aluminum observed in the wheel film came from the brake block surface. An increased iron content of the wheel film is probably iron oxide (Fe_3O_4) formed by oxidation of the wear debris from the wheel.

The EDS composition of the Washougal rail samples is shown in Figure 2. At this site a film was observed covering a large portion of the rail head and was notable greasy at field side of the running surface, corresponding to sample #1. Sample #3 consisted of film scrapings in the middle of contact band on the rail head. The results show a decrease in the amount of carbon, presumably oils and other hydrocarbons, as the main contact band between wheel and rail is approached. The silicon content is the highest in the contact band as well. This suggests that the processes forming and maintain the film in the contact band between wheel and rail act to exclude or minimize carbon compounds. In initial work on the Buford Site A sample received from TTC, Fast Fourier Infrared Spectroscopy (FTIR) results on rail sample with a detectable film showed no signs of hydrocarbons.

Figure 3 shows the results of analysis of rail samples taken at the Gothenburg, Nebraska site. At this site there were two sets of tracks. The south set carried east bound traffic, primarily loaded coal trains while the north track set carried mainly general freight. The north bound sample showed much more iron in the film, as iron oxide presumably, than samples from the south track set. The south track set also showed more calcium in the film. A source of calcium is the glass fibers in the composition brake shoes typically used. As the east bound trains are approaching crossing in a town, it is likely they are applying some brakes at this point. The westbound trains on the north track set are leaving the town and are not likely applying any brakes.

Rail samples taken from the Sterling, Nebraska site H are shown in Figure 4. The Site H sample, obtained from TTC early in the program shows higher carbon and iron levels than samples taken several months later. While this difference may be due to seasonal effects, some of the variation may be explained by the fact that a rail section was obtained as the initial Site H sample. Through handling, shipping, and simple normal oxidation processes, the nature of the film may have changed. With exception of the initial Buford Site A sample and the initial Sterling Site H sample obtained from TTC, all rail film samples and most wheel film samples were taken from rails and wheels fresh from use.

The Buford film rail samples, shown in Figure 5, show the same pattern and the Sterling samples, with higher iron contents in the early film samples (as iron oxide) and high silicon in later samples.

EDS composition of all rail film samples are shown in Figure 6. It can be seen that generally the film has a high silicon and iron content with some aluminum and calcium as well. Carbon was seen at times as well. The silicon, aluminum, and calcium are believed to be present in the form of a glassy oxide (confirmed by TEM work) while the iron is present as an iron oxide. All these compounds are highly resistive.

The results of 10 wheel film samples are shown in Figure 7. The amounts of iron detected are about half of that observed in rail film samples, however the silicon contents are much high. Additionally substantial amount of aluminum and calcium are present. As these elements are present in the glass fibers of composition brake shoes, it is likely that the wheel films are originating from the braking action. Indeed the film formed on the wheel which only saw braking action (from the AAR Brake Test) is essentially the same composition as films obtain on wheels in revenue service.

TEM/EDS Analysis

Samples for transmission electron microscopy (TEM) were made of film scrapings from the Washougal site, samples 2 and 3; the brake test wheel; the revenue wheel obtained from AAR; the Gothenburg site, south track; the sterling site, sample 3; and the Buford site, sample 8. These are still being examined, however the results thus far reveal the film to be a mixed structure of very small (10-150 Å) crystalline grains in an amorphous glassy matrix. EDS spectra taken in the TEM revealed elemental distributions to have the iron concentrated in the crystalline areas while the amorphous glassy regions, essentially a matrix, were predominantly silicon containing aluminum and calcium. While the EDS detector on the TEM is a windowed detector, incapable of detecting x-rays from light elements, analysis of diffraction patterns from the film fragments were used to get more positive identification of the phases present. Diffraction patterns from the larger crystalline regions were identified to be either Fe_2O_3 and Fe_3O_4, iron oxides, or iron silicate compounds (Fe_2SiO_4). Feldspar, $Fe(Al)SiO_4$, was also identified in the Buford samples. Most of the crystalline regions were iron oxide. The glassy areas did not produced clearly identifiable diffraction patterns, but the observations were consistent with glassy oxide materials.

At this point the there are two probable hypothesis for the film formation. One is that under the pressures and traction forces in the wheel-rail contact zone, materials such as brake block debris and dusts from the roadbed are physically melted and mixed. The other is that under the repeat contact cycles between wheel and rail, the brake debris and trackside dusts are mechanically agglomerated into particles which are continuously broken done and re-agglomerated.

TABLE OF EDS RESULTS

Sample I.D.	% C	% O	% Al	% Si	% Ca	% Fe
Buford Site A, Rail	1.4	7.9	2.1	32.0	1.9	54.7
Buford #5, Rail	0.7	7.4	0.9	45.4	0.7	45.0
Buford #8, Rail	0.8	5.1	1.4	50.8	1.8	40.1
Sterling Site H, Rail	13.8	2.2	1.7	9.4	6.6	66.3
Sterling #1, Rail	1.8	9.4	1.7	32.0	4.5	50.6
Sterling #3, Rail	1.6	5.6	2.3	32.6	2.5	55.4
WA5-1 Rail	71.0	4.8	1.7	22.5	0	0
WA5-2 Rail	16.8	3.9	3.4	49.1	0	26.8
Sample A1	0.4	4.3	1.8	47.9	4.5	41.2
Sample A4	0.4	3.8	0.2	73.9	1.7	20.0
WA5-3 Rail	14.9	6.1	4.0	54.0	3.1	18.0
UP Wheel, UP 218228	13.3	10.7	5.8	61.2	1.4	7.6
BN Wheel, BN 624136	19.7	11.1	10.7	46.0	2.9	9.6
AAR Brake Wheel	14.5	9.3	3.8	55.2	1.4	15.9
AAR Brake block, surf.	11.3	4.3	36.7	43.5	0	4.2
AAR Brake block, bulk	56.2	2.0	15.2	24.0	0	2.7
AAR Car Wheel	14.7	15.0	9.0	42.4	3.0	16.0
NORX 2488 L3	2.2	2.9	17.0	63.8	6.2	8.0
NORX 2488 R3	0.9	6.7	8.3	65.0	2.9	16.1
UP 79760 Wheel	2.1	5.8	10.1	64.4	6.2	7.9
North Rail, Gothenburg	14.1	5.1	5.1	39.1	18.6	17.9
South Rail, Gothenburg	11.5	14.3	1.9	32.5	1.3	39.0
KCLX 91054 L1	0.4	3.8	6.6	58.6	16.3	14.3
Wheel 57990	0.3	7.1	6.2	53.0	4.6	28.9
Wheel 47166	1.8	5.1	10.7	57.4	2.3	22.7

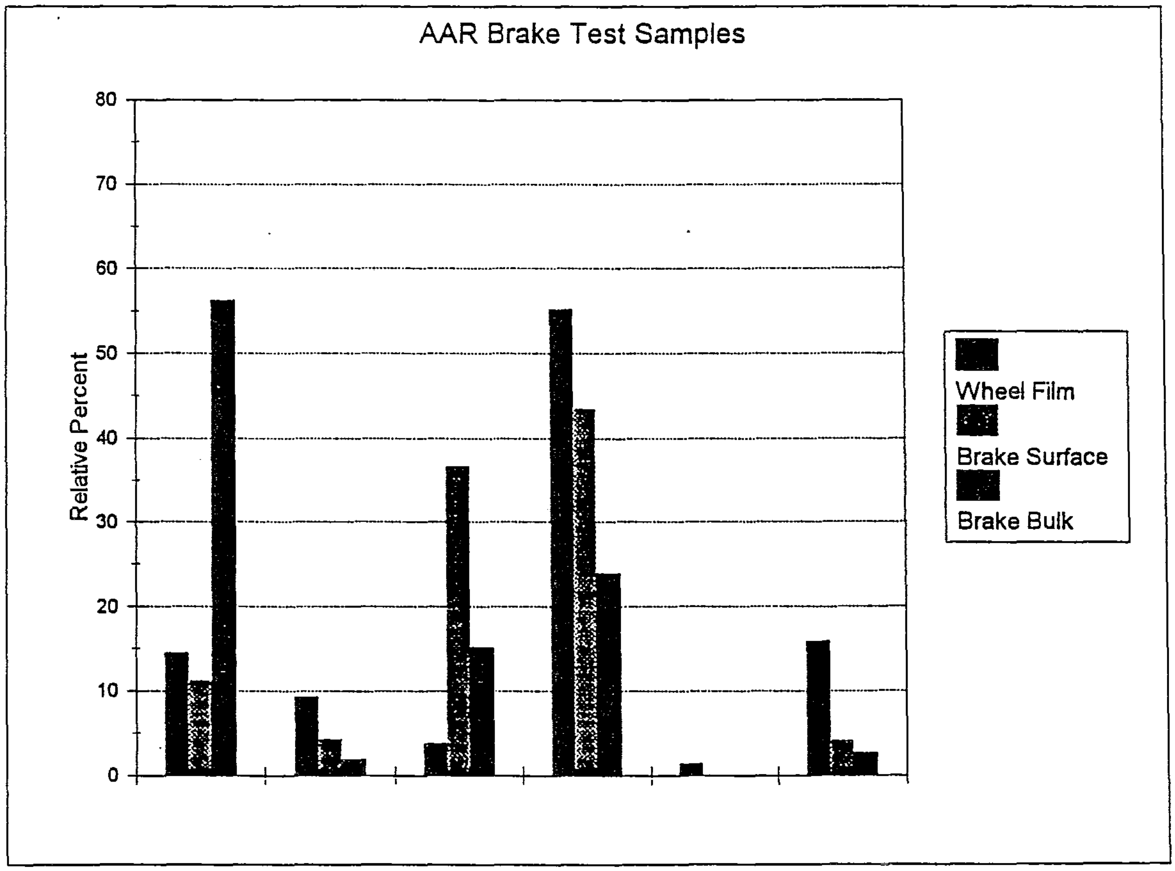


Figure 1. EDS Spectra of AAR Brake Test Samples

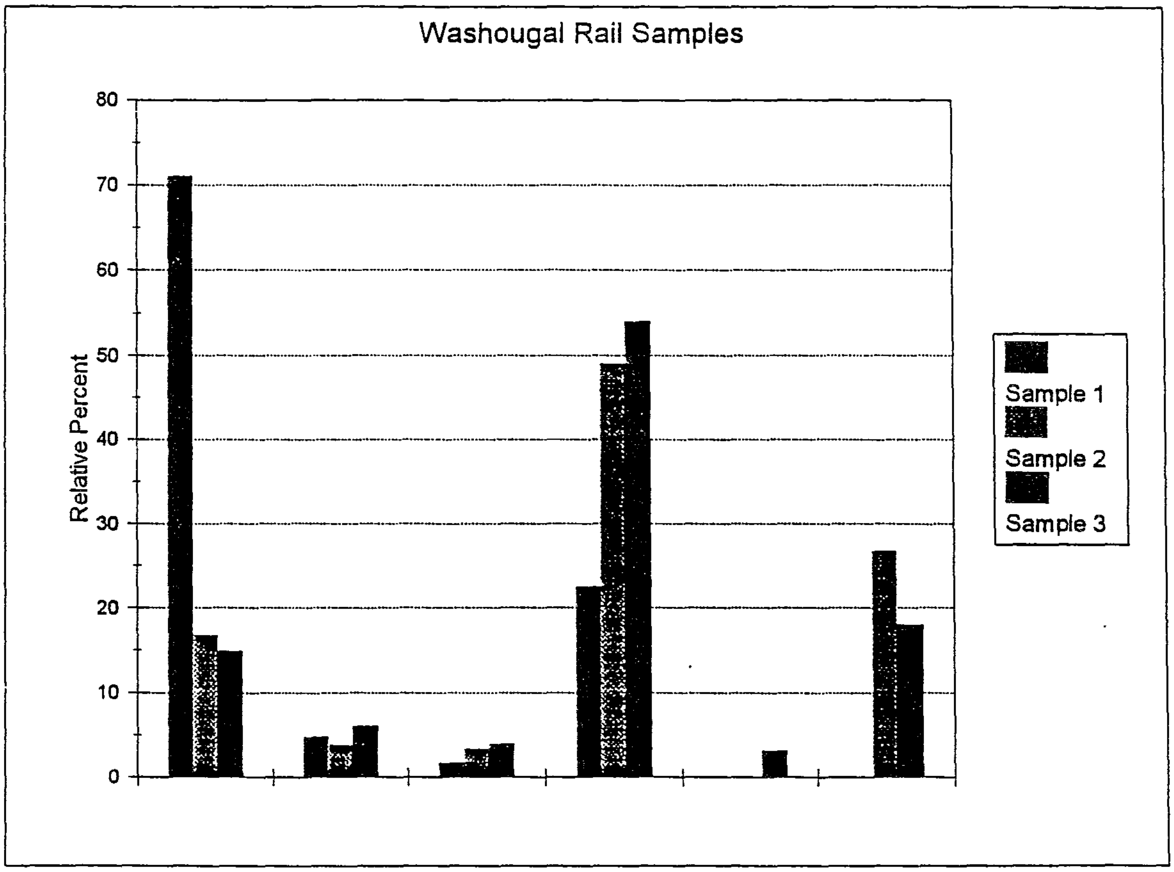


Figure 2. EDS Spectra of Washougal Rail Samples

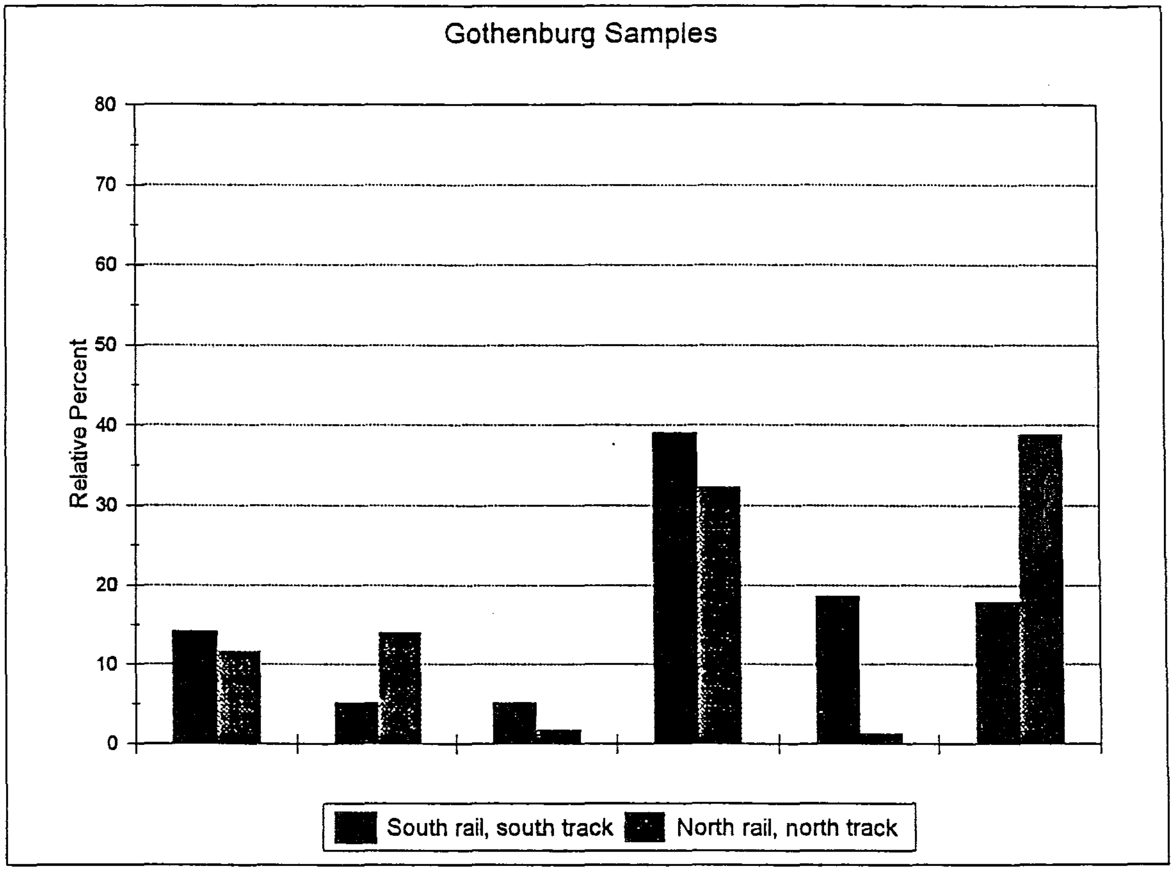


Figure 3. EDS Spectra of Gothenburg Rail Samples

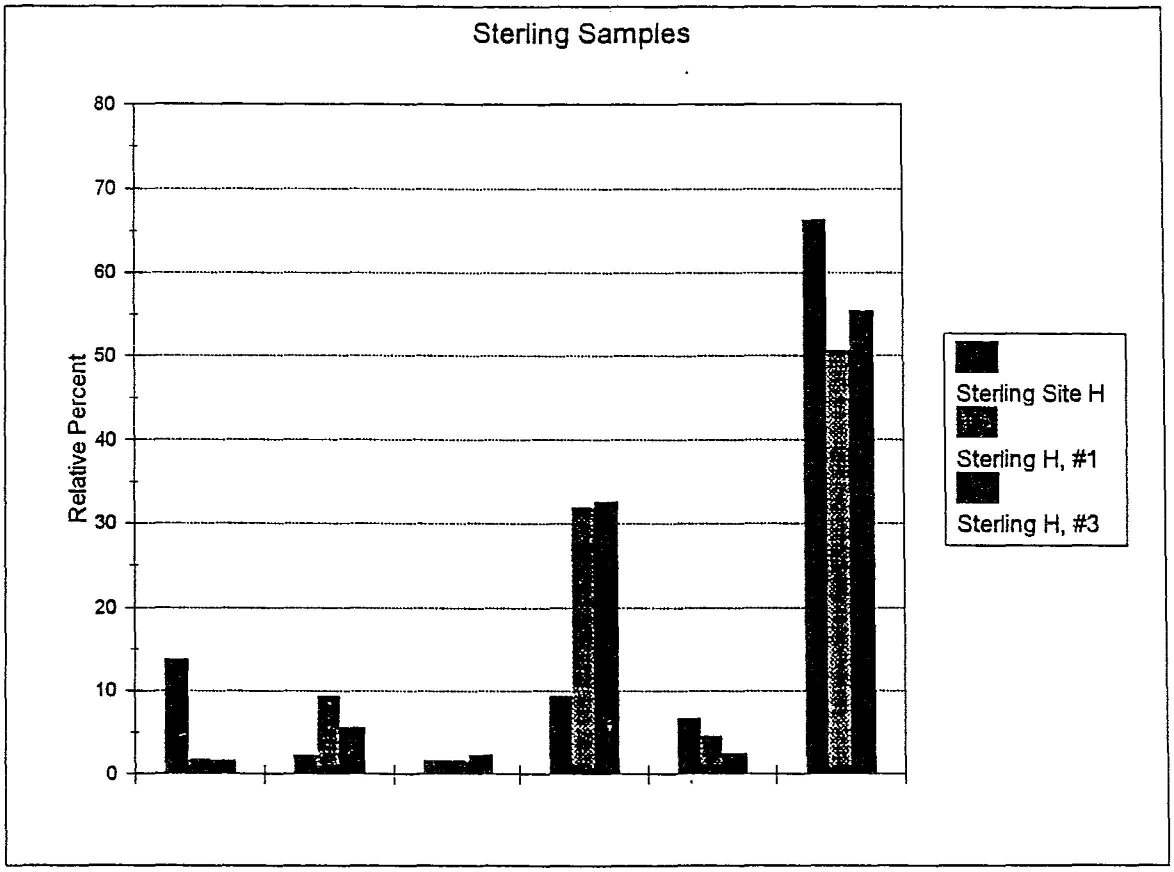


Figure 4. EDS Spectra of Sterling Rail Samples

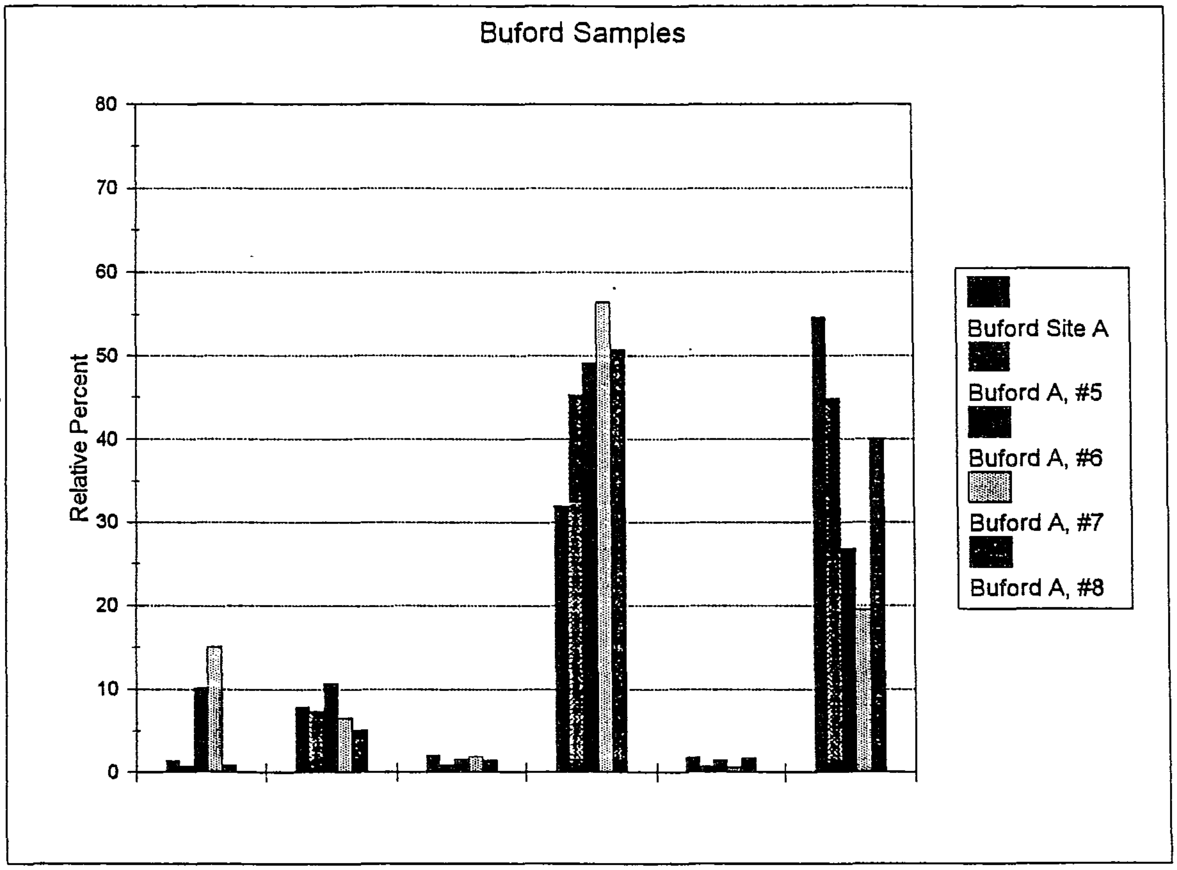


Figure 5. EDS Spectra of Buford Rail Samples

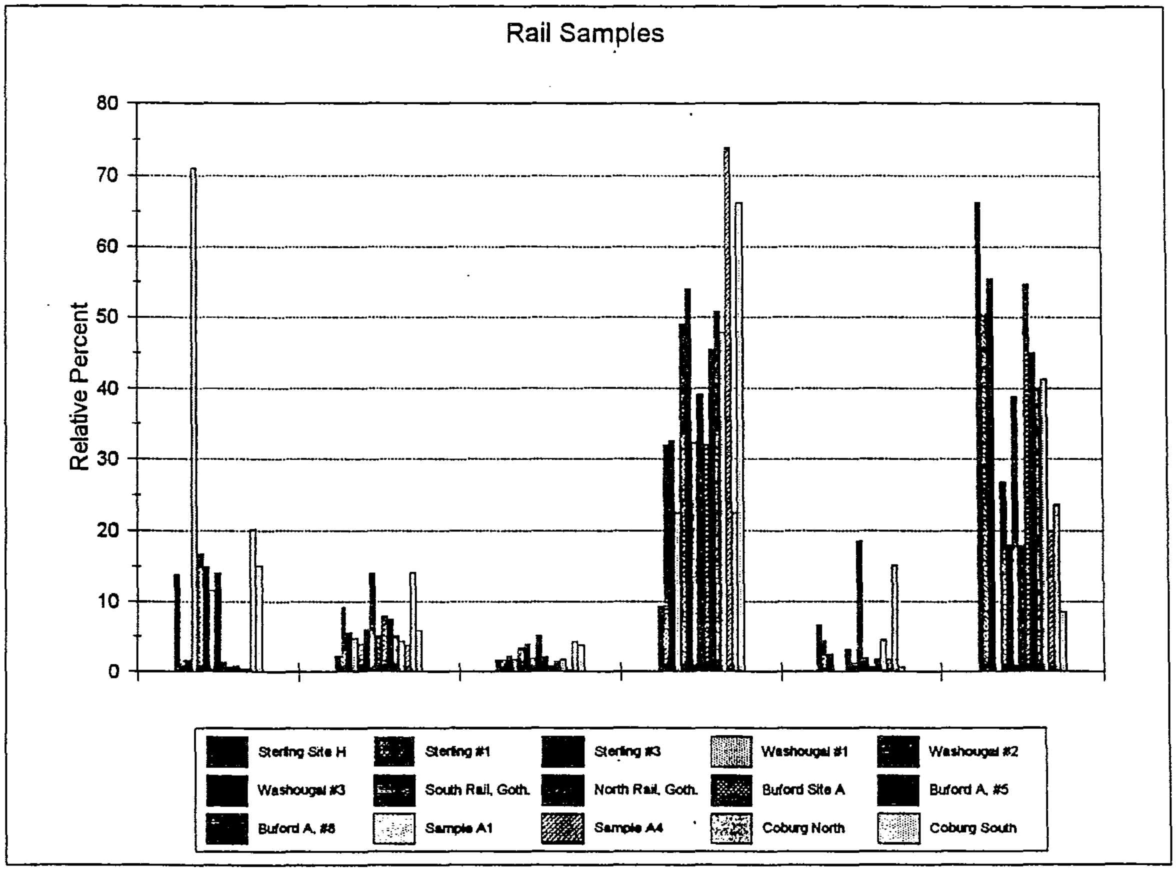


Figure 6. EDS Spectra of All Rail Samples

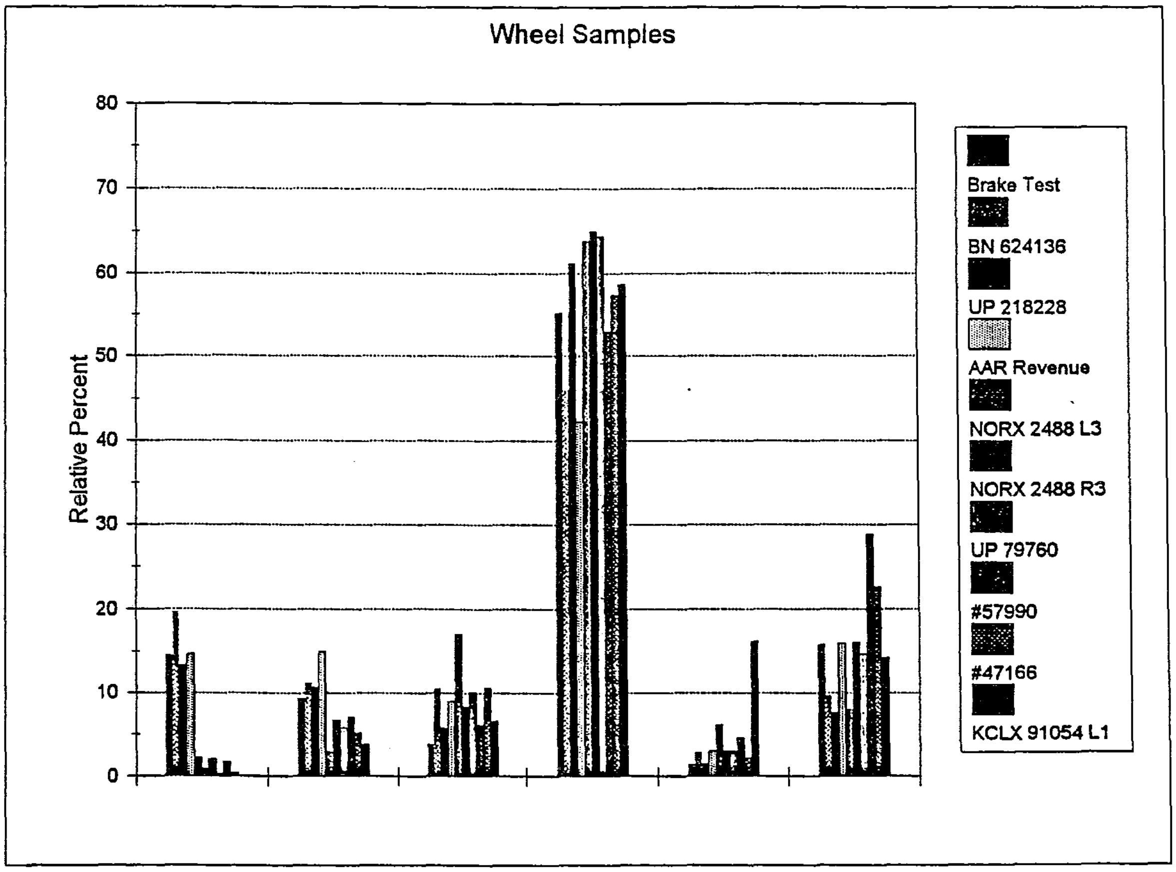


Figure 7. EDS Spectra of All Wheel Samples

APPENDIX C

Dynamometer Test Run Log

Test Sequence A

OBTAINED FILM SAMPLES A, B

- Run 000a - Heavily contaminated track wheel, rust and residue present from over a years period of no operation of track wheel.

- Run 001a, 002a - No data, system check out.

- Run 003a - Re-run heavily contaminated case

FILM SAMPLES C, D
CLEANED BOTH WHEELS

- Run 004a - Clean wheel on clean wheel, no brake application, 6300 lbs wheel load, 5 mph

- Run 005a - Clean wheel on clean wheel, no brake application, 6300 lbs wheel load, 20 mph

- Run 006a - Repeat run 005, increased to 40 mph on the fly.

- Run 007a - Decreased to 5 mph from 40 mph of previous run.

FILM SAMPLE E

- Run 008a - Clean wheel on clean wheel, no brake application, 32000 lbs wheel load, 5 mph

- Run 009a - Continue run 008, increased to 20 mph

- Run 010a - Repeat run 009, increased to 40 mph on the fly. Coast to a stop @210 seconds

- Run 011a - Light brake application (925 lbs.), increased brake application to 1450 lbs. @ 1450 seconds.

FILM SAMPLES F & G

- Run 012a - Brake malfunction, no data

- Run 013a - Obtained speed of 40 mph, applied brake and released when speed declined to 5 mph. Repeated for 3 cycles.

- Run 014a - Added lubrication, allowed water to drip on track during running, shut water off and proceeded with 3 cycle braking accelerating to 40 mph each time. Wheel load at

6,300 lbs.

- Run 015a - Added lubrication while rotating at slow rpm. Accelerate to 40 mph.

FILM SAMPLES H & I

- Run 016a - Increased wheel load to 32,000 lbs. Added lubrication at slow rpm and then accelerated to 40 mph. Higher wheel load squeezed lube out of the running surface as it was being applied.

FILM SAMPLES J & K

- Run 017a - Added lubrication at slow rpm, Increased speed to 40 mph, no braking, wheel load at 12,000 lbs. - stopped data collection @ 450 sec.

- Run 018a - Increased wheel load to 18,000 lbs., added lube at slow rpm, increased speed to 40 mph, decelerate at 320 sec.

- Run 019a - Increased wheel load to 24,000 lbs., re-applied lubrication at slow rpm, increased to 40 mph.

- Run 020a - Reduced wheel load to 9,000 lbs, repeated run 019a sequence.

- Run 021a - Reduced wheel load to 6,300 lbs, added lube at slow rpm, accelerated to 40 mph. Re-applied lube during the run @ 500 sec at 40 mph.

- Run 022a - Increased wheel load to 12,000 lbs, accelerate to 40 mph, added lube @ 140 sec at 40 mph.

- Run 023a - Hand wiped the excess lube from the track wheel surface. Began brake application. Accelerated to 40 mph, used 3,300 lbs brake force and released brake when the speed was 5 mph, this cycle was repeated three times. Run terminated @ 540 sec.

- Run 024a - Continued with run 023a. Added additional lube after first braking cycle.

- Run 025a - Wiped track wheel and car wheel with cloth rags to remove excess lubrication. Repeated the run 024a.

REMOVED BRAKE SHOE FOR PHOTO/FILM SAMPLE FROM SHOE SURFACE

- Run 026a - Repeated run 025, performed four braking cycles.

- Run 027a - Increased wheel load to 18,000 lbs, repeated run 026a, three cycles

FILM SAMPLE M

- Run 028a - Reduced wheel load to 9,000 lbs, repeated previous run sequence
- Run 029a - Reduced wheel load to 6,300 lbs, accelerated to 40 mph, one brake application then stopped.
- Run 030a - Added lubrication to the car wheel of approx 18 inches to introduce a small presence of lube in an effort to repeat earlier results. Repeated three cycle braking application from 5 to 40 mph.
- Run 031a - Computer general protection fault error - No Data
- Run 032a - Added lubrication to the track wheel, ran at 40 mph for 200 seconds, sand was added @ 55 sec. Continued with three cycle braking.

FILM SAMPLE N

- Run 033a - Repeated run 032a, used dirt instead of sand. Continued with 3 cycle braking

FILM SAMPLE O

- Run 034a - Hand wiped both wheels, repeated parameters of 032a & 033a introduced leaves, organic mixture.
- Run 035a - Varied voltage; @ 320 sec - 2 volts; @ 400 sec - 1.5 volts; @690 sec - 1.2 volts; @ 750 sec - 1.0 volt; @ 810 sec - 0.8 volts; @ 900 sec - 0.5 volts; @ 1200 sec - 10 volts.
- Run 036a - Applied lubrication, ran at 40 mph with water running continuously. Cyclic braking activity
- Run 037a - No Data
- Run 038a - Repeated run 036a, brake force increased to 6,050 lbs.

Test Sequence B

FILM SAMPLE 2A

- Run 003b - Apply lubrication at slow rpm, accelerated to 40 mph, reduced speed using regenerative braking.
- Run 004b - Hand wiped excess lube, acyl. to 40 mph, regenerative braking
- Run 005b - No Data

- Run 006b - Re-applied lubrication, repeat run 004b.
- Run 007b - Hand wiped excess lube, repeat run 006b.
- Run 008b - Re-applied lube, accelerated from to 40 mph for three cycles. Used regenerative braking to slow the dyno.
- Run 009b - Re-applied lube, accelerate to 40 mph, cycled from 5 to 40 mph four times using a 3,290 lbs brake application.

FILM SAMPLE 2B

- Run 010b - Applied mixture of locomotive sand and lubrication at slow rpm, cycled three times, first cycle used regenerative braking, the following used brake application.
- Run 011b - Reduced speed to 20 mph from previous run, drag brake shoe application at 1,500 lbs

FILM SAMPLE 2C

- Run 012b - Added dirt to previous mixture of lube and sand, applied mixture, repeated run 010b.
- Run 013b - Added grass clippings and leaves to mixture and applied, Ran two cycles at 40 mph, no brakes were applied.

FILM SAMPLE 2D, 2E
CLEANED BOTH WHEEL WITH ACETONE

- Run 014b - No Data
- Run 015b - Ground a groove in the brake shoe to simulate a non-conformal contact in line with the running surface. Repeated three cycle brake run from 5 to 40 mph.
- Run 016b - No Data
- Run 017b - Added lube at slow rpm, repeated run 015b
- Run 018b - No Data
- Run 019b - Re-applied lubrication, repeat cyclic braking activity with one cycle of regenerative braking.

Test Sequence C

- Run 011c, 012c - No data, check out runs.
- Run 013c - Brake application only. Accelerated to 40 mph, 3,290 lbs brake appl., acyl to 40 mph, brake and released at 20 mph twice, then coast
- Run 014c - Added lubrication, accelerate to 40 mph, sustain and regenerative braking
- Run 015c - Re-applied lube, repeat run 014c.
- Run 016c - Redistributed existing lubrication, ran 3 cycles using regenerative braking.
- Run 017c - Redistributed existing lube, ran at 40 mph, 3,290 lbs braking applied at 420 seconds into the run for three cycles releasing at 20 mph
- Run 018c - Added mixture of lube, sand, dirt, and organic material from test series B, accelerated to 40 mph, maintained, no braking
- Run 019c - Redistributed lube mixture, accelerated to 40 mph, used regenerative braking to cycle from 40 to 20 mph.

FILM SAMPLE 3A, 3B
CLEANED WHEELS WITH DIESEL FUEL

- Run 020c - Accelerate to 40 mph
- Run 021c - No Data - Brake malfunction
- Run 022c - Light drag brake application (925 lbs) at 20 mph.
- Run 023c - Ran at 40 mph to check effects of previous drag brake application. Used regenerative braking to cycle.
- Run 024c - Light brake appl. to stop previous run.
- Run 025c - Applied lube mixture, used light brake application of 925 lbs to cycle from 40 to 20 mph.
- Run 026c - Added additional mixture, repeat previous run.

FILM SAMPLE 3C, 3D

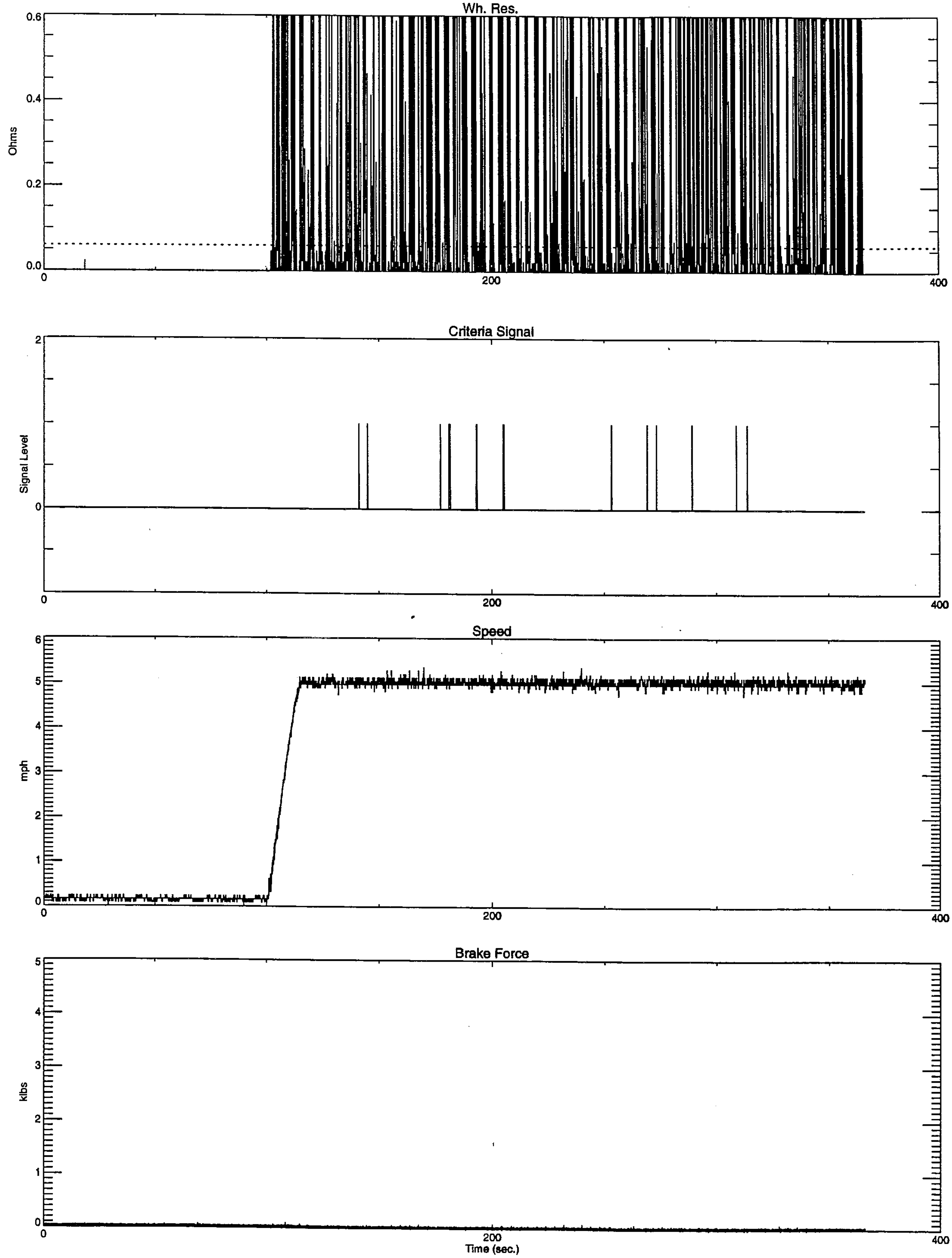
- Run 027c - Redistributed mixture, light (925 lbs) and heavy (3,290 lbs) brake application

FILM SAMPLE 3E, 3F

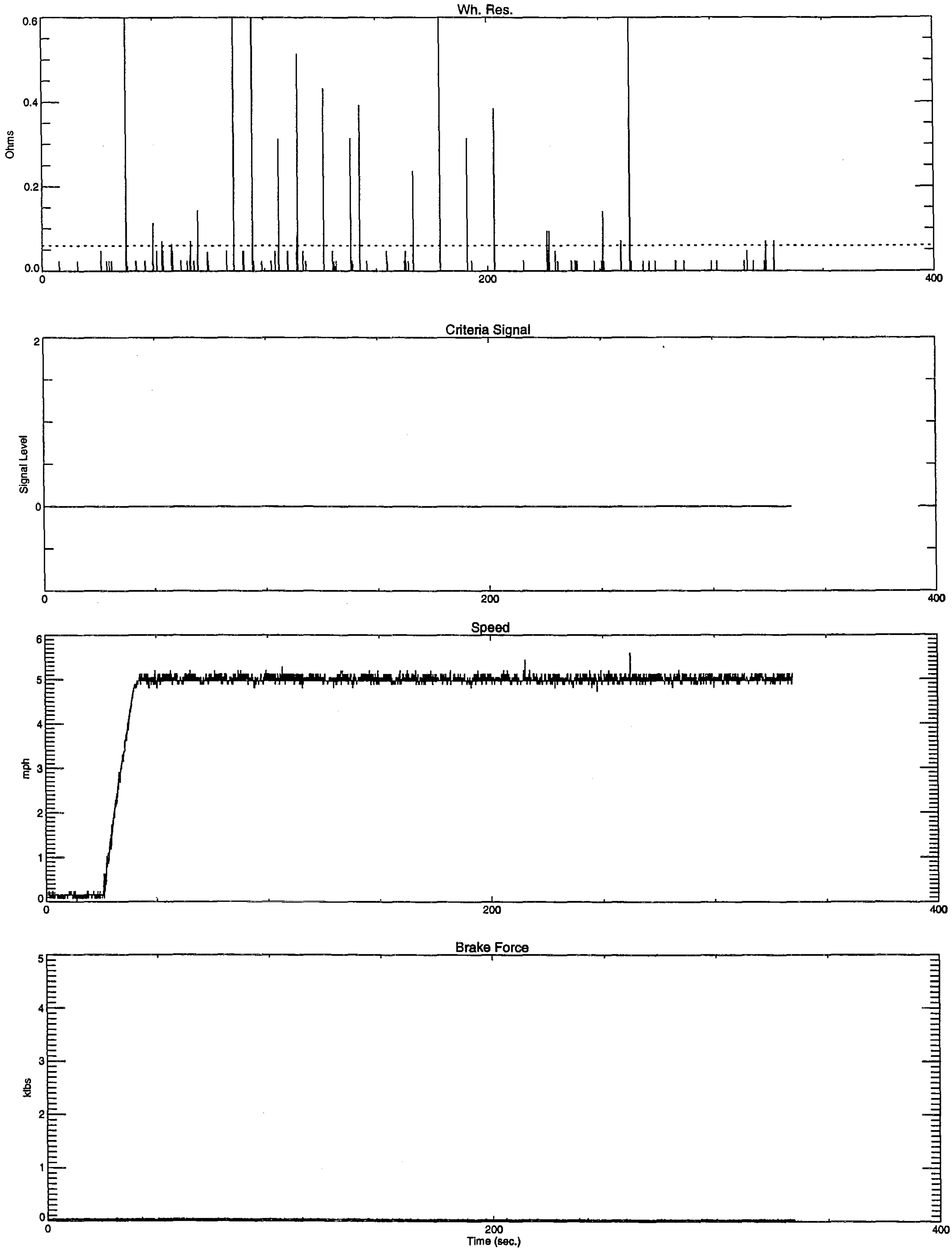
APPENDIX D

Data Runs

Run 000a - Wheel Load 6,300 lbs.

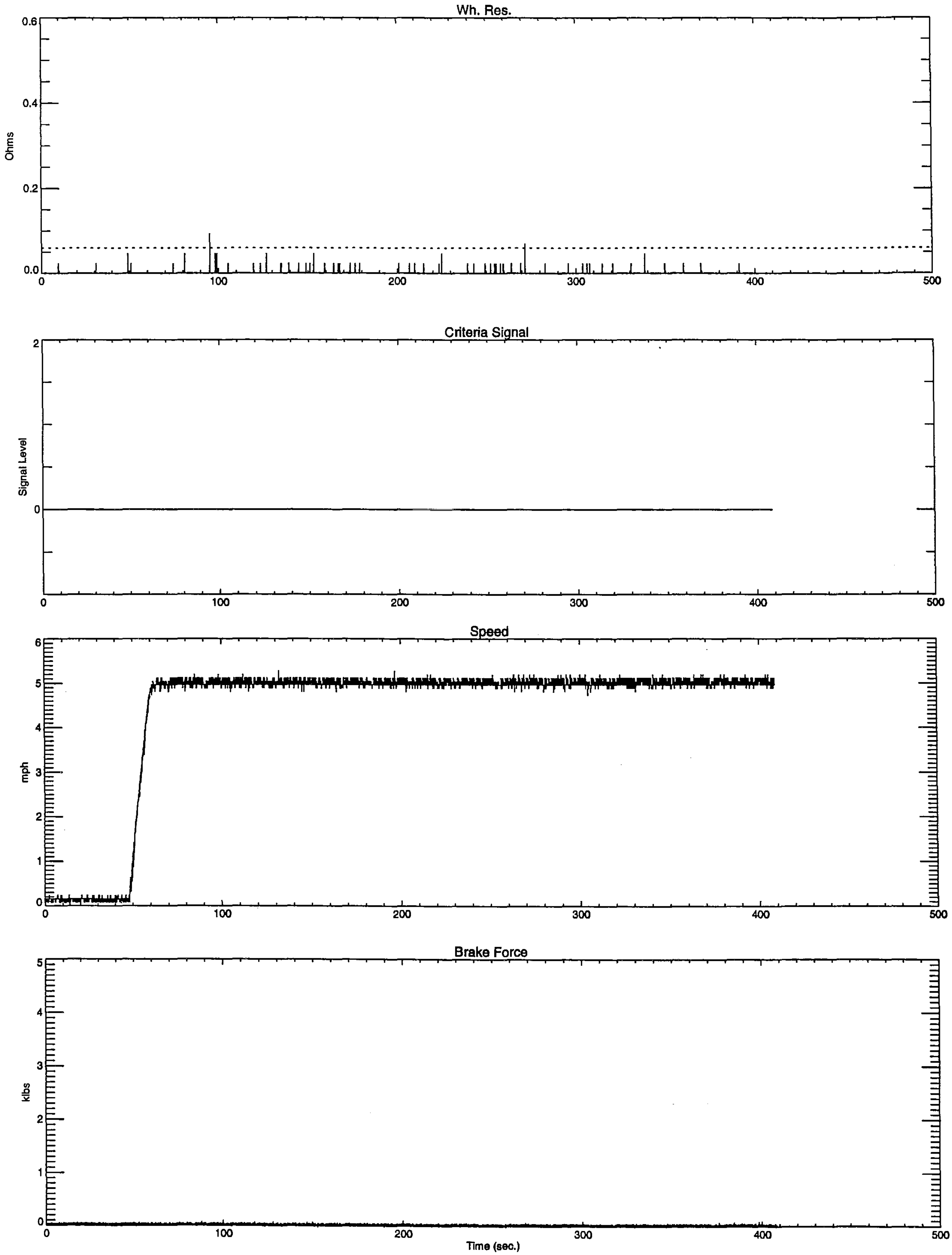


Run 003 A

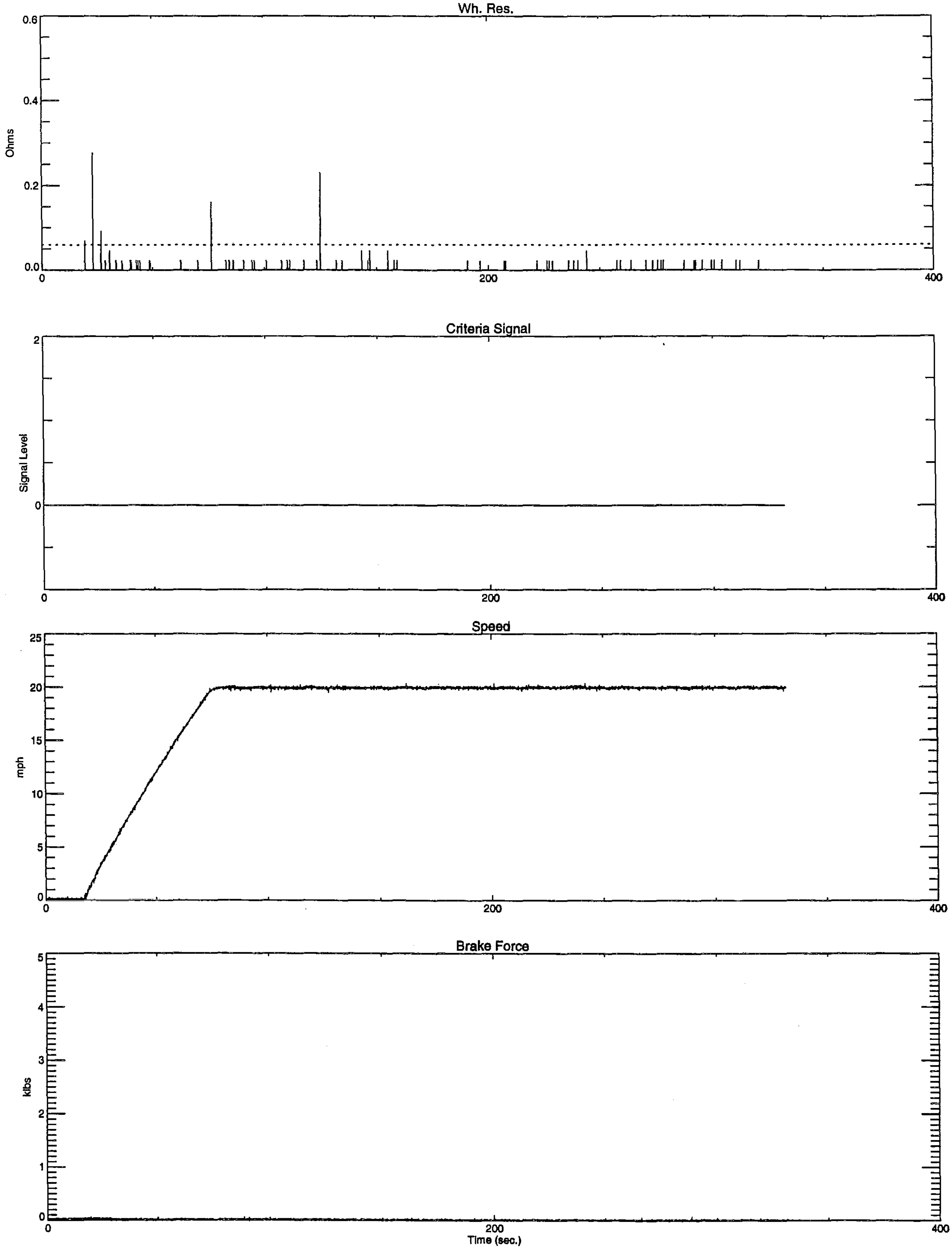


Wh. Res.
Ohms
0.6
0.4
0.2
0.0
0
200
400
Criteria Signal
Signal Level
2
0
0
200
400
Speed
mph
6
5
4
3
2
1
0
0
200
400
Brake Force
klbs
5
4
3
2
1
0
0
200
400
Time (sec.)

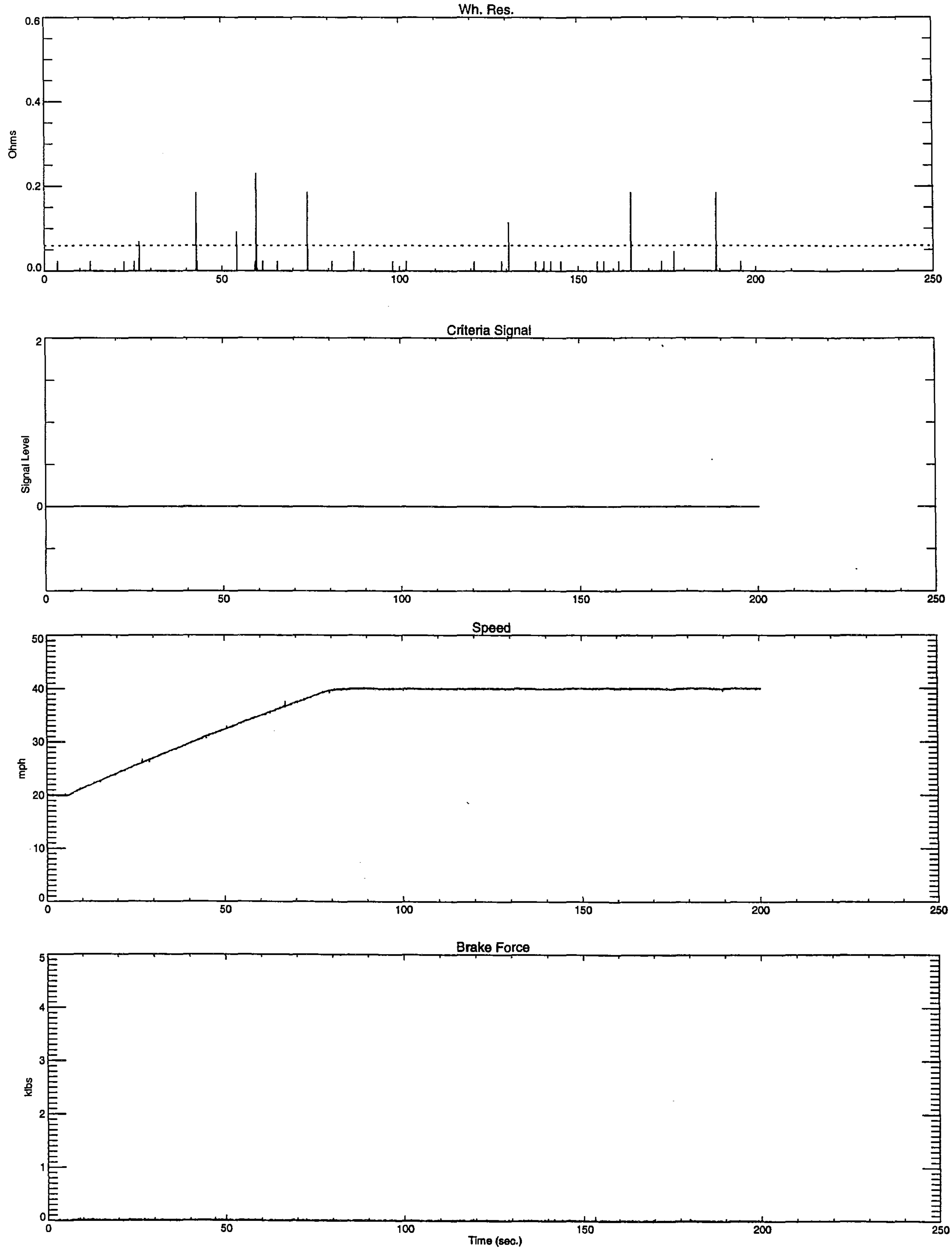
Run 004 A - 6,300 lbs.



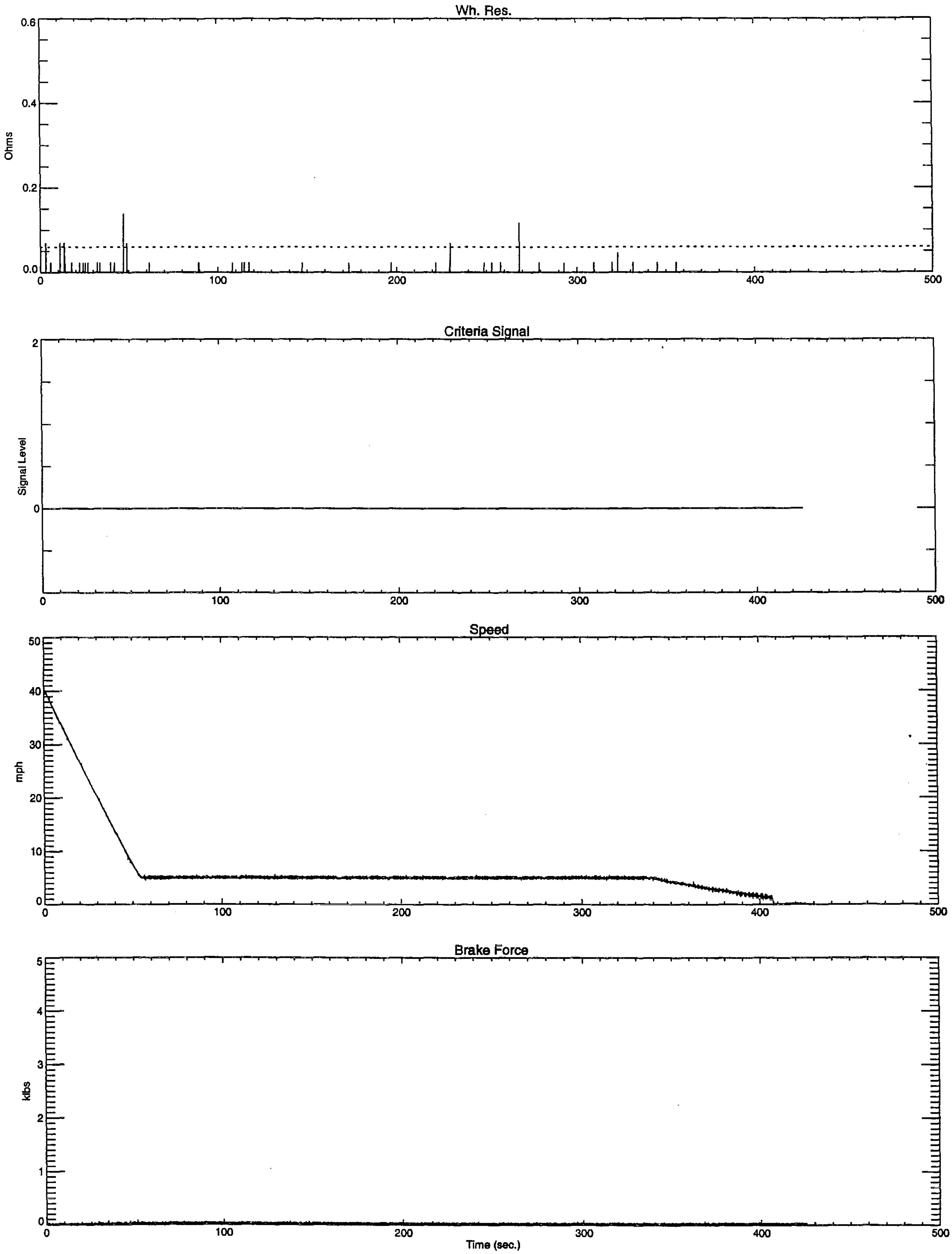
Run 005 A - Wheel Load 6,300 lbs.



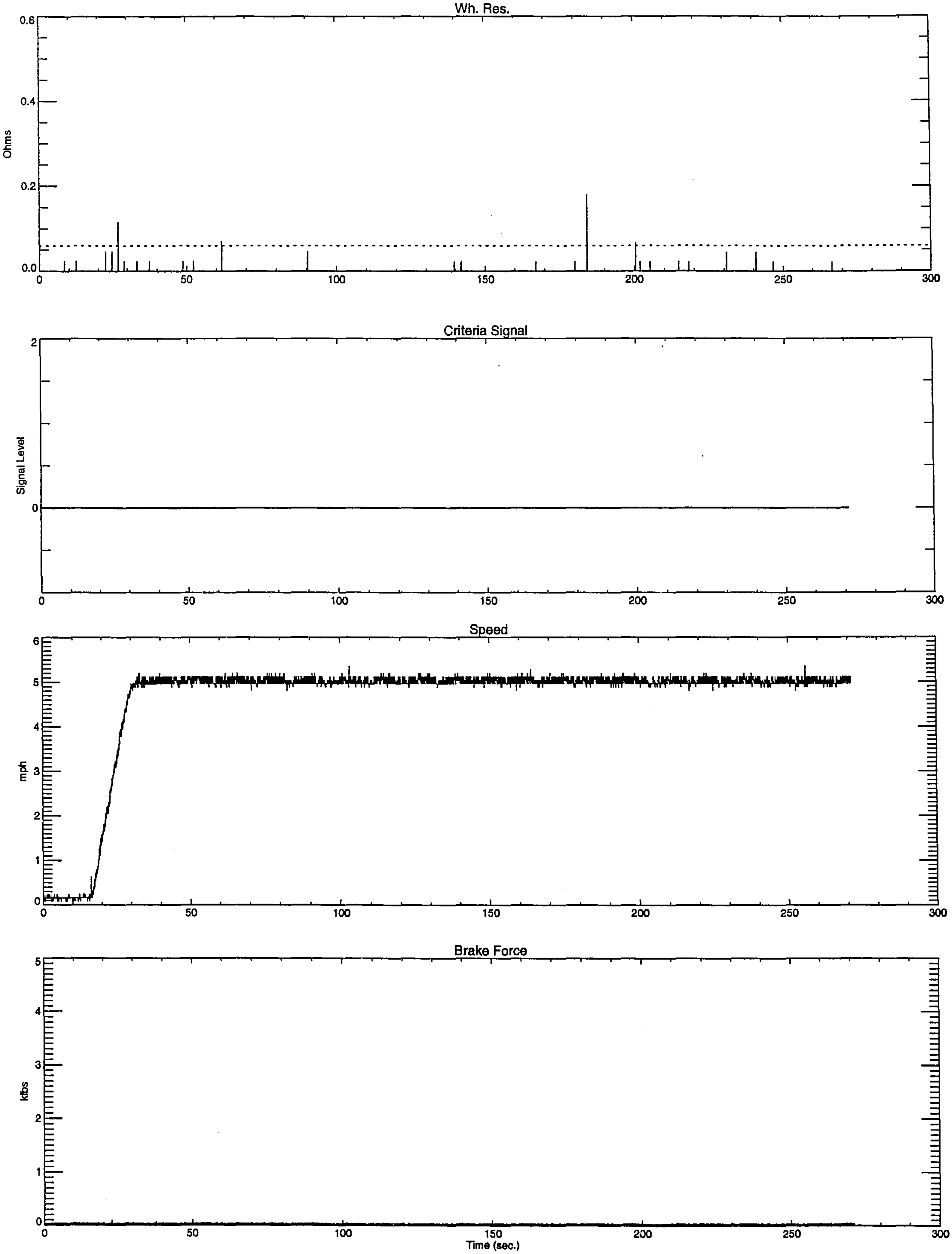
Run 006 A - Wheel Load 6,300 lbs.



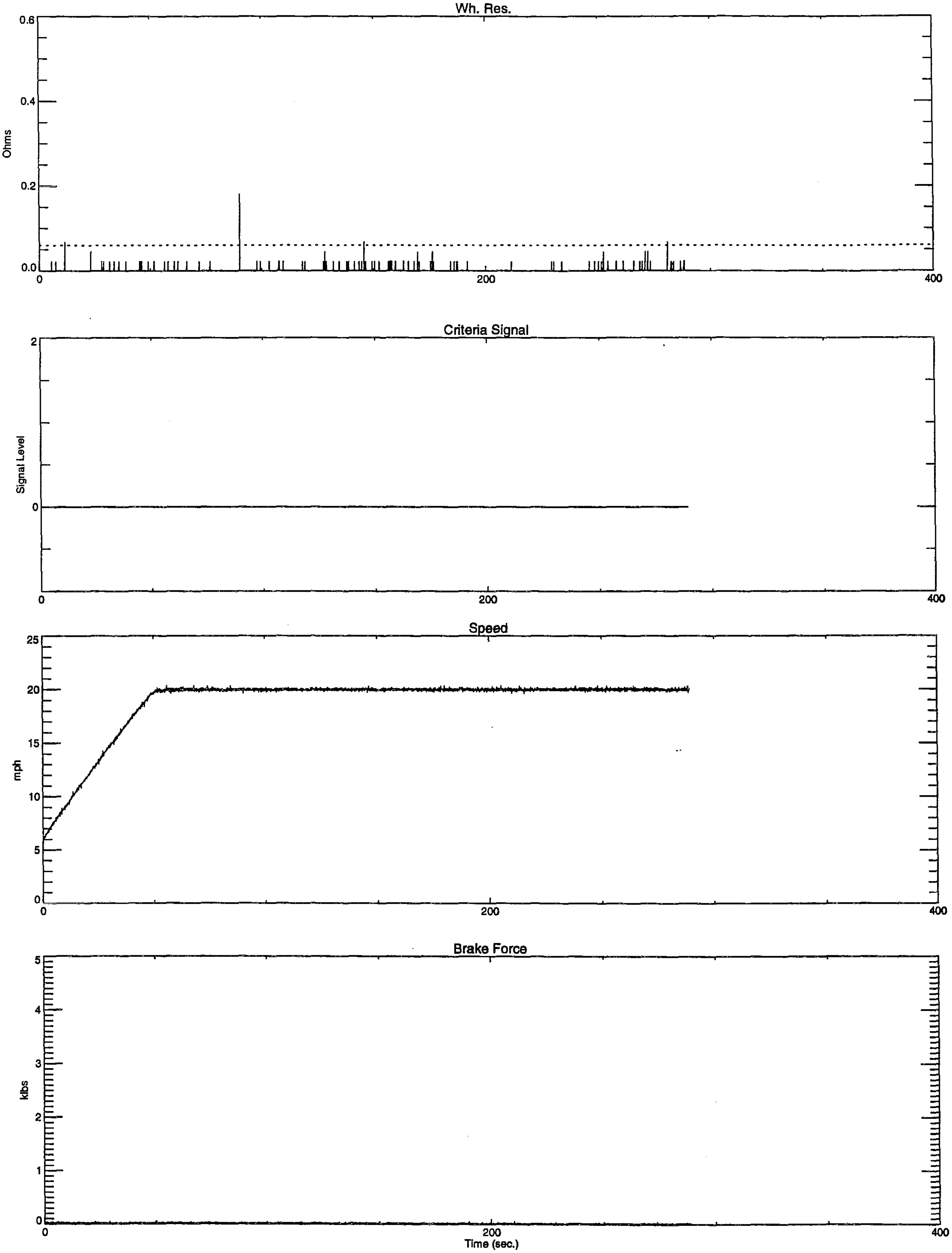
Run 007 A - Wheel Load 6,300 lbs.



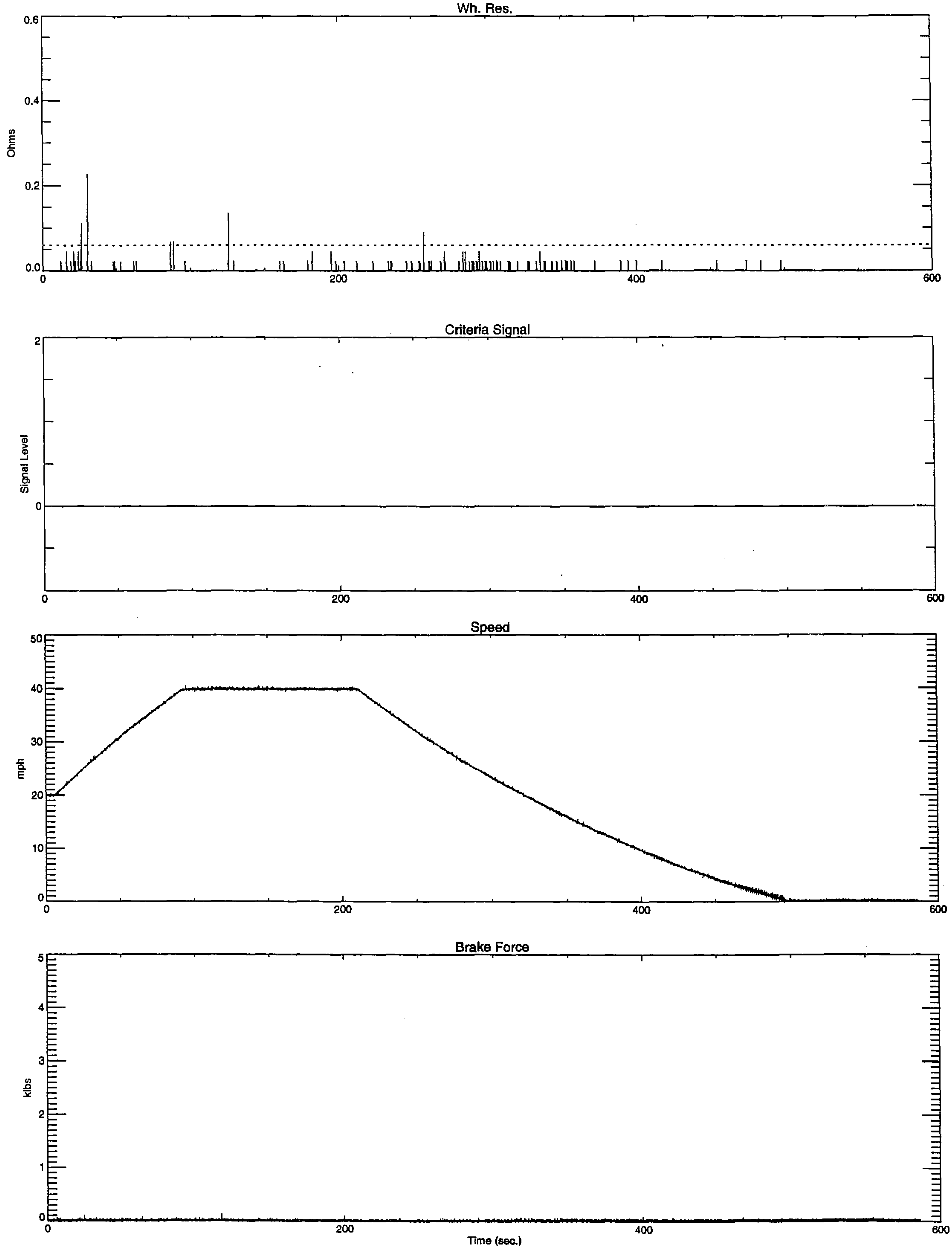
Run 008 A - Wheel Load 32,000 lbs.



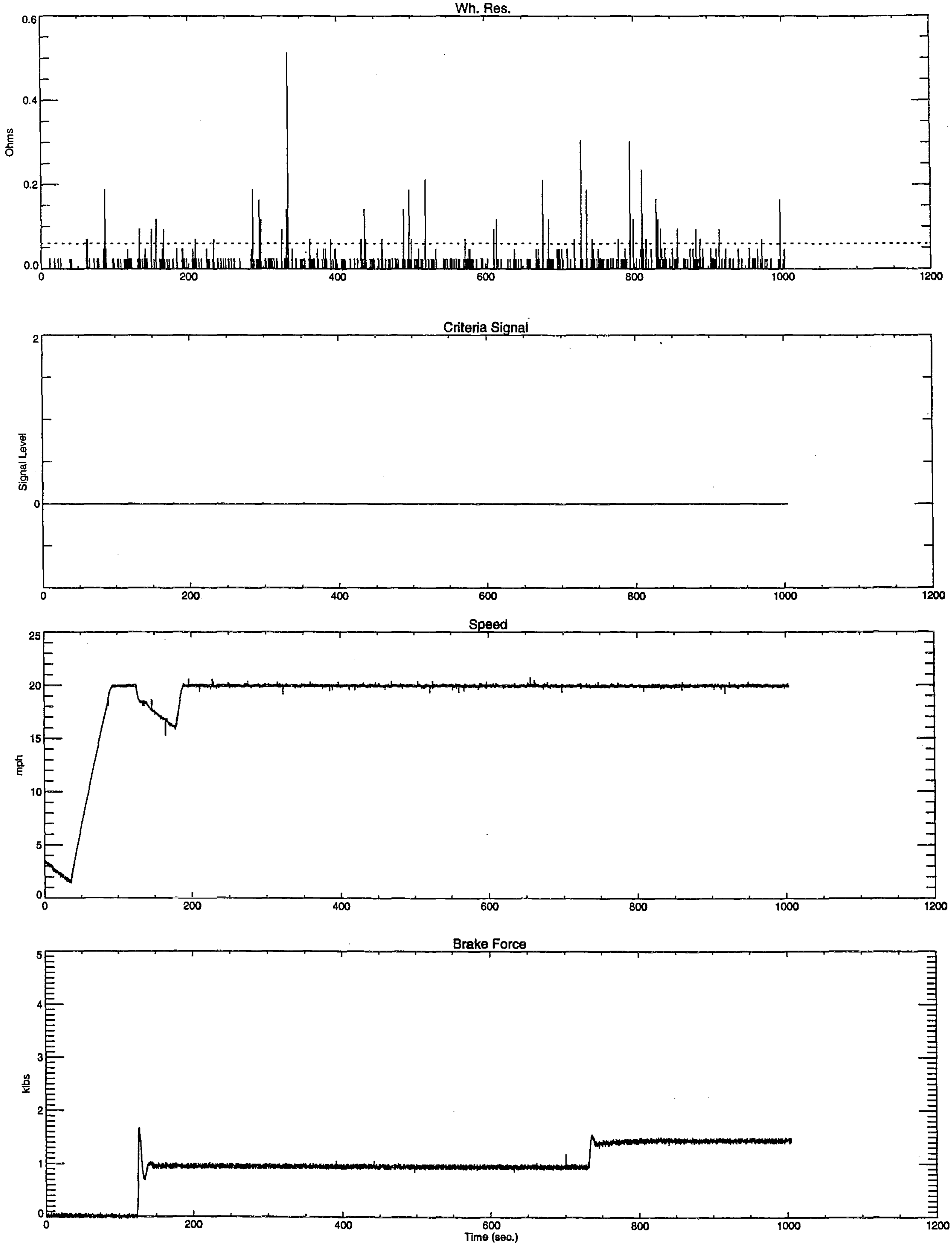
Run 009 A - Wheel Load 32,000 lbs.



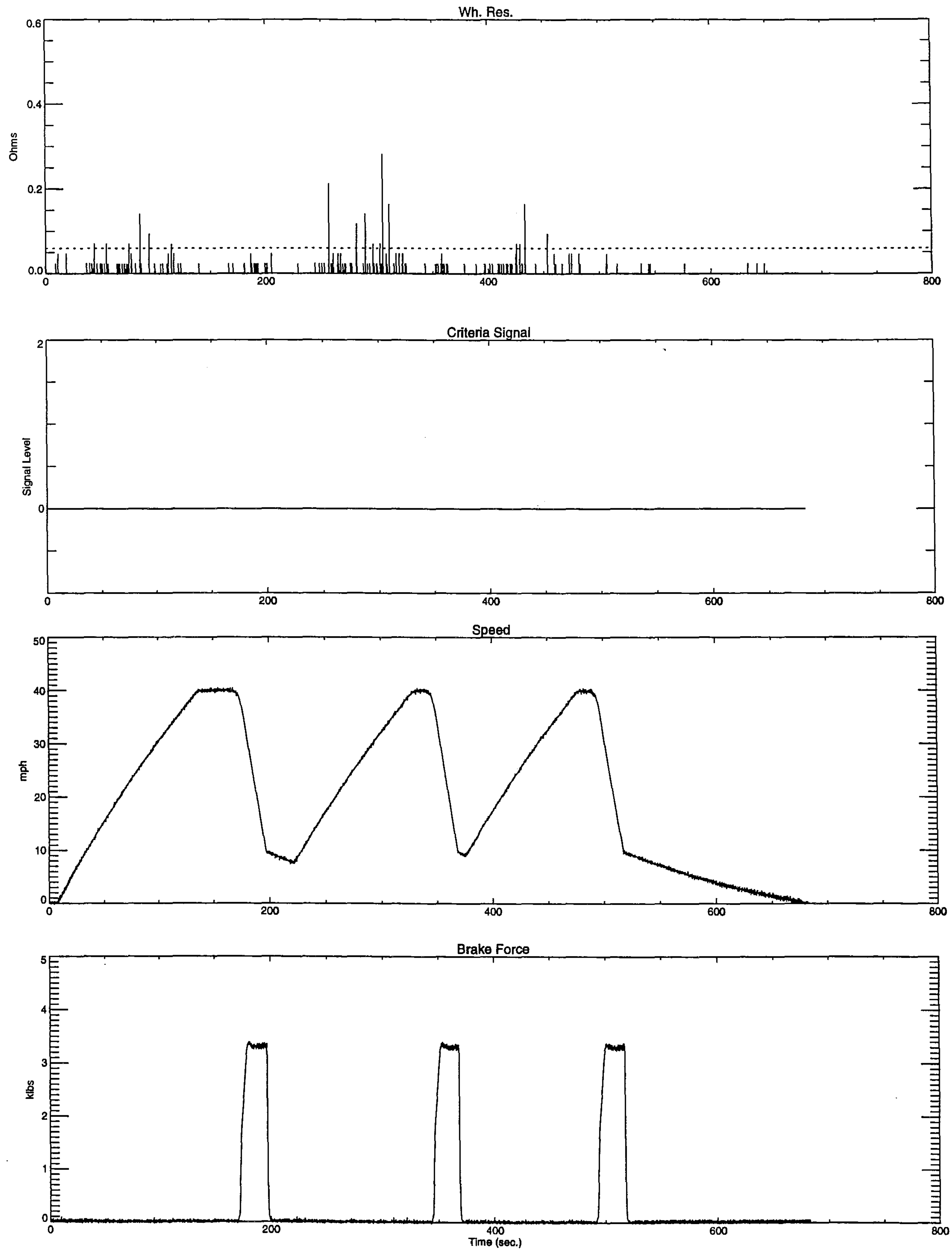
Run 010 A - Wheel Load 32,000 lbs.



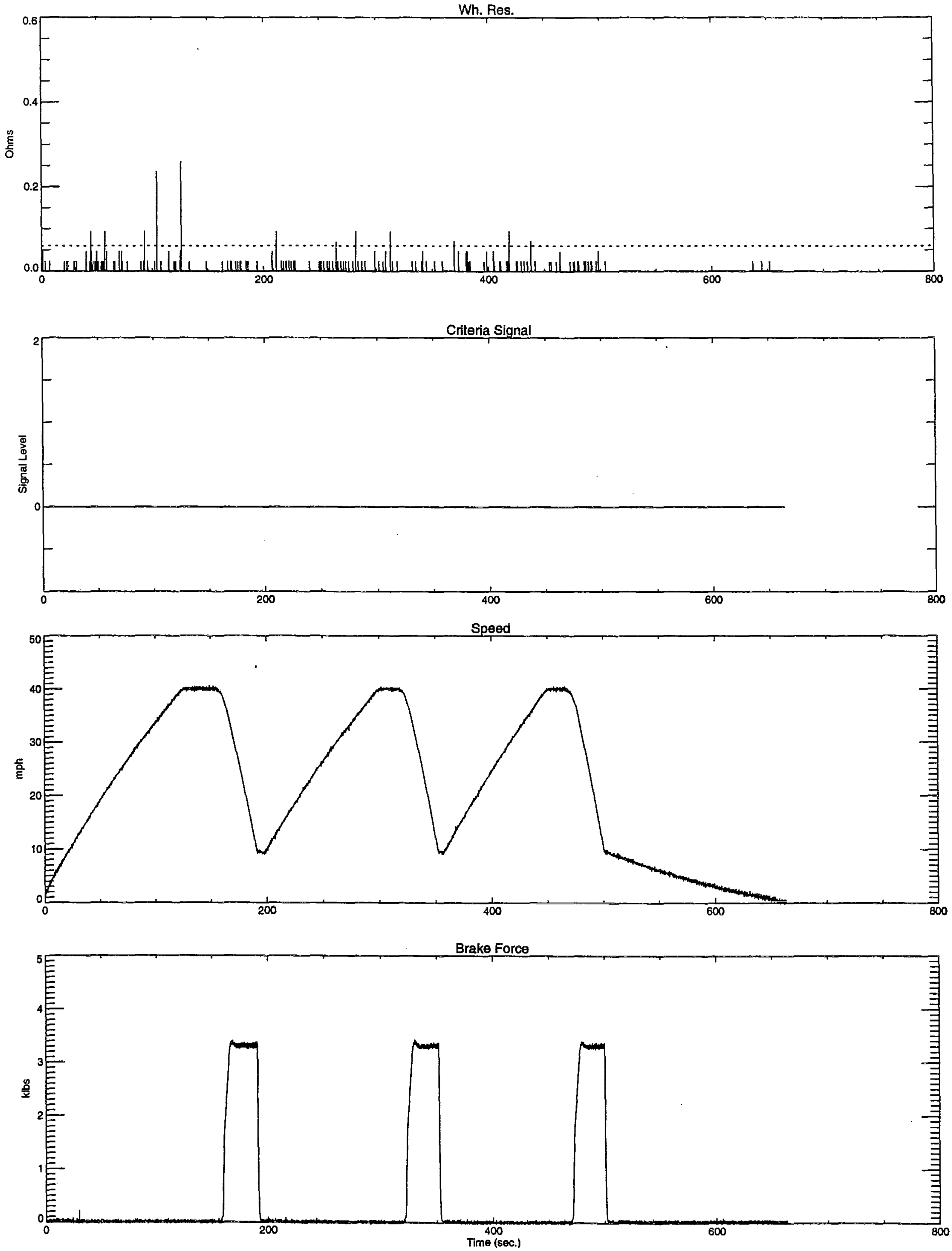
Run 011 A - Wheel Load 6,300 lbs.



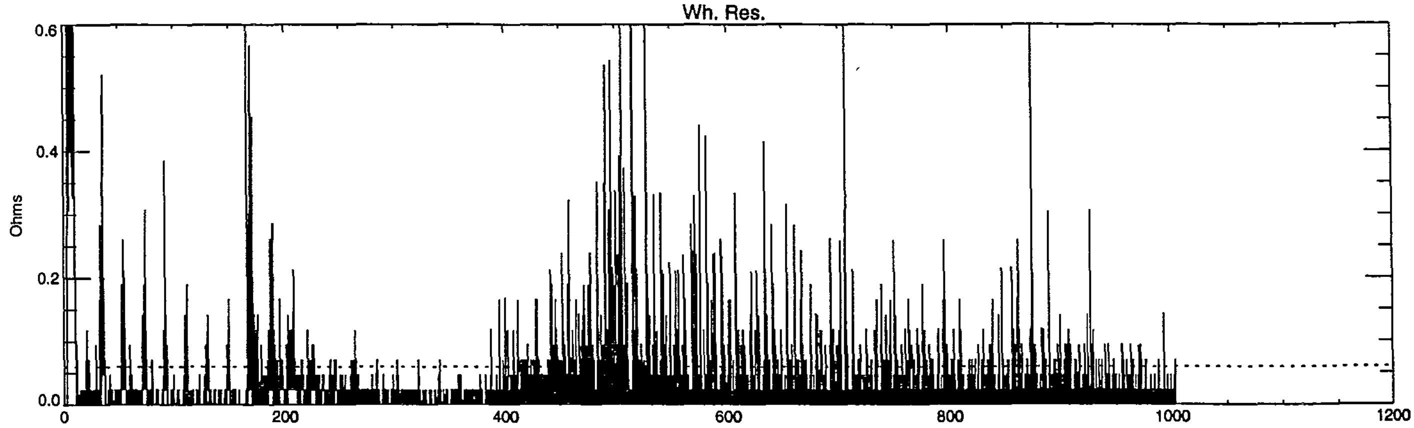
Run 013 A - Wheel Load 6,300 lbs.

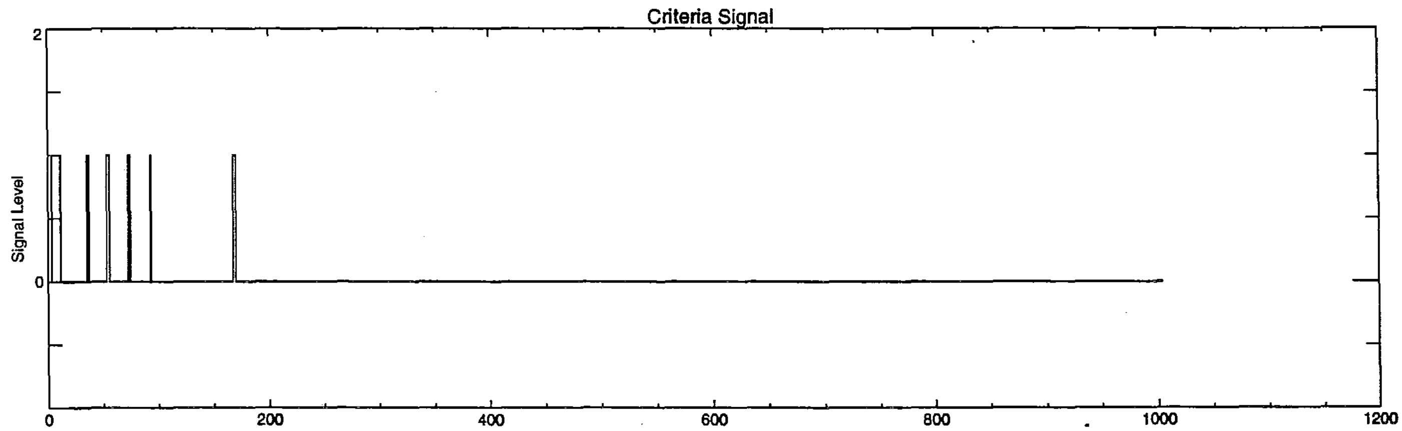


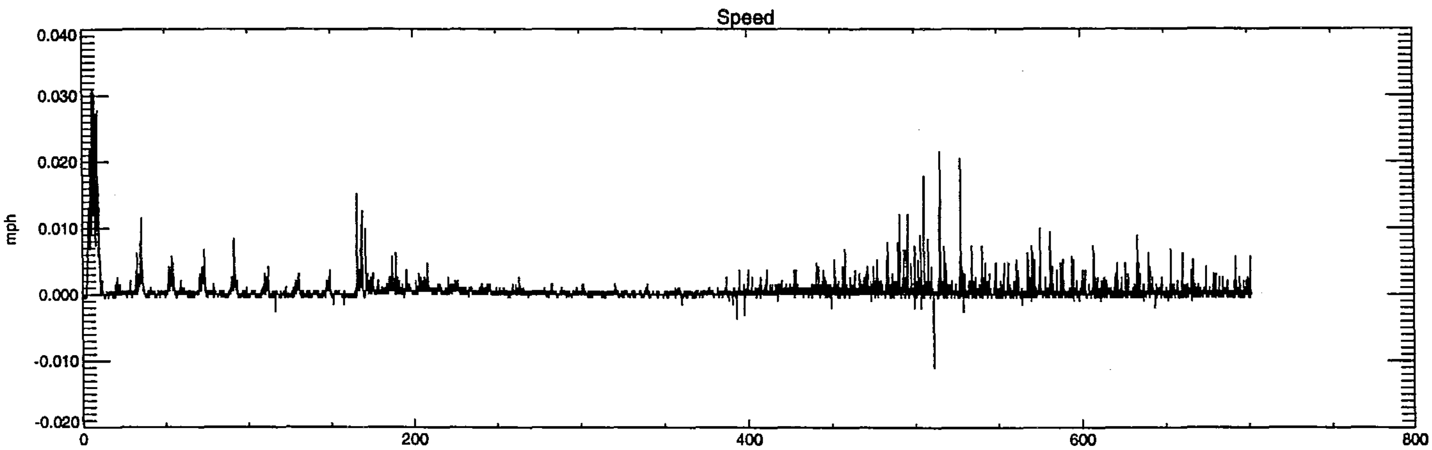
Run 014 A - Wheel Load 6,300 lbs.

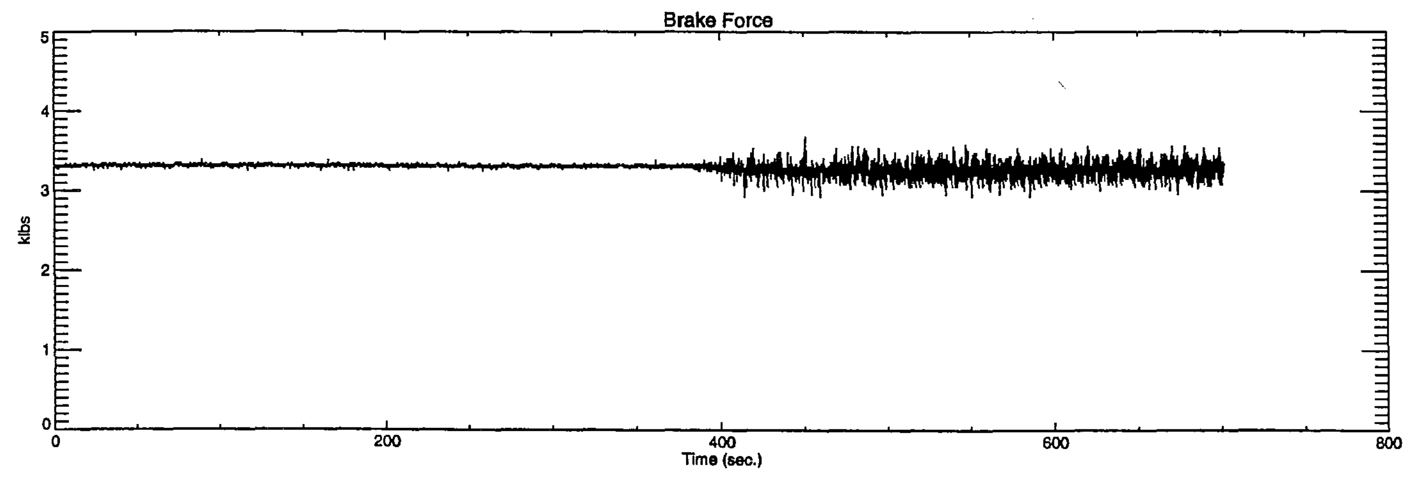


Run 015 A - Wheel Load 6,300 lbs.

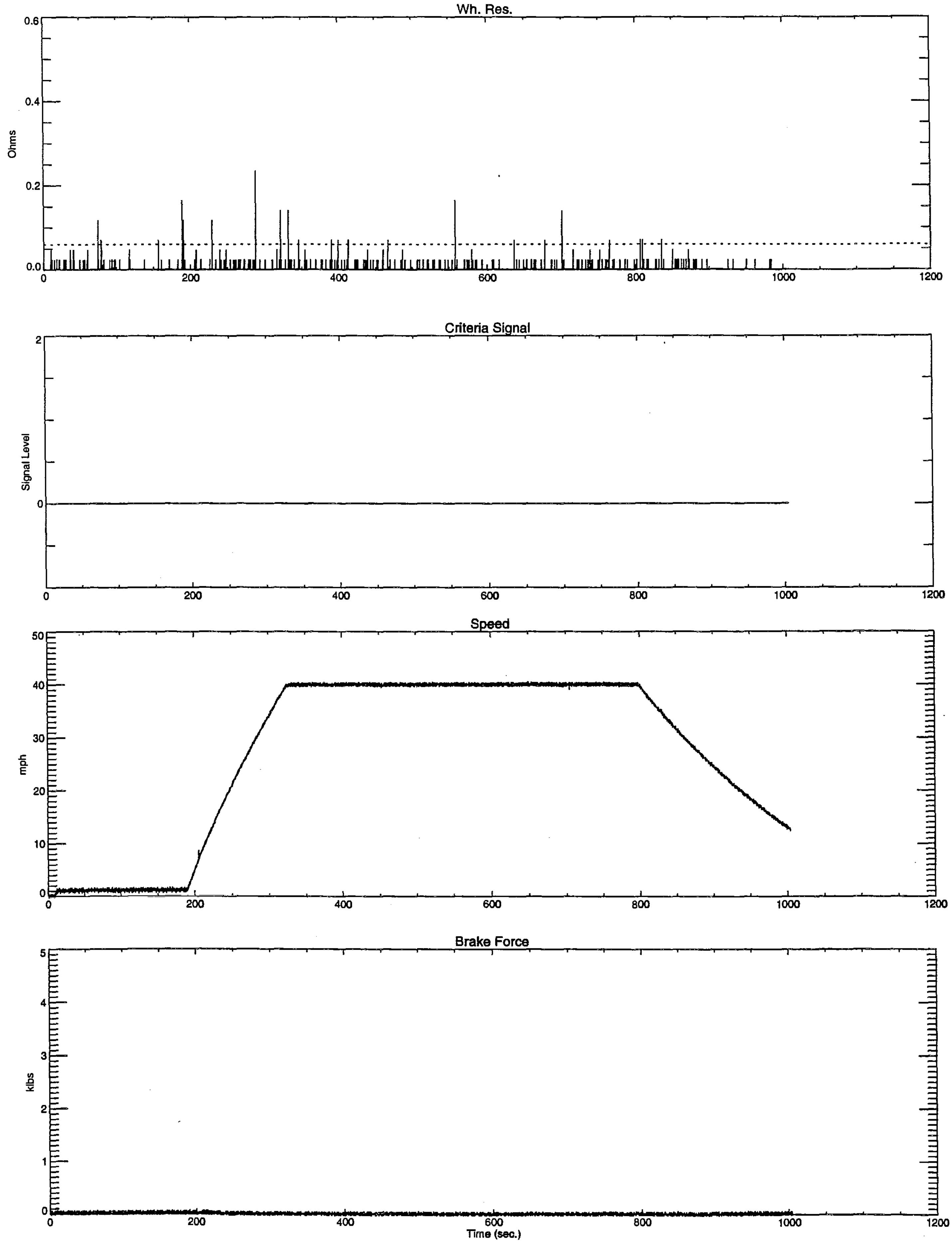




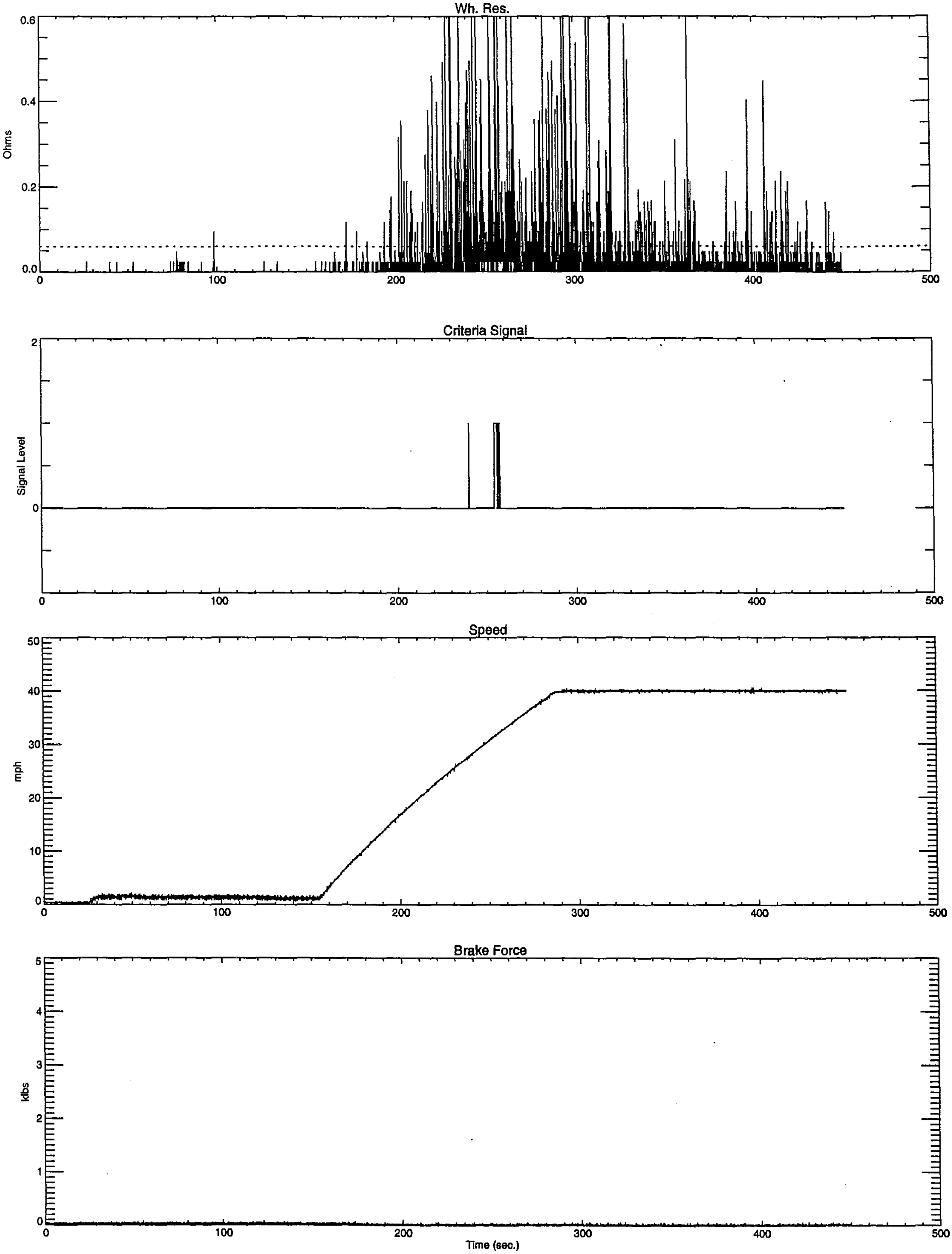




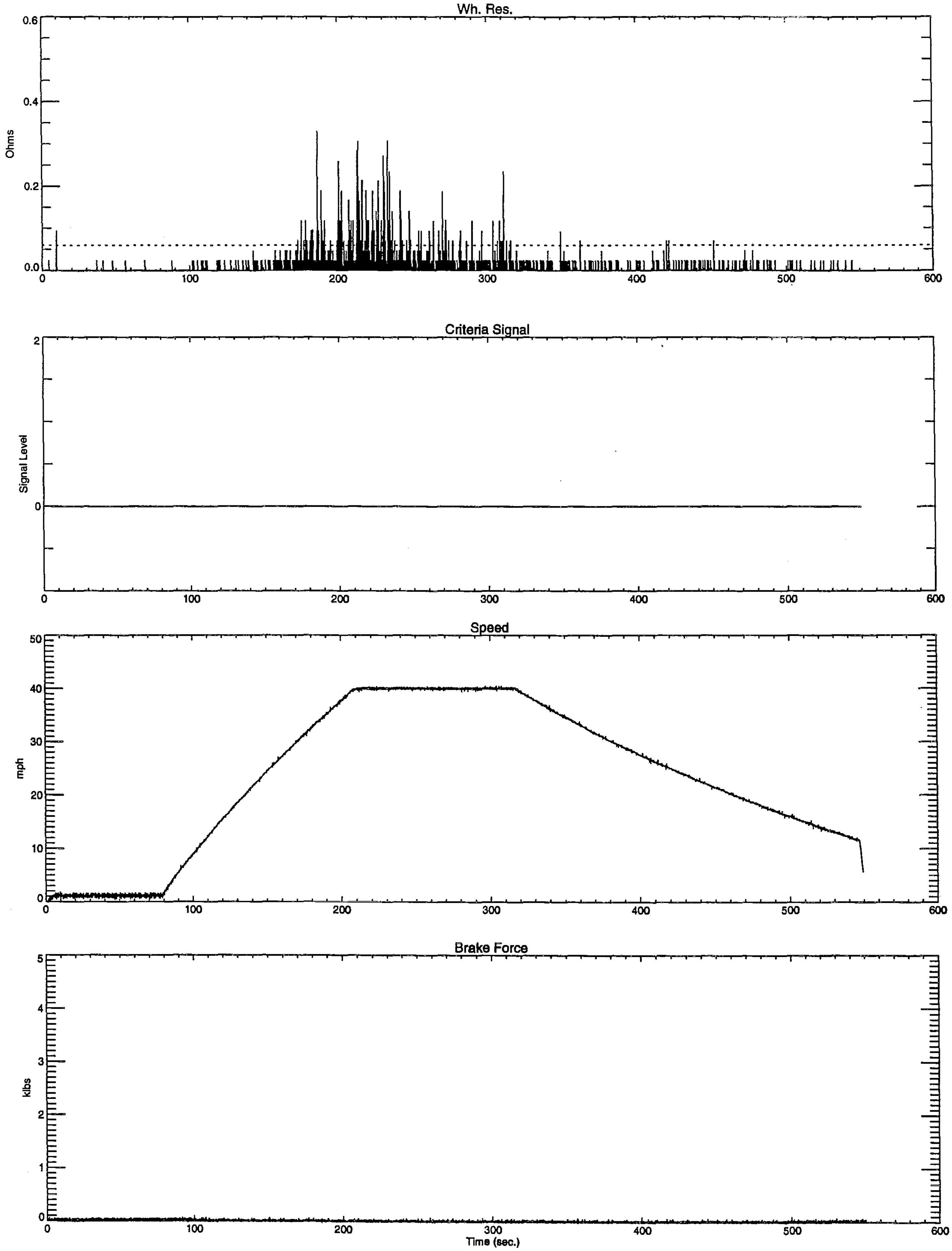
Run 016 A - Wheel Load 32,000 lbs.



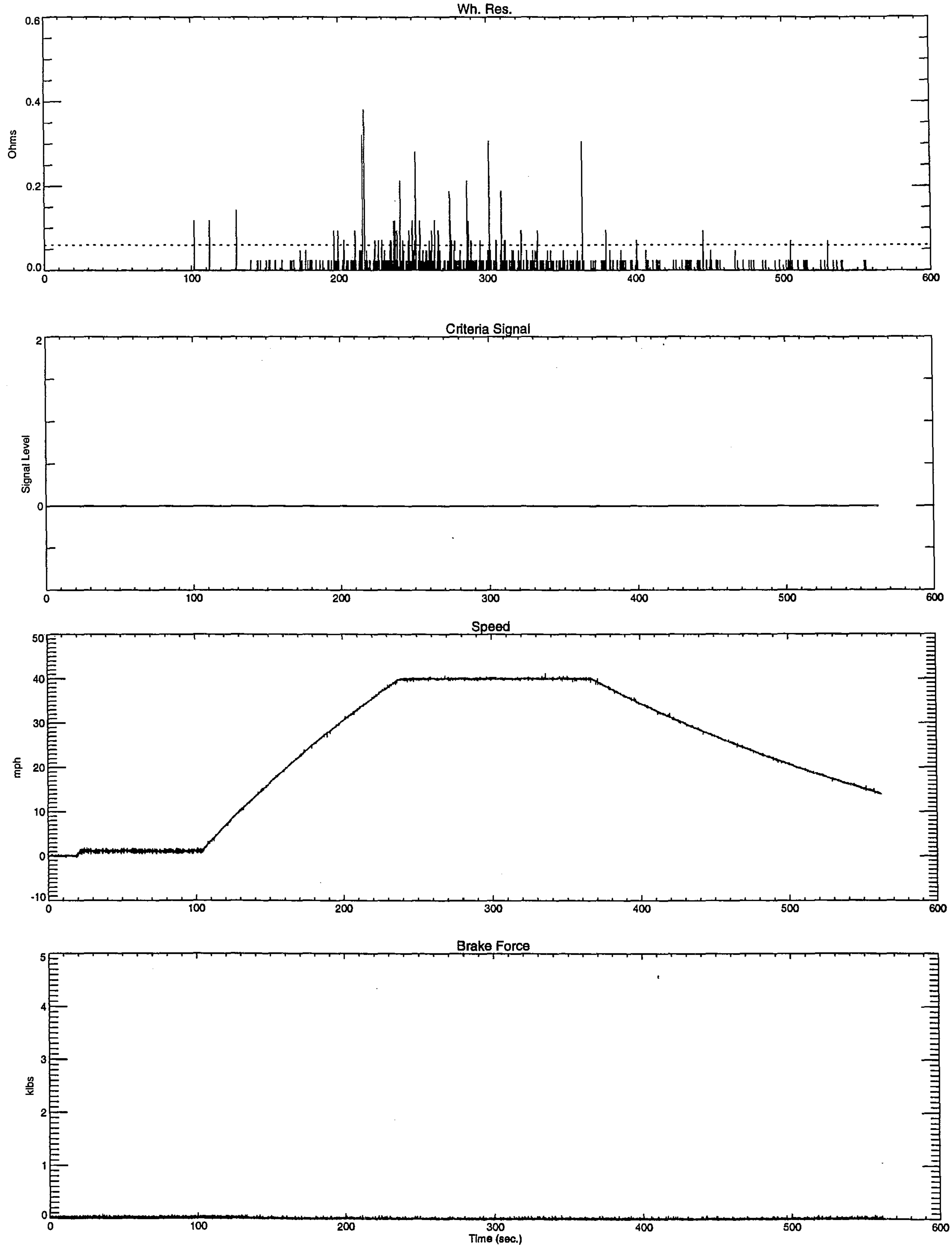
Run 017 A - Wheel Load 12,000 lbs.



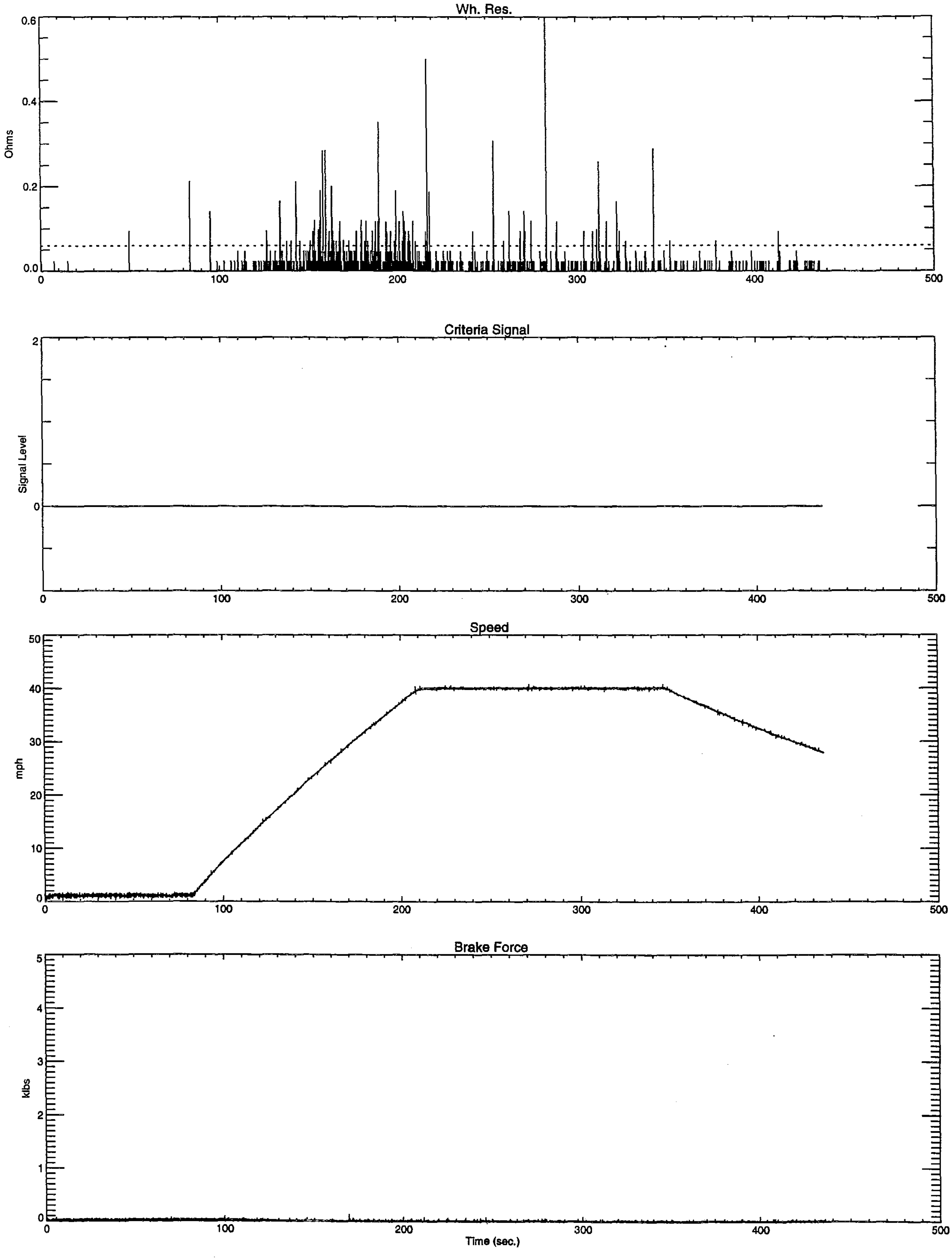
Run 018 A - Wheel Load 18,000 lbs.



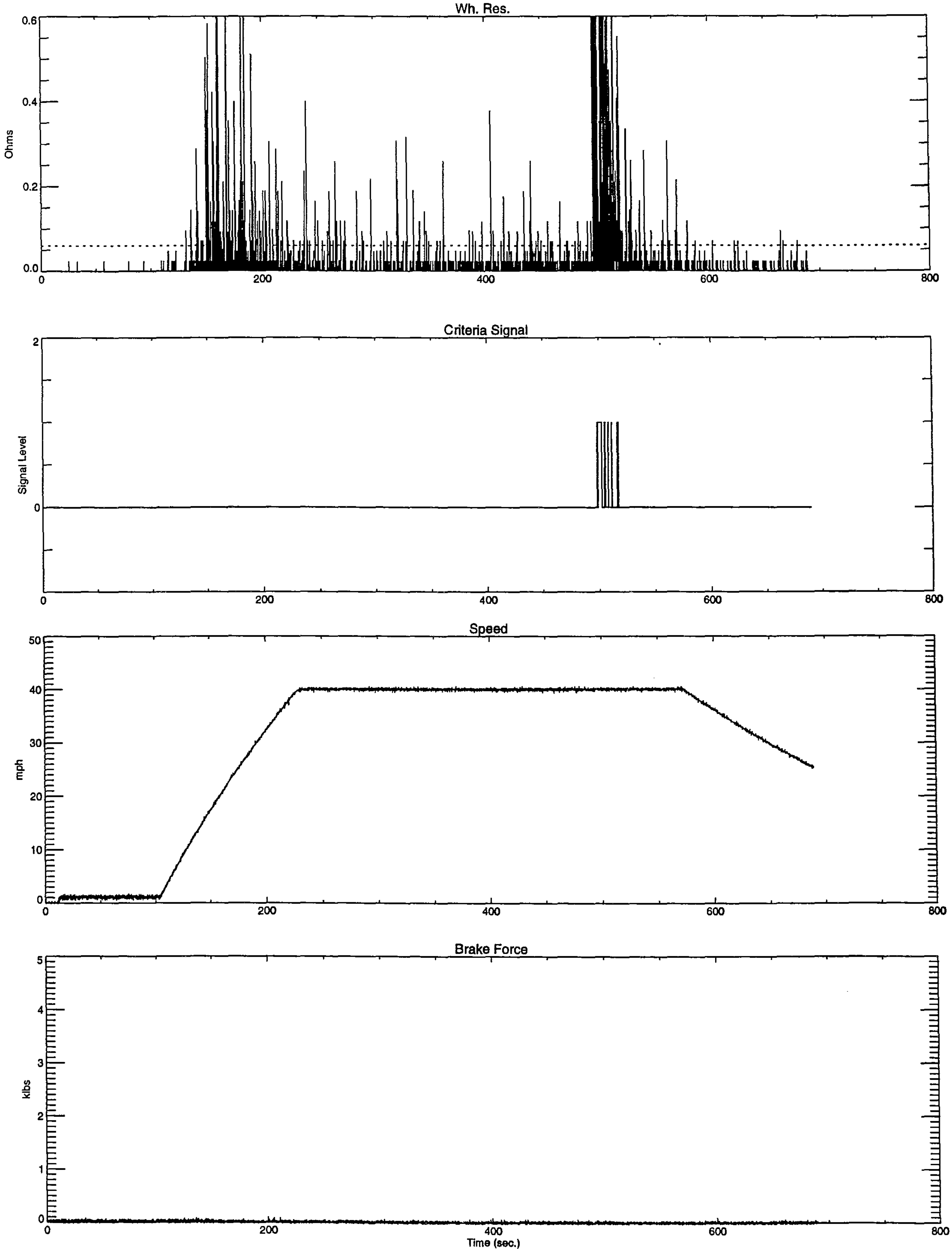
Run 019 A - Wheel Load 24,000 lbs



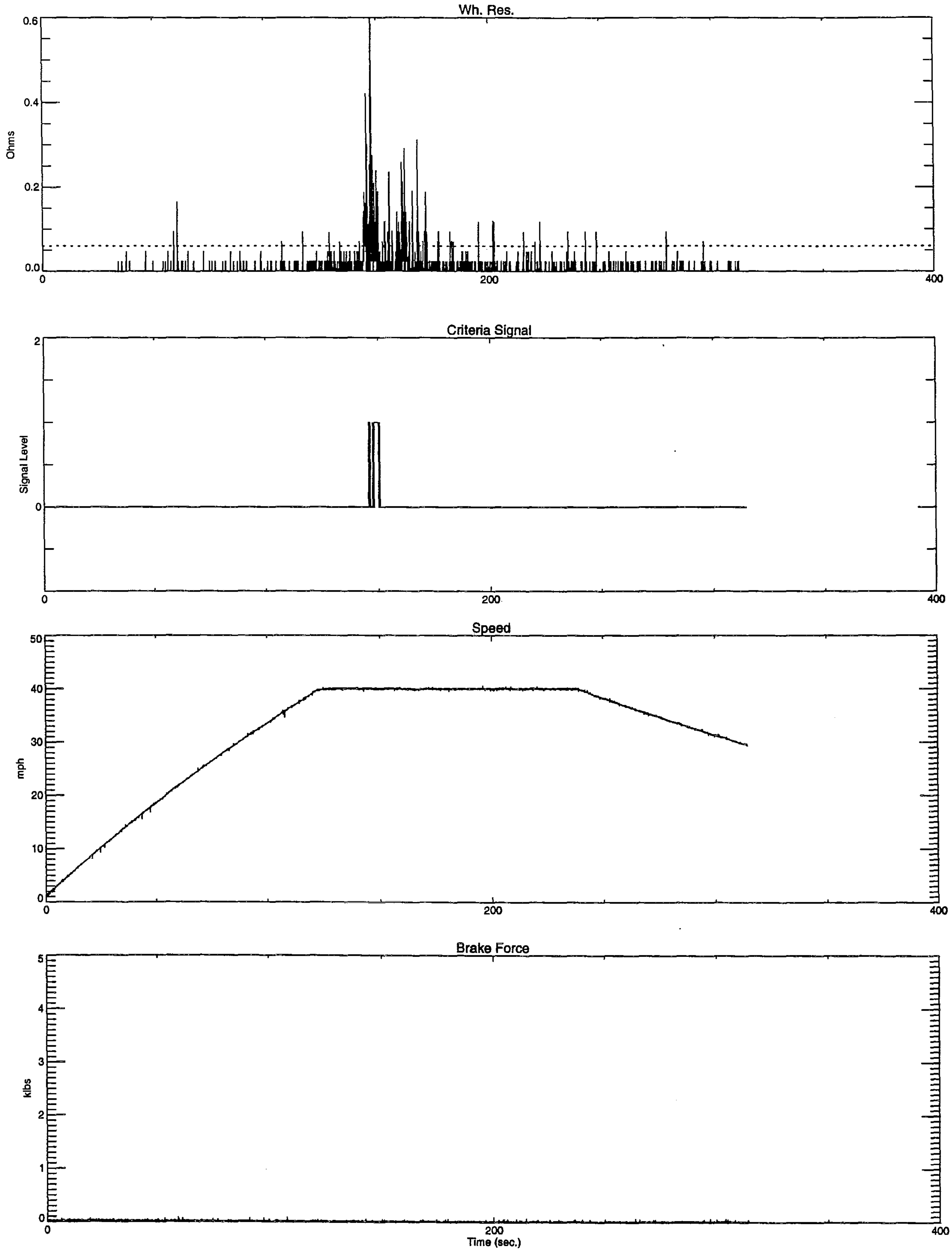
Run 020 A - Wheel Load 9,000 lbs.



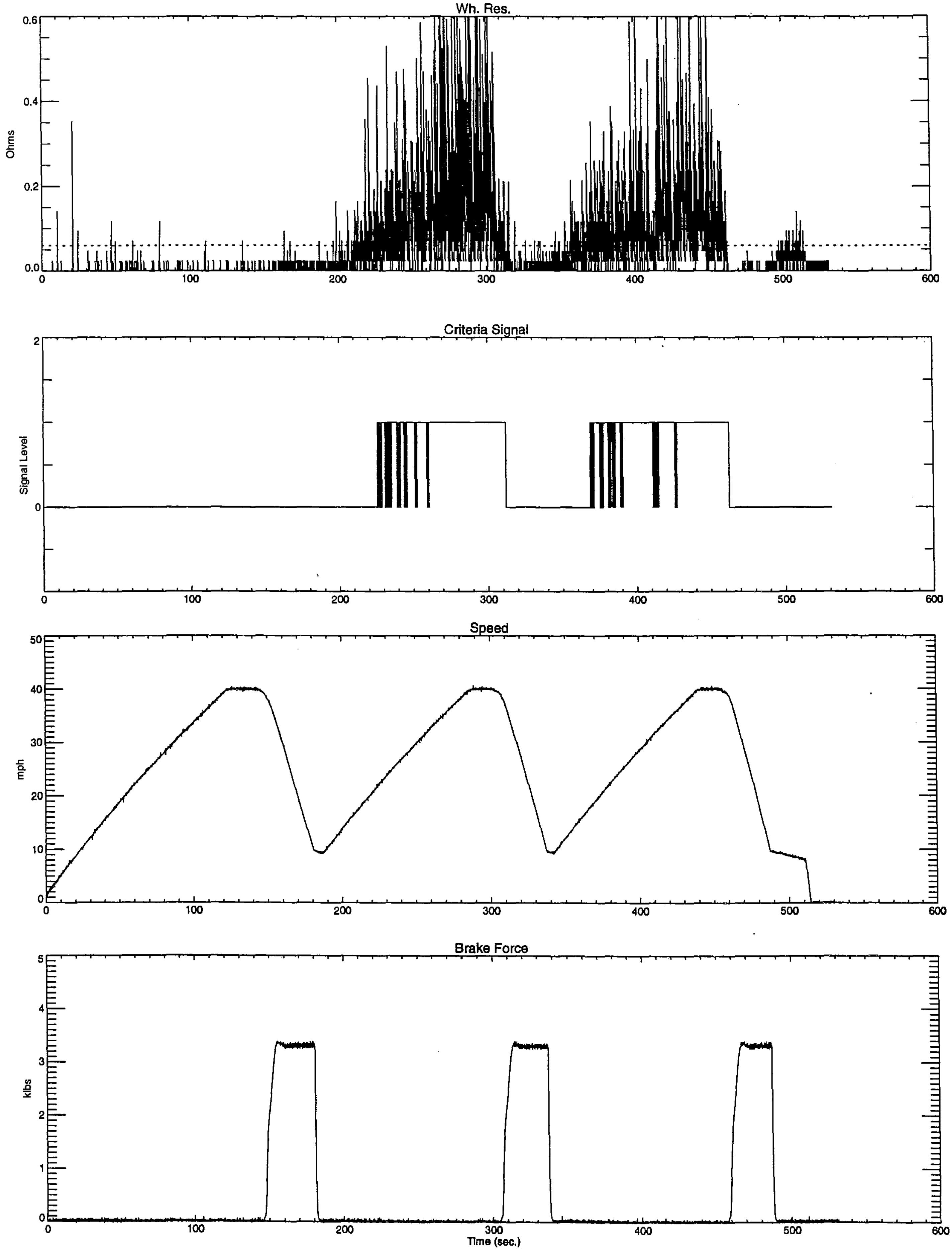
Run 021 A - Wheel Load 6,300 lbs.



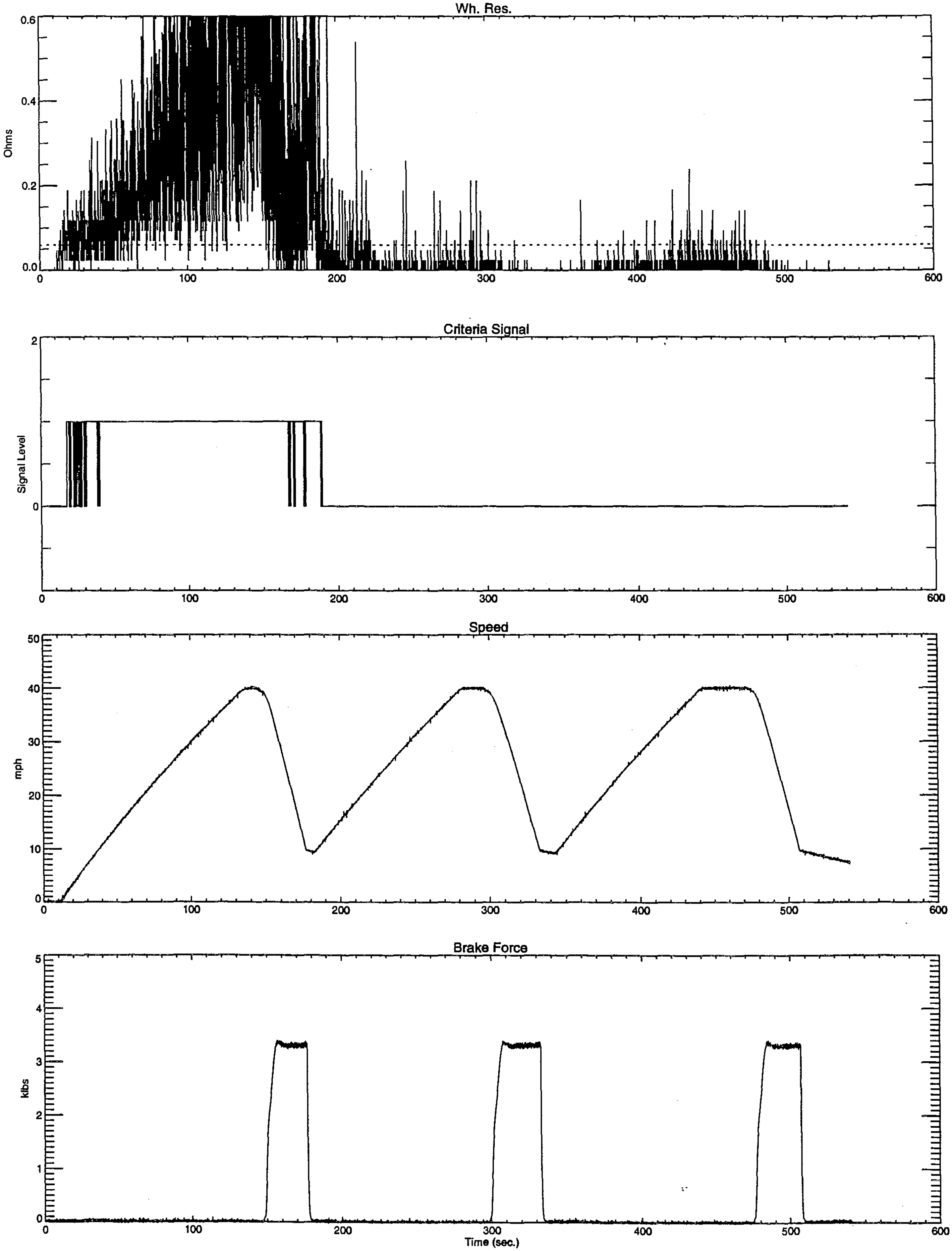
Run 022 A - Wheel Load 12,000 lbs.



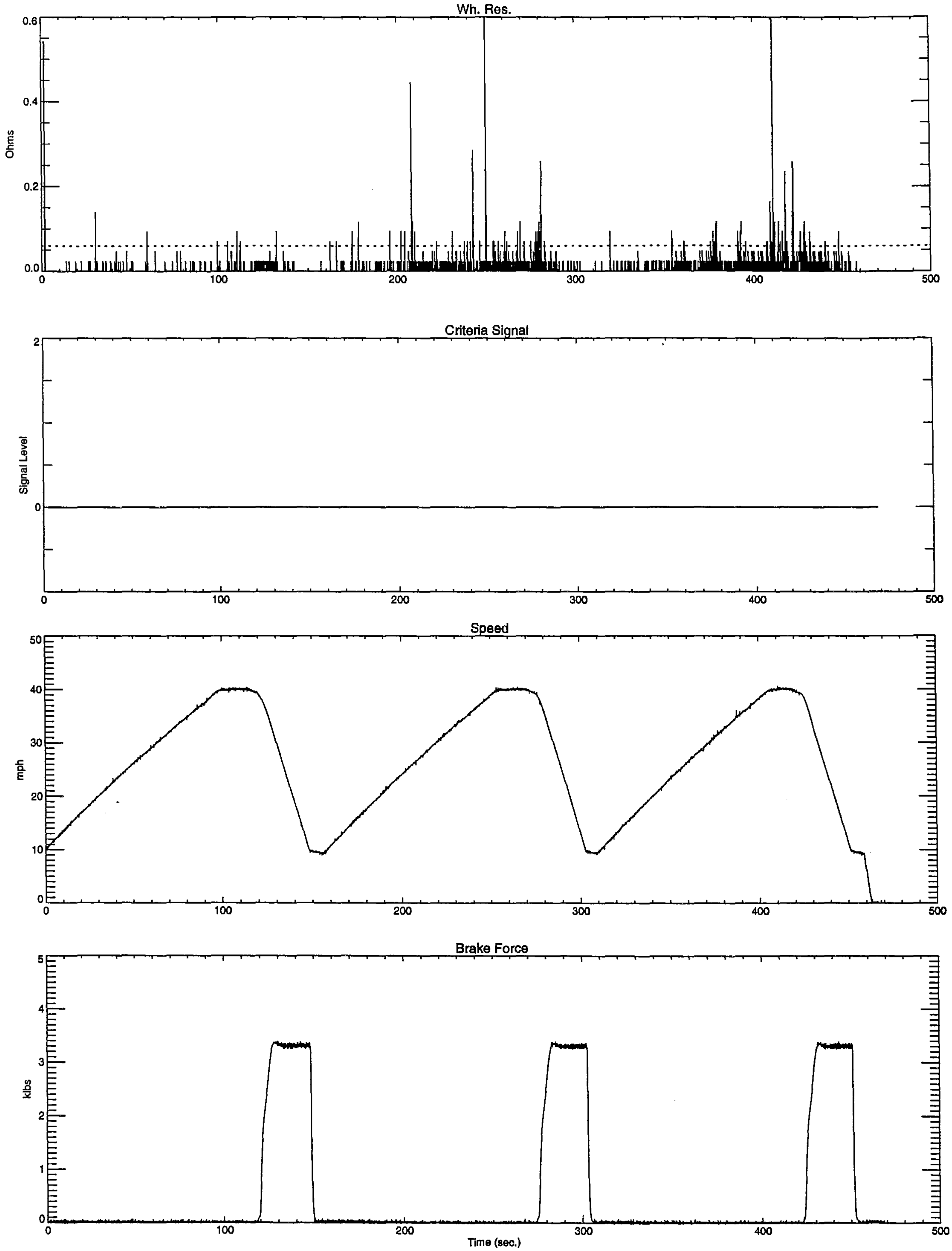
Run 023 A - Wheel Load 6,300 lbs.



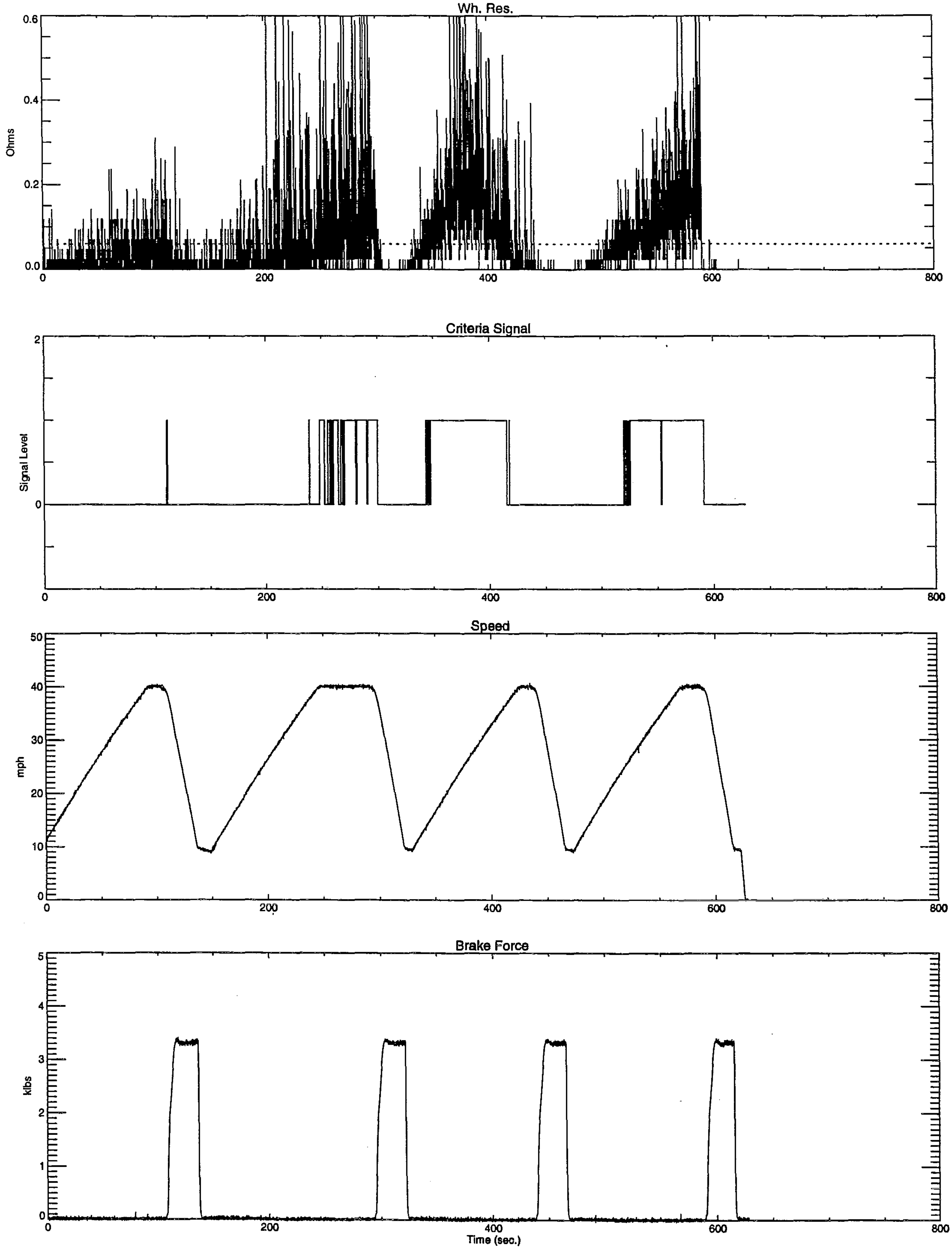
Run 024 A - Wheel Load 6,300 lbs.



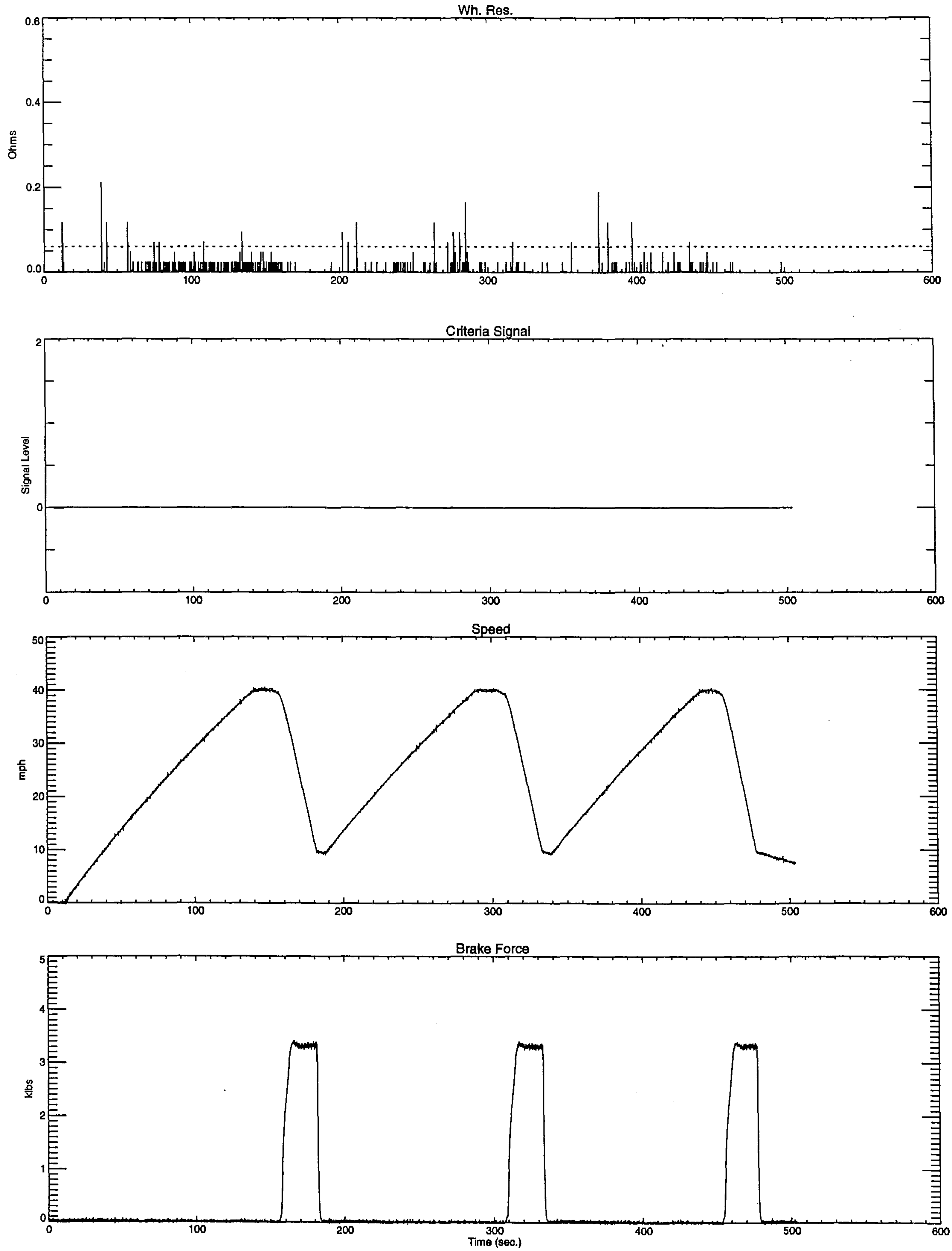
Run 025 A - Wheel Load 6,300 lbs.



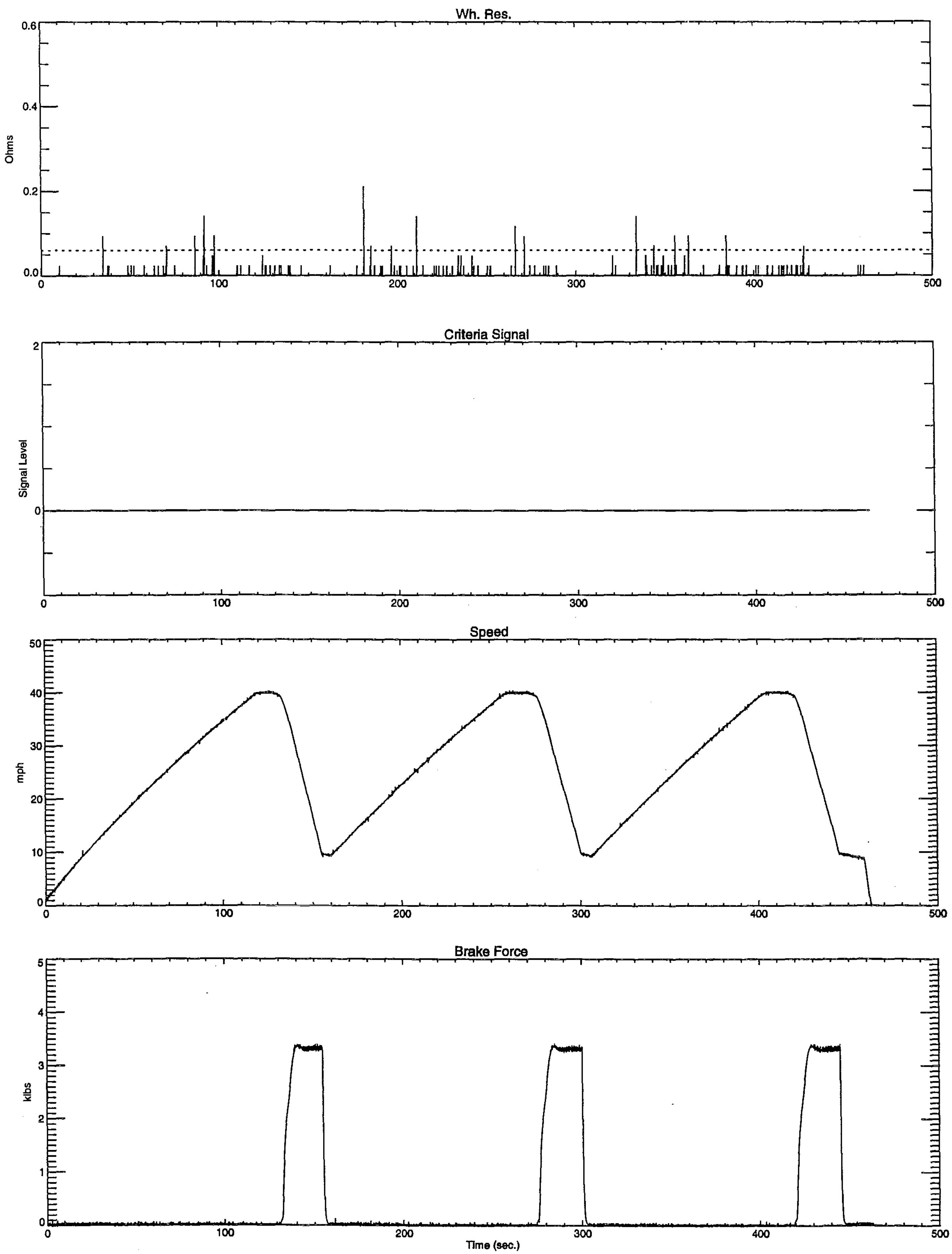
Run 026 A - Wheel Load 6,300 lbs.



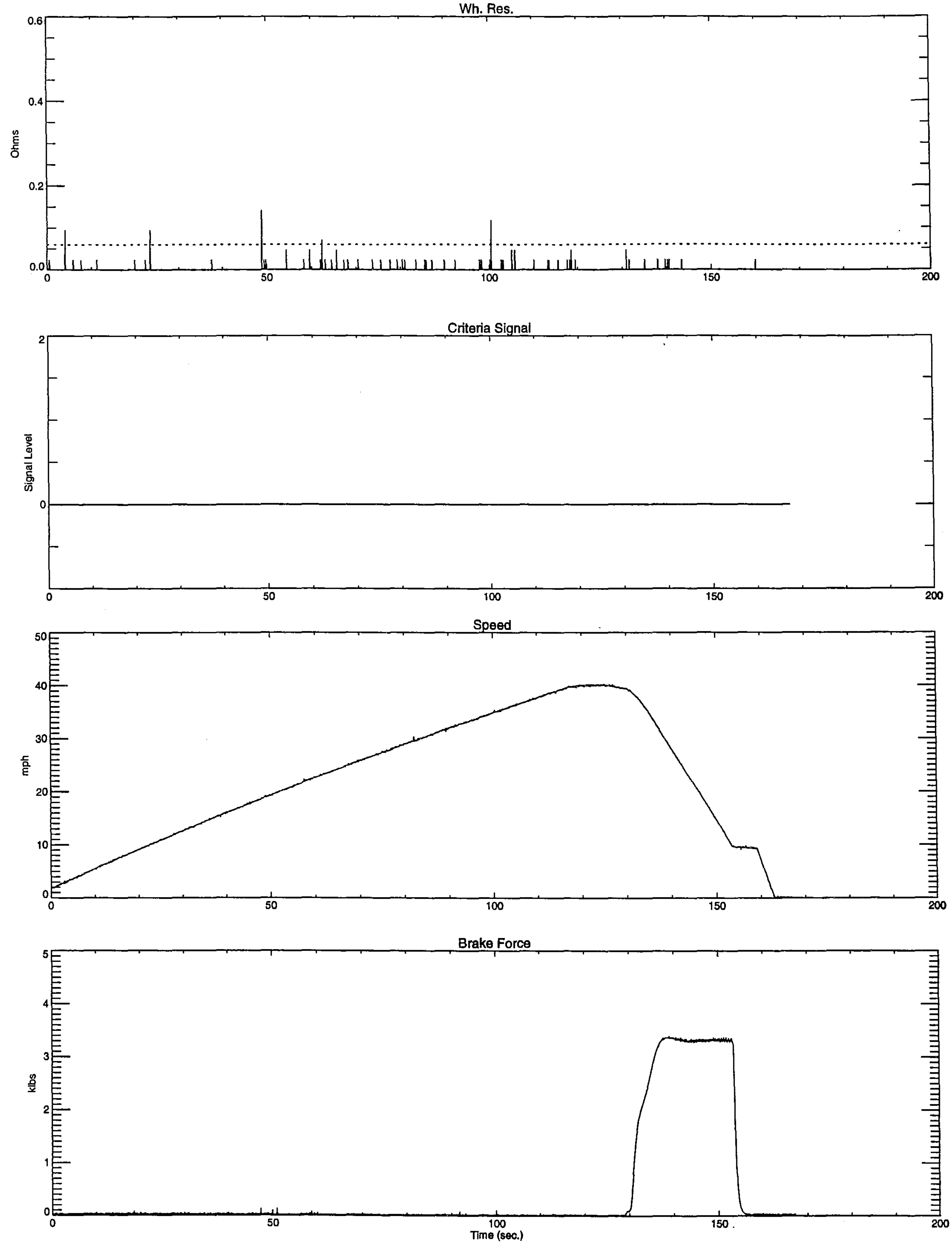
Run 027 A - Wheel Load 18,000 lbs.



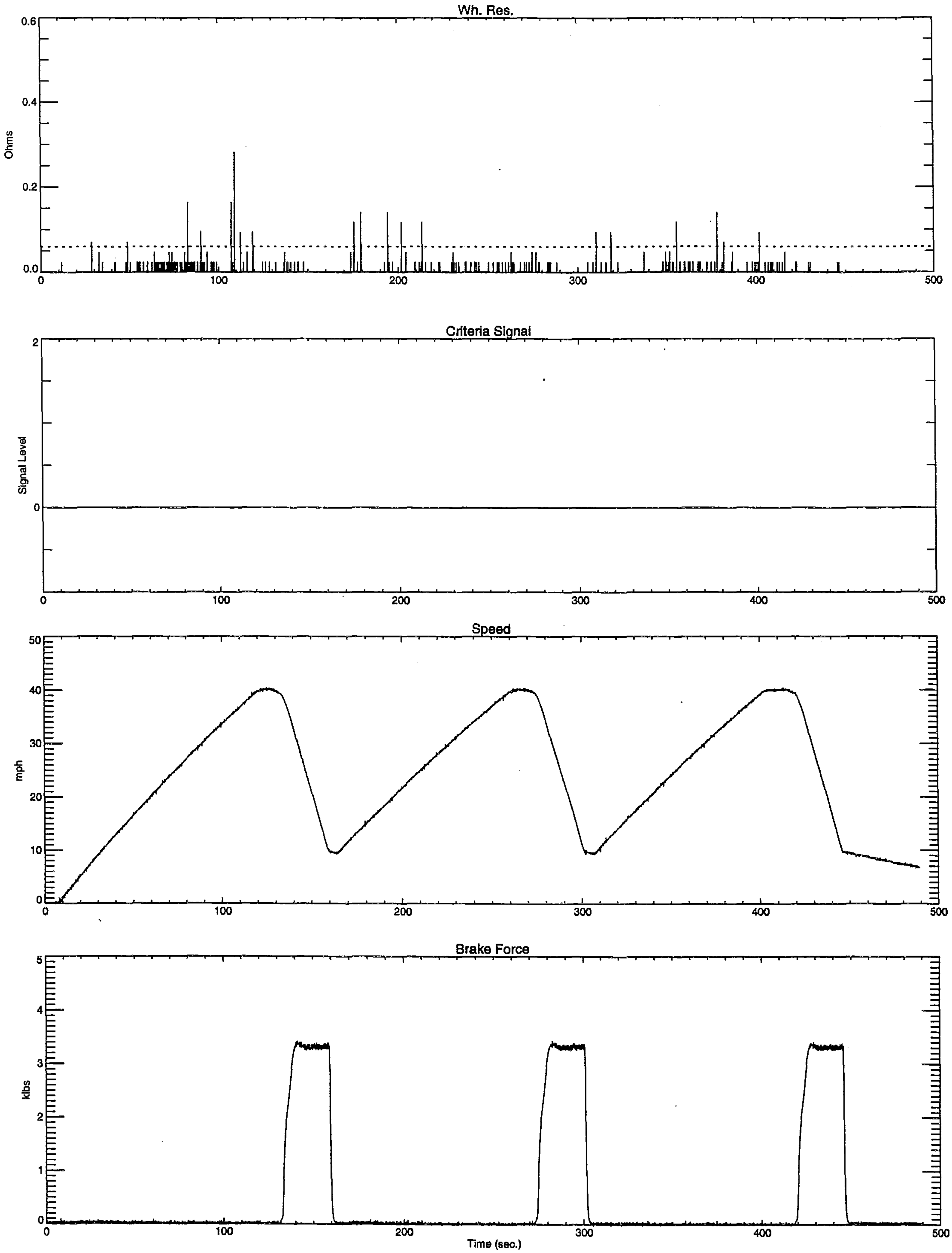
Run 028 A - Wheel Load 9,000 lbs.



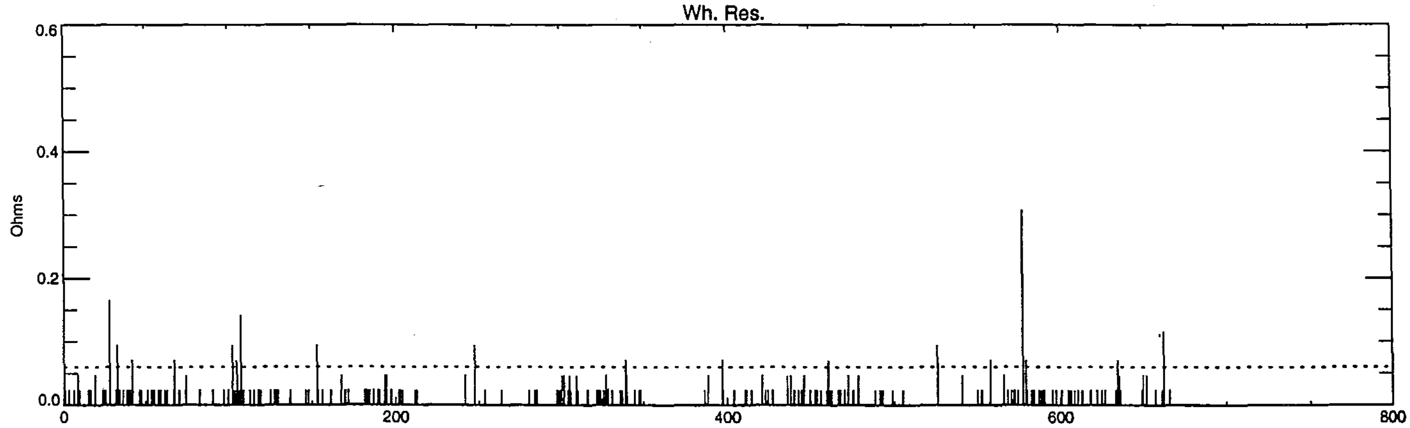
Run 029 A - Wheel Load 6,300 lbs.

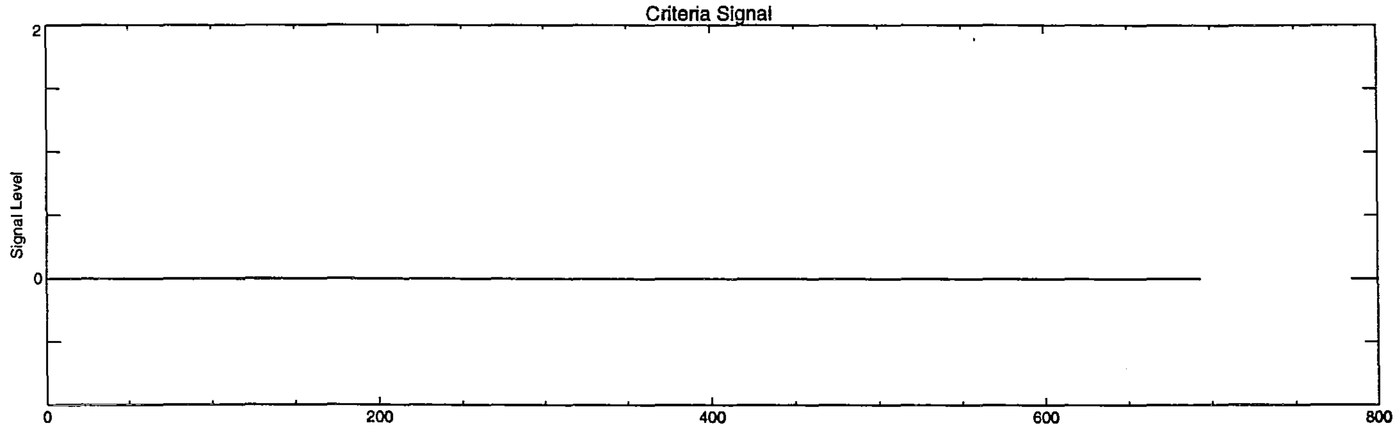


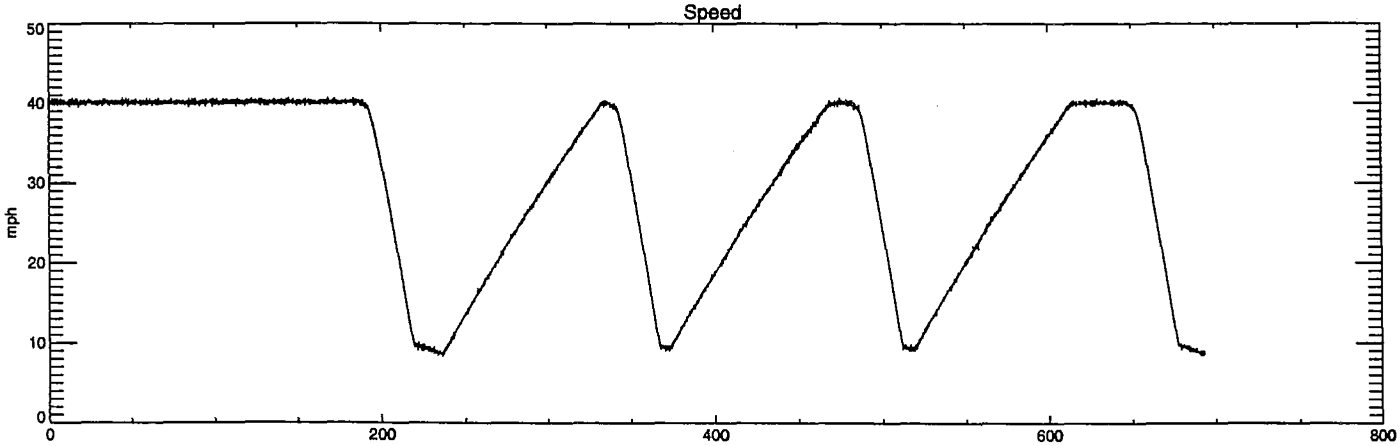
Run 030 A - Wheel Load 6,300 lbs.

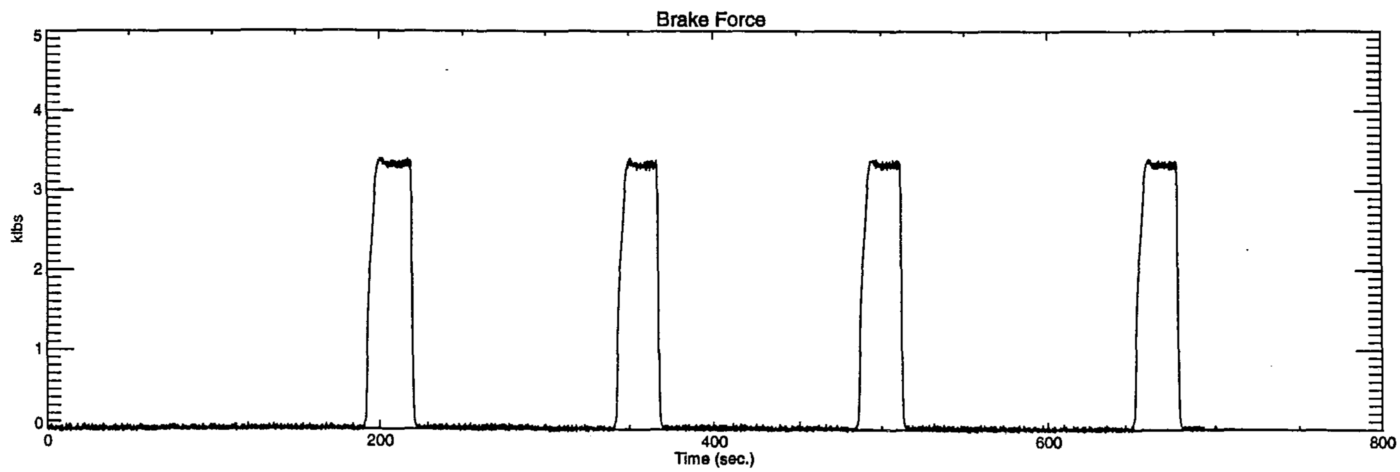


Run 032 A - Wheel Load 6,300 lbs.

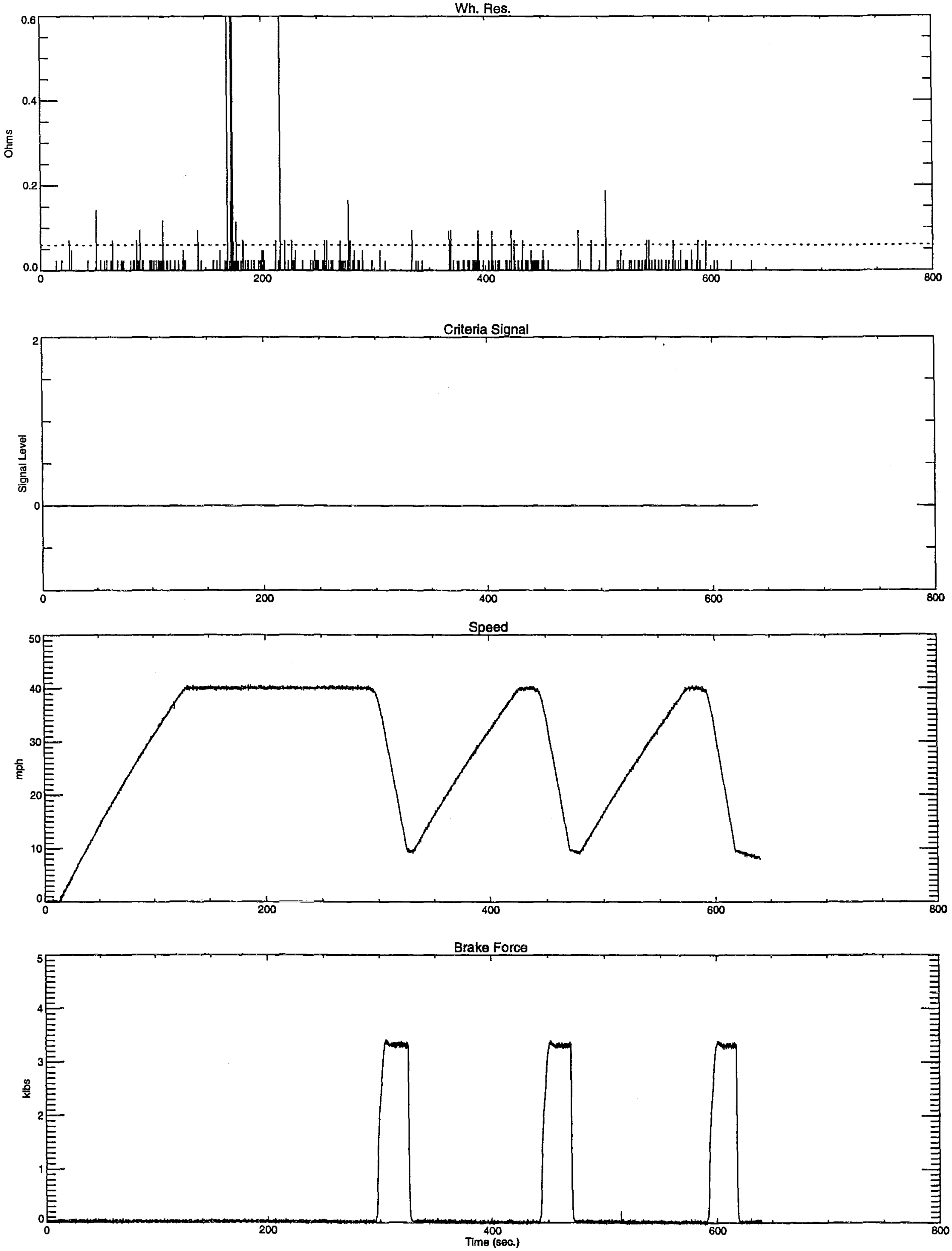




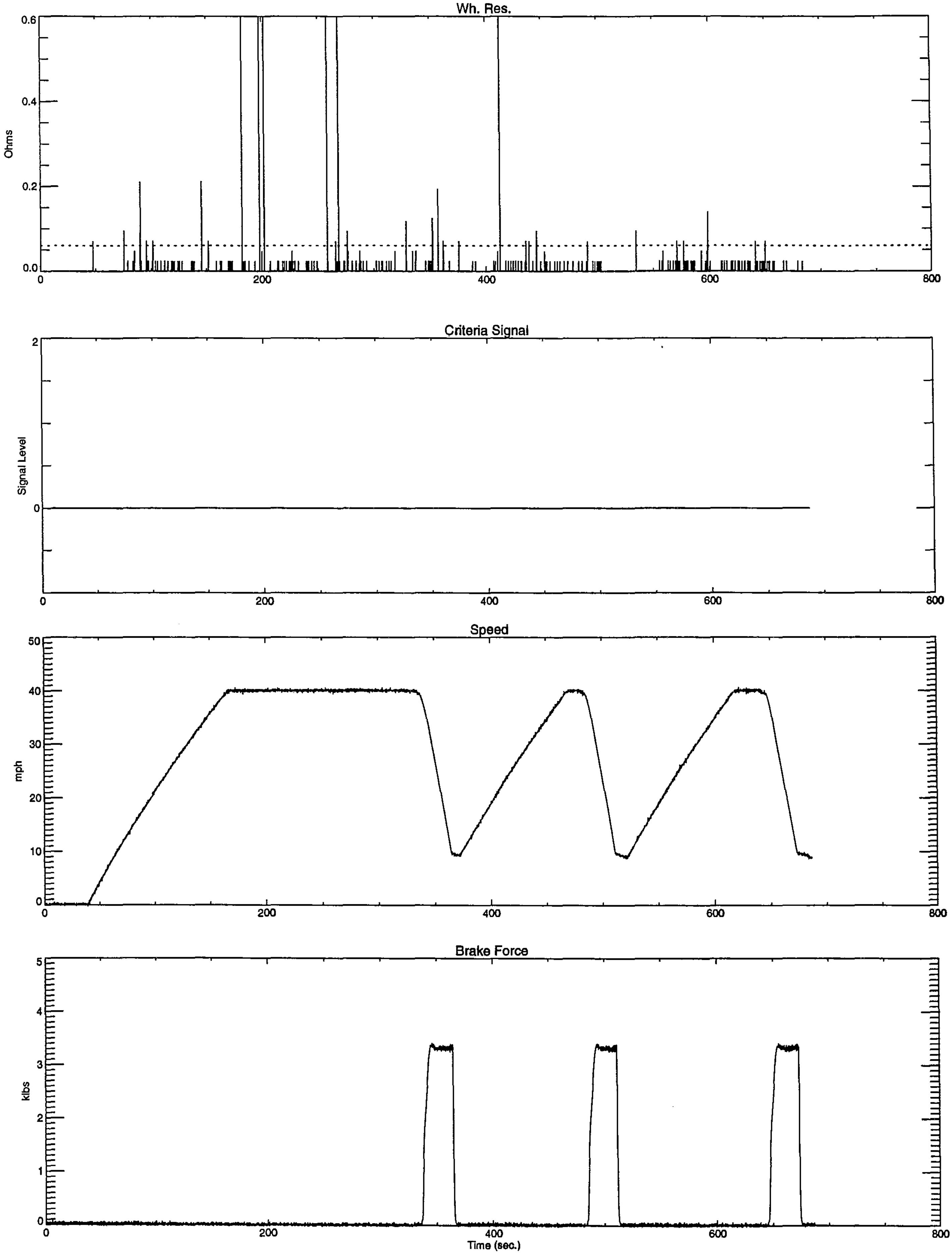




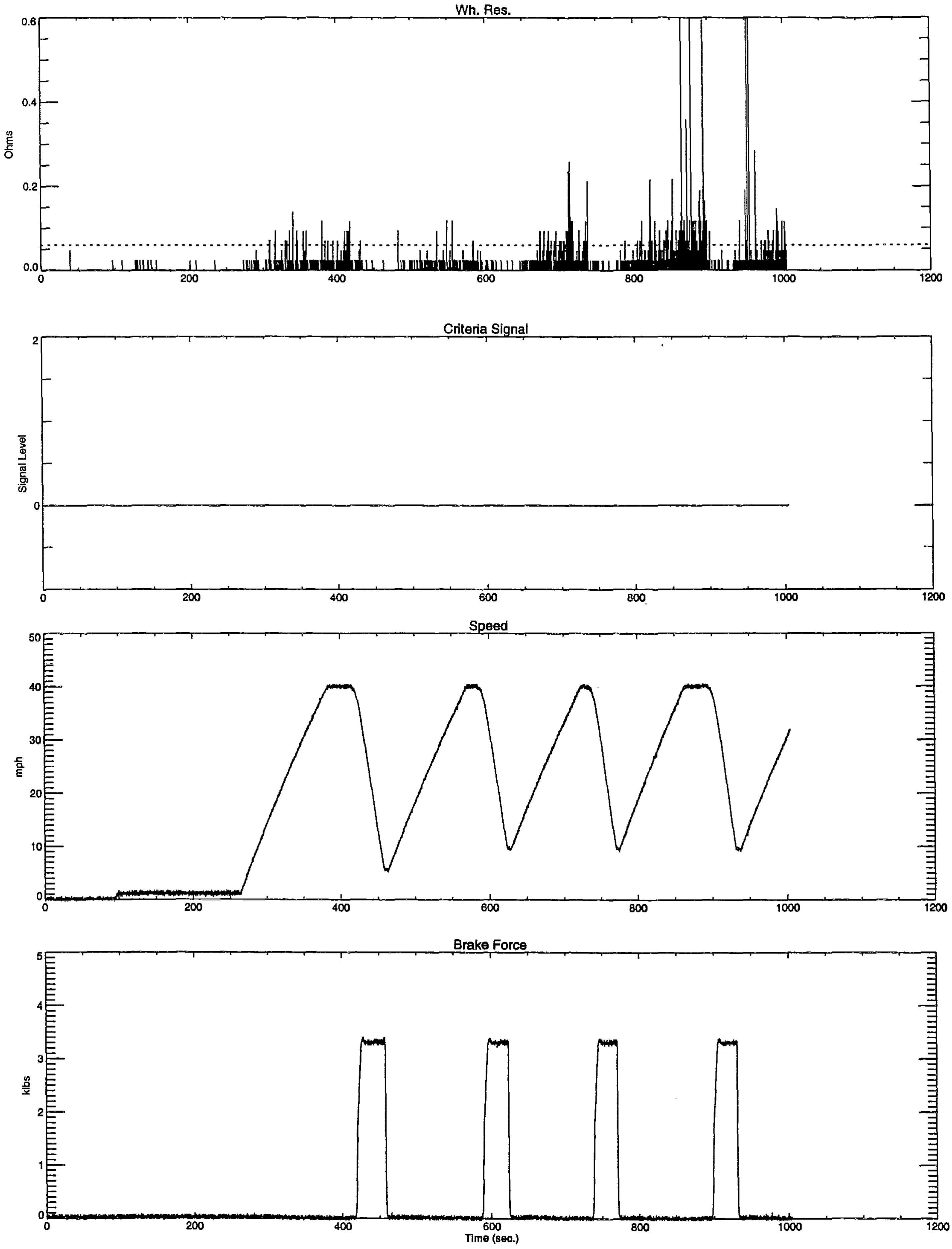
Run 033 A - Wheel Load 6,300 lbs.



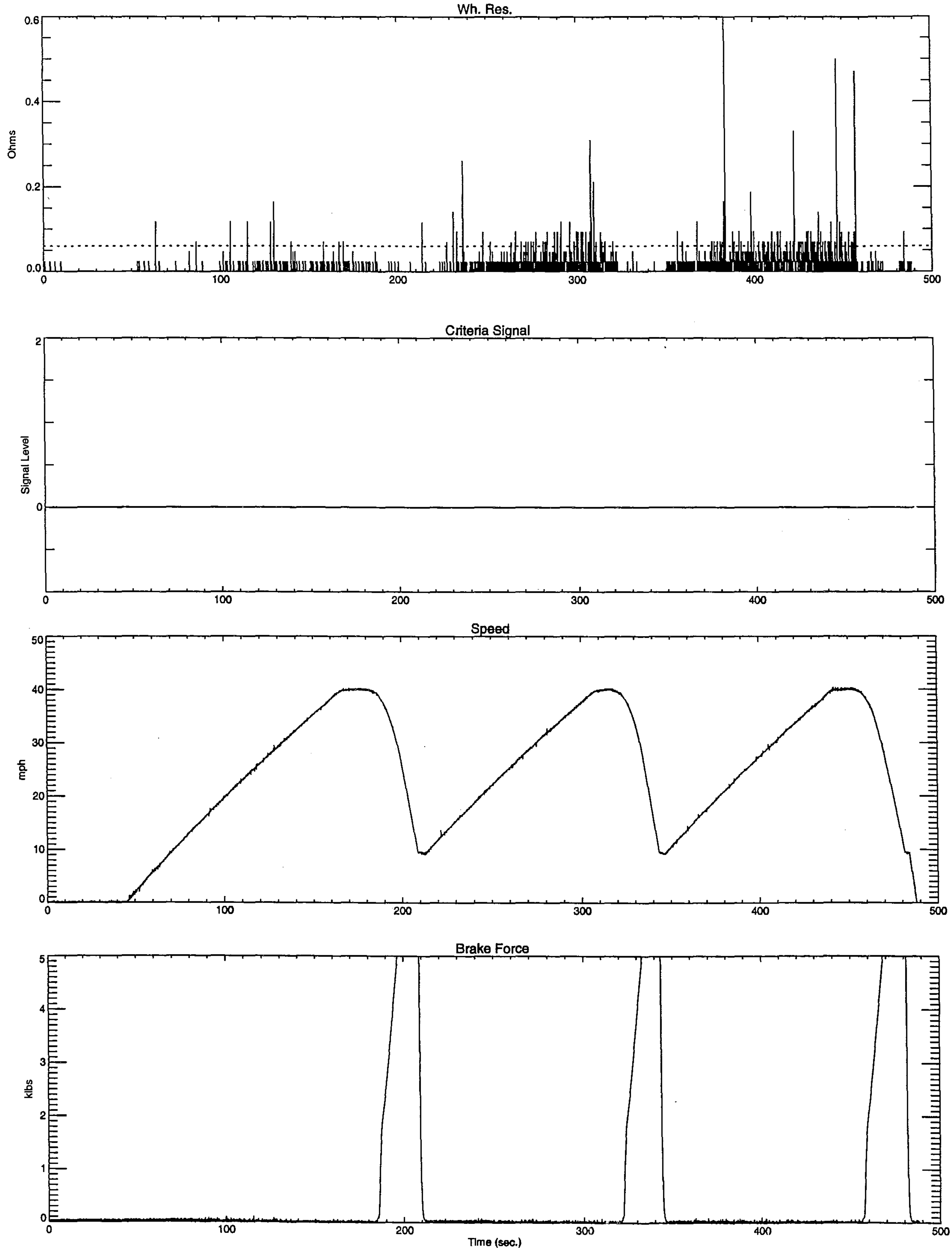
Run 034 A - Wheel Load 6,300 lbs.



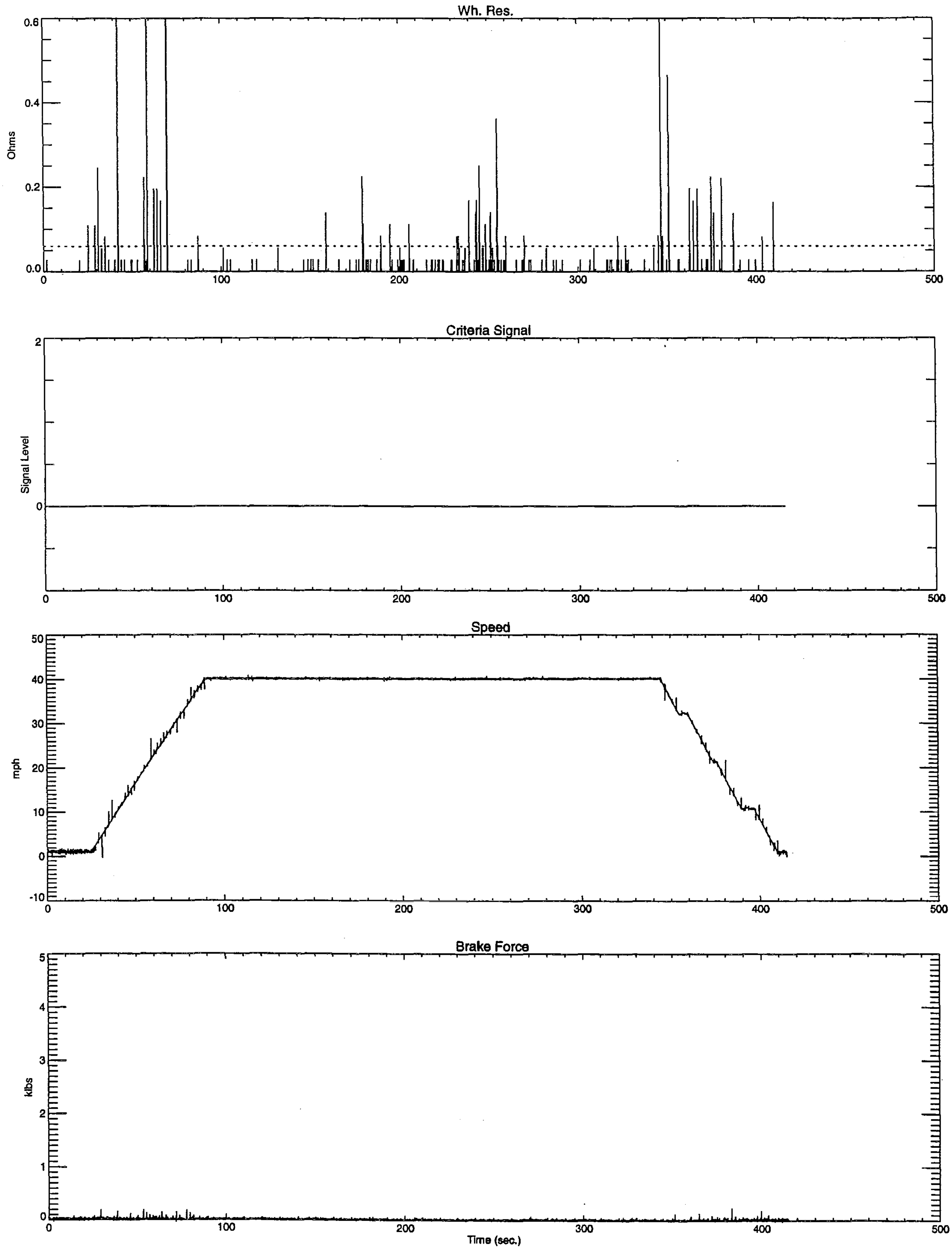
Run 036 A - Wheel Load 6,300 lbs.



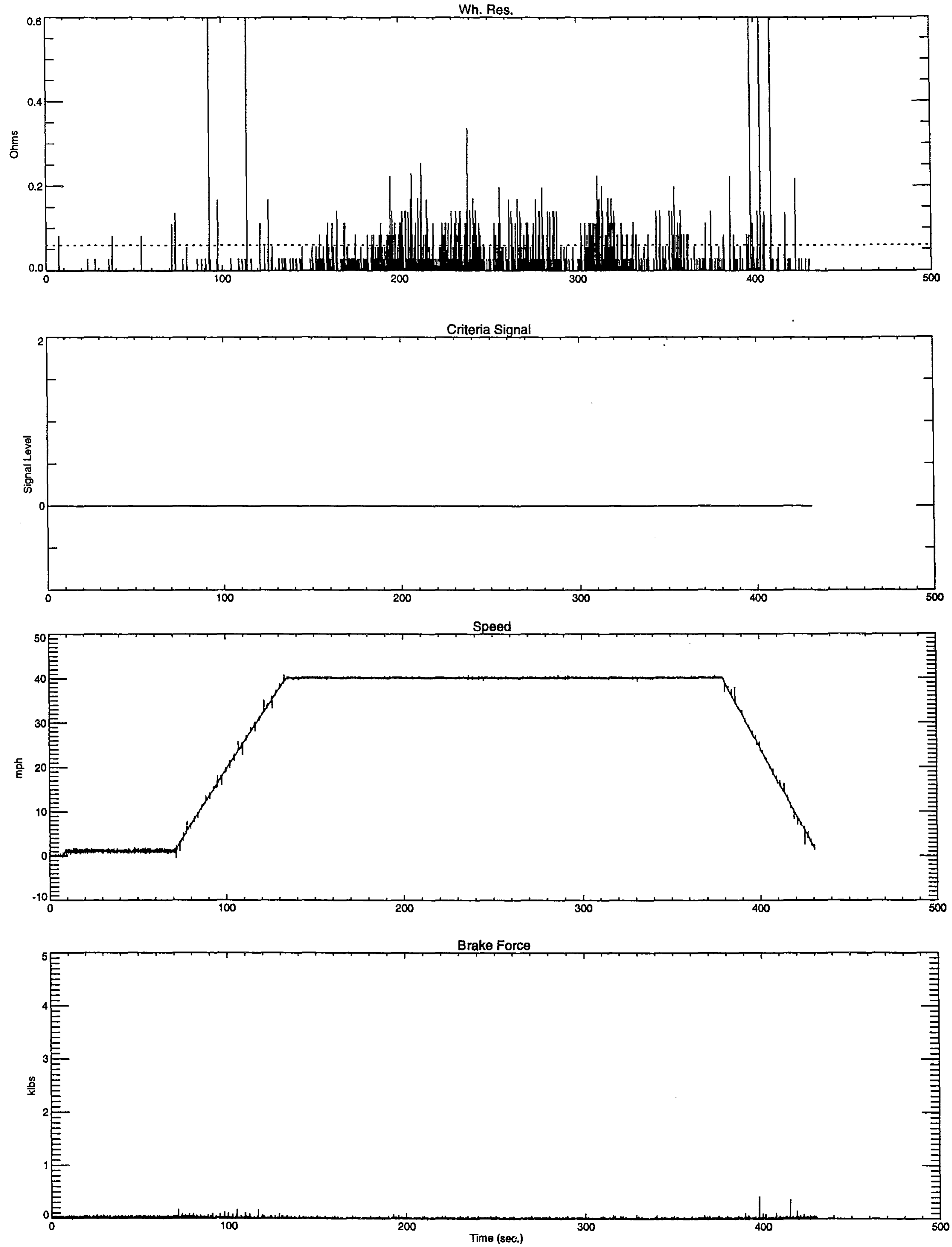
Run 038 A - Wheel Load 6,300 lbs.



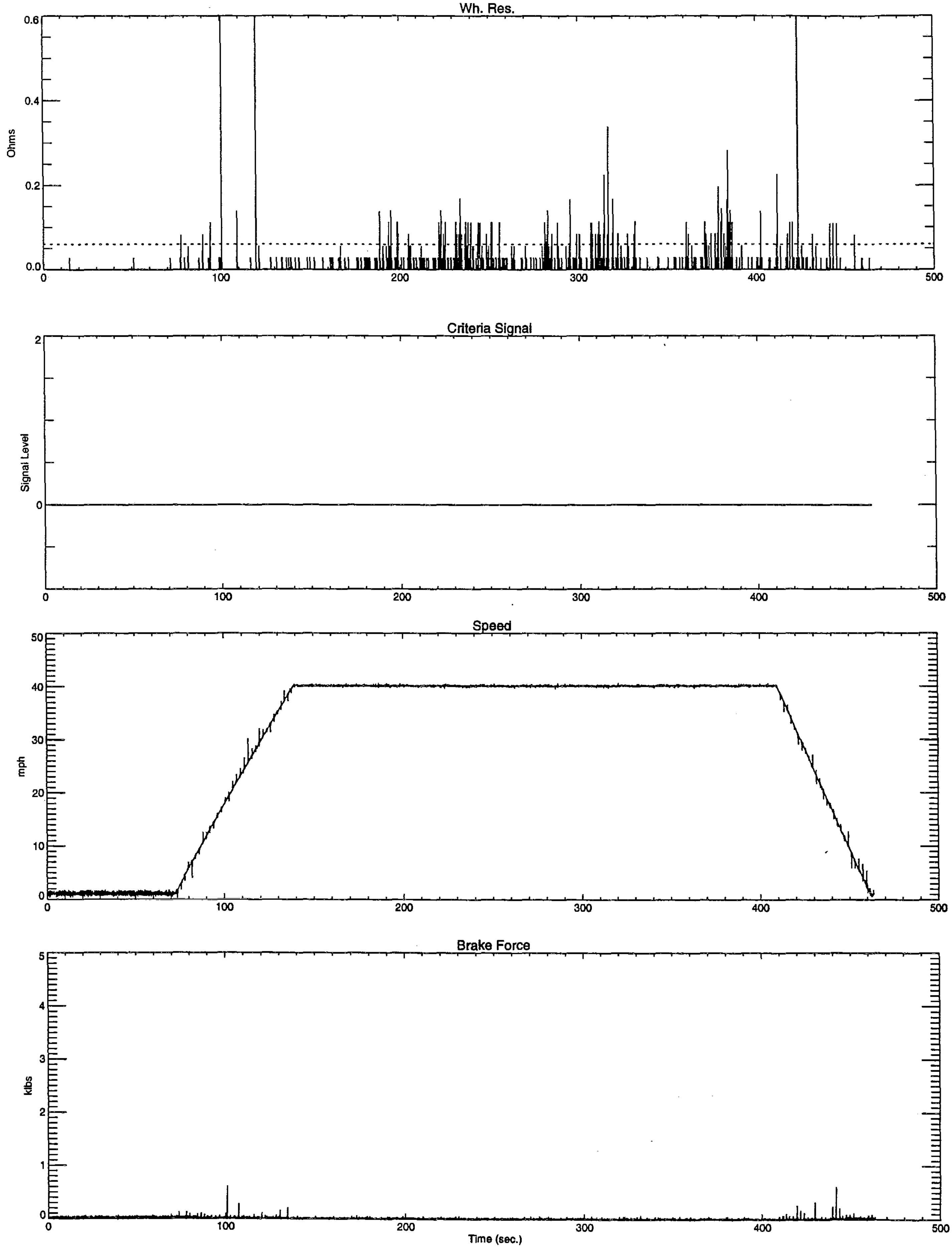
Run 003 B - Wheel Load 6,300 lbs.



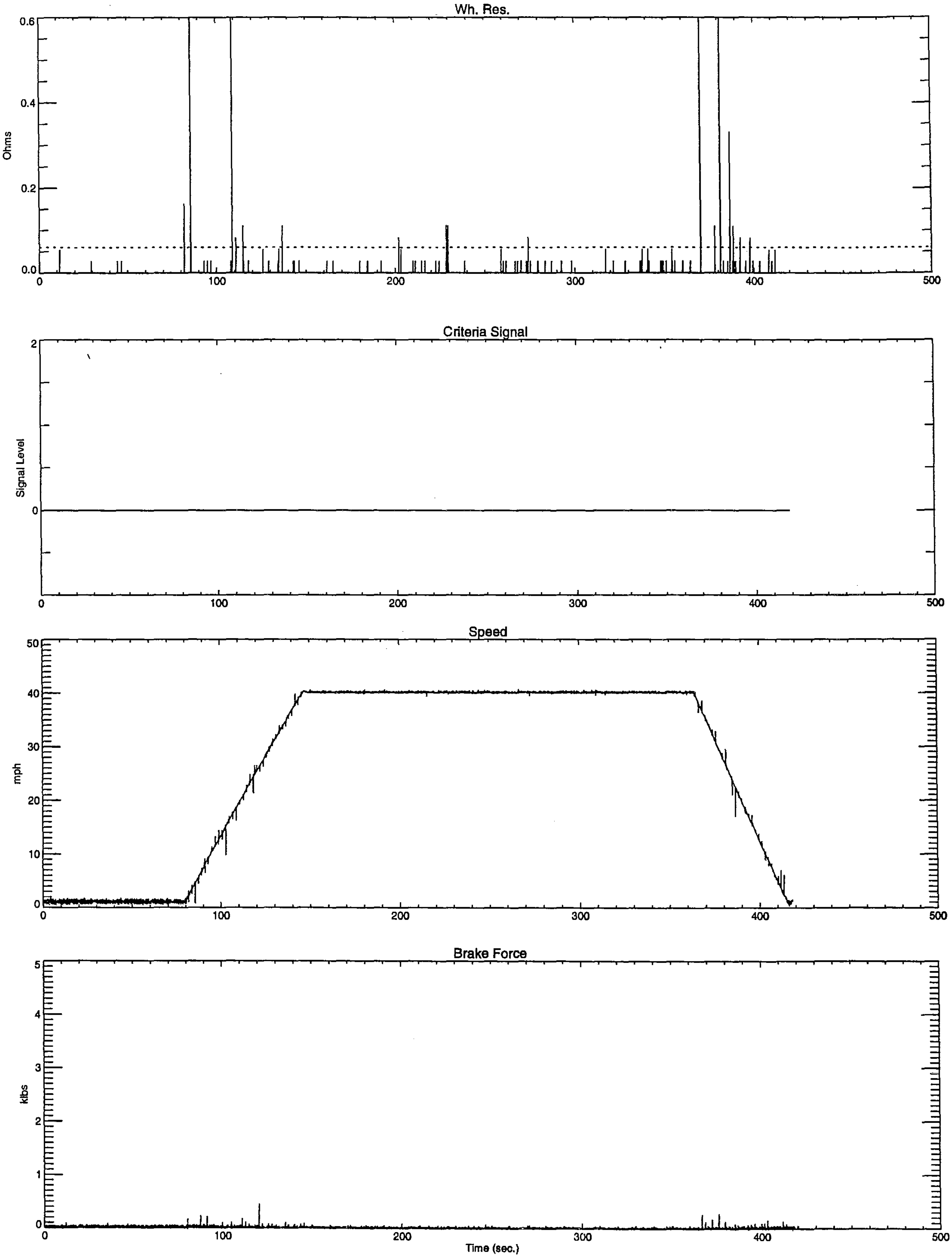
Run 004 B - Wheel Load 6,300 lbs.



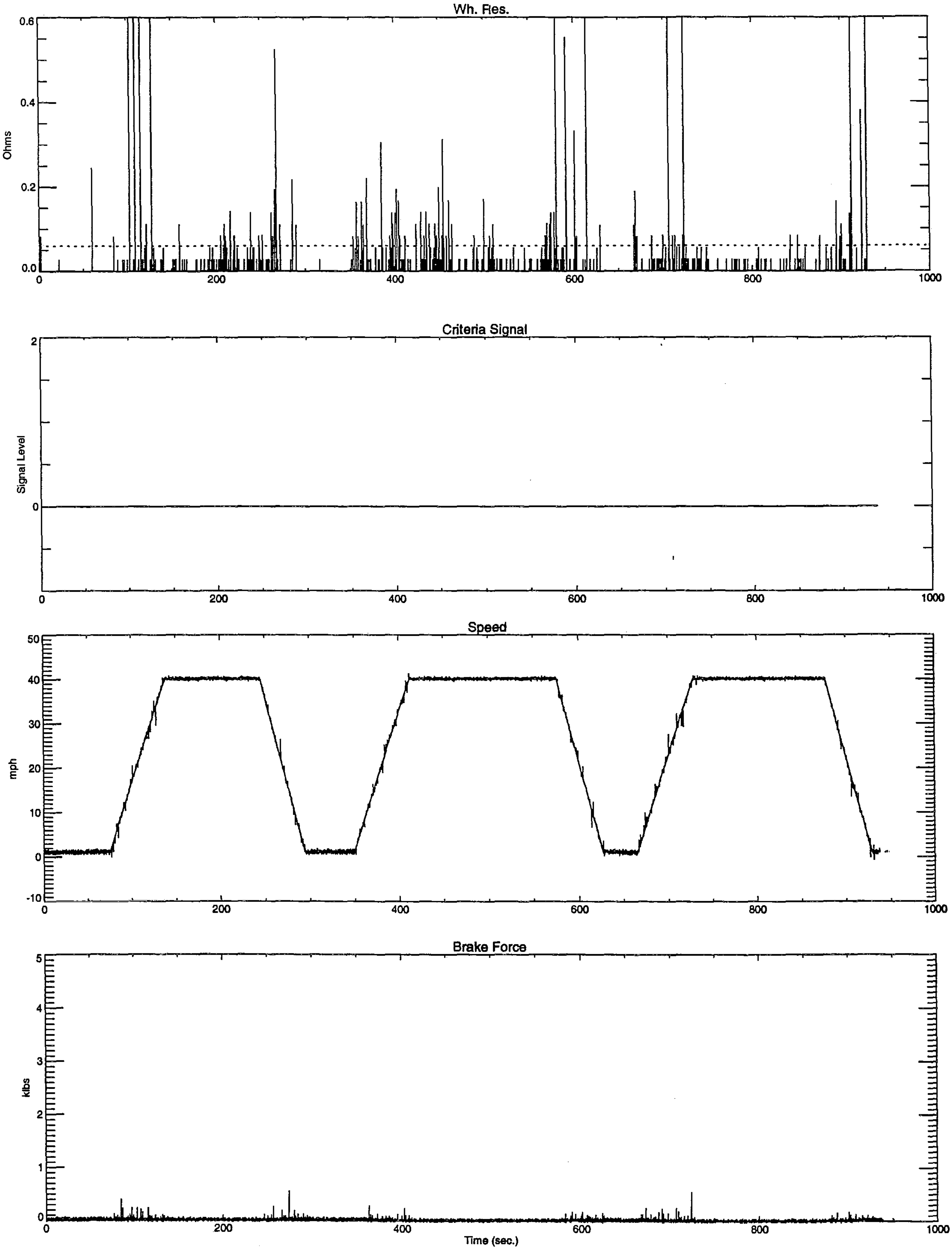
Run 006 B - Wheel Load 6,300 lbs.



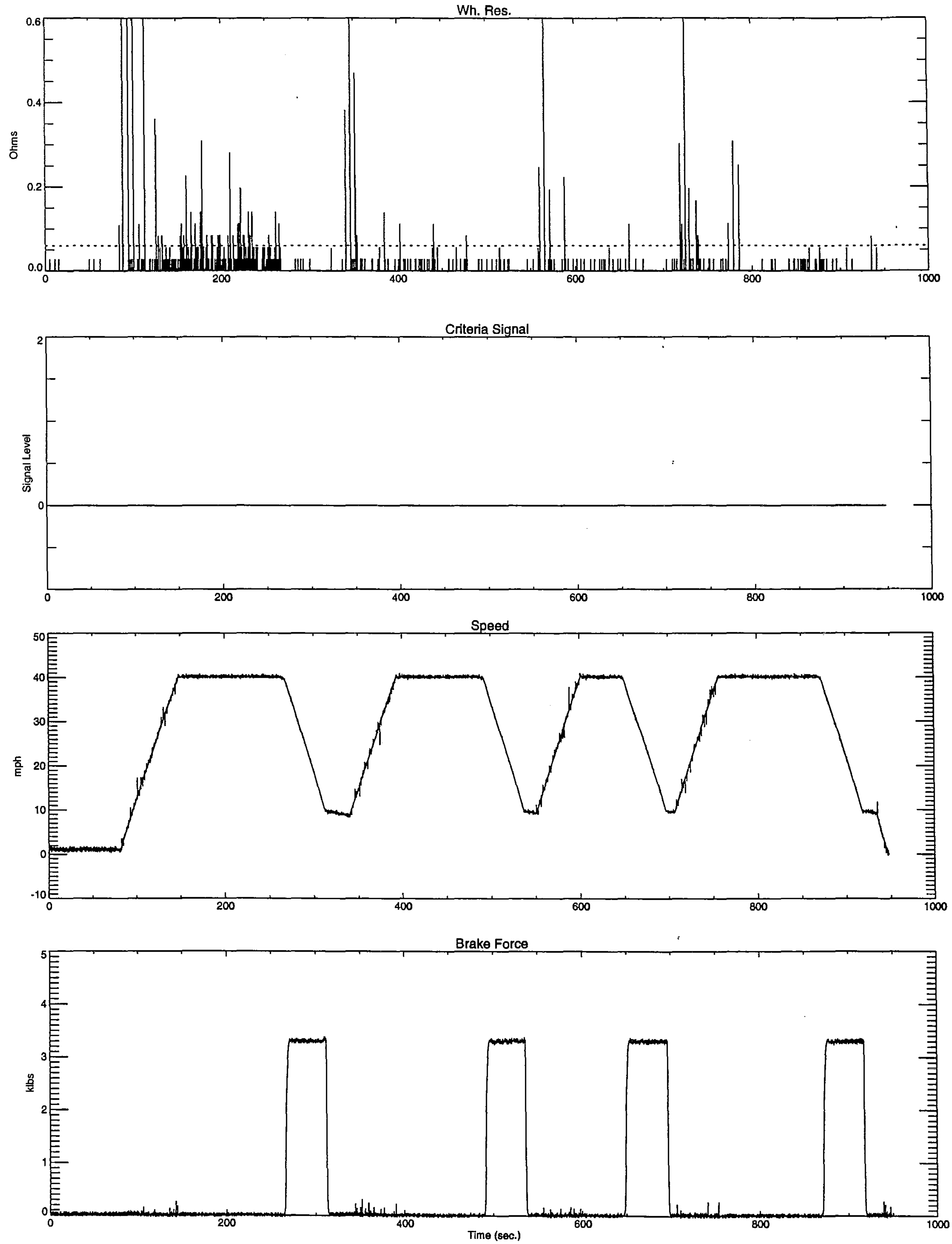
Run 007 B - Wheel Load 6,300 lbs



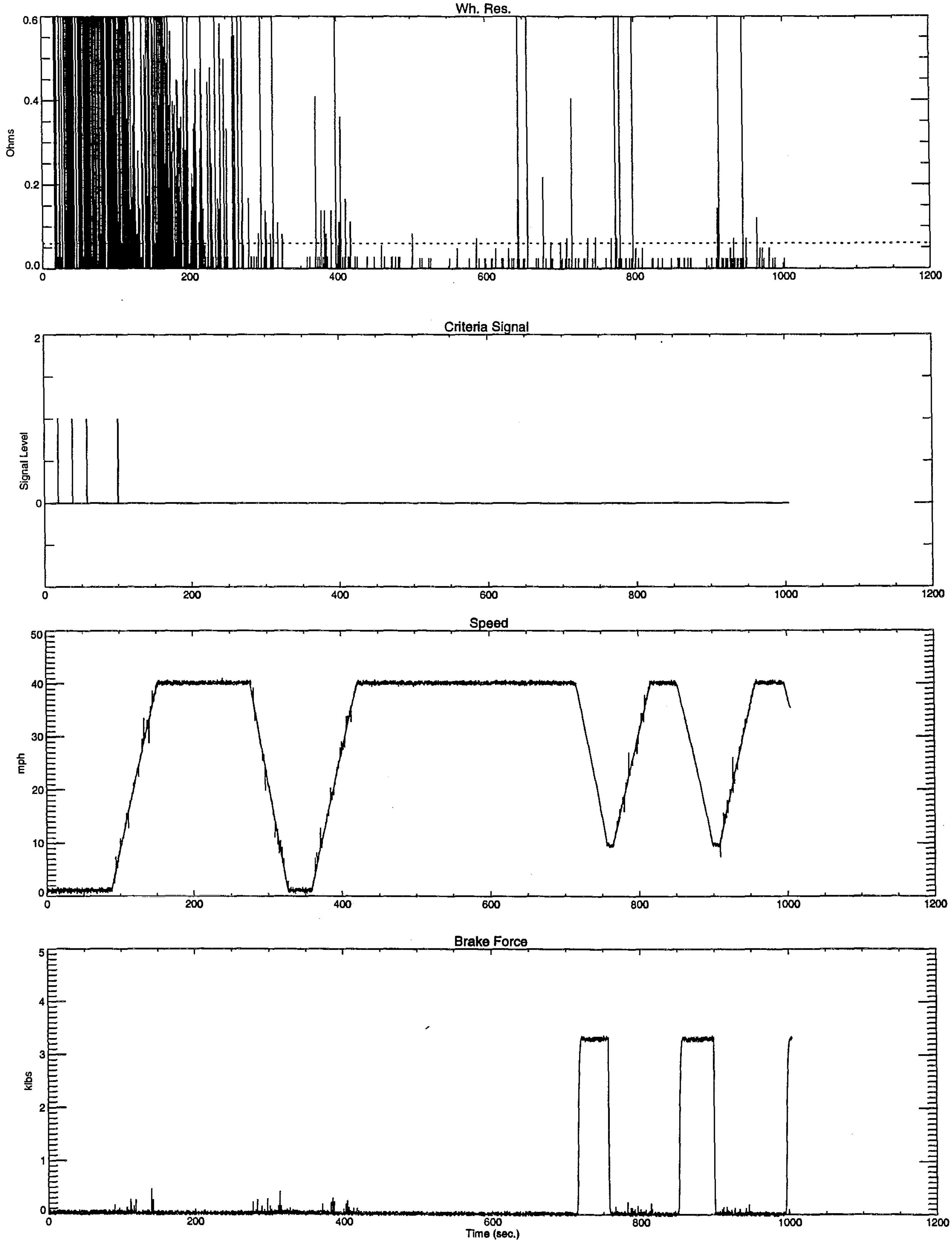
Run 008 B - Wheel Load 6,300 lbs.



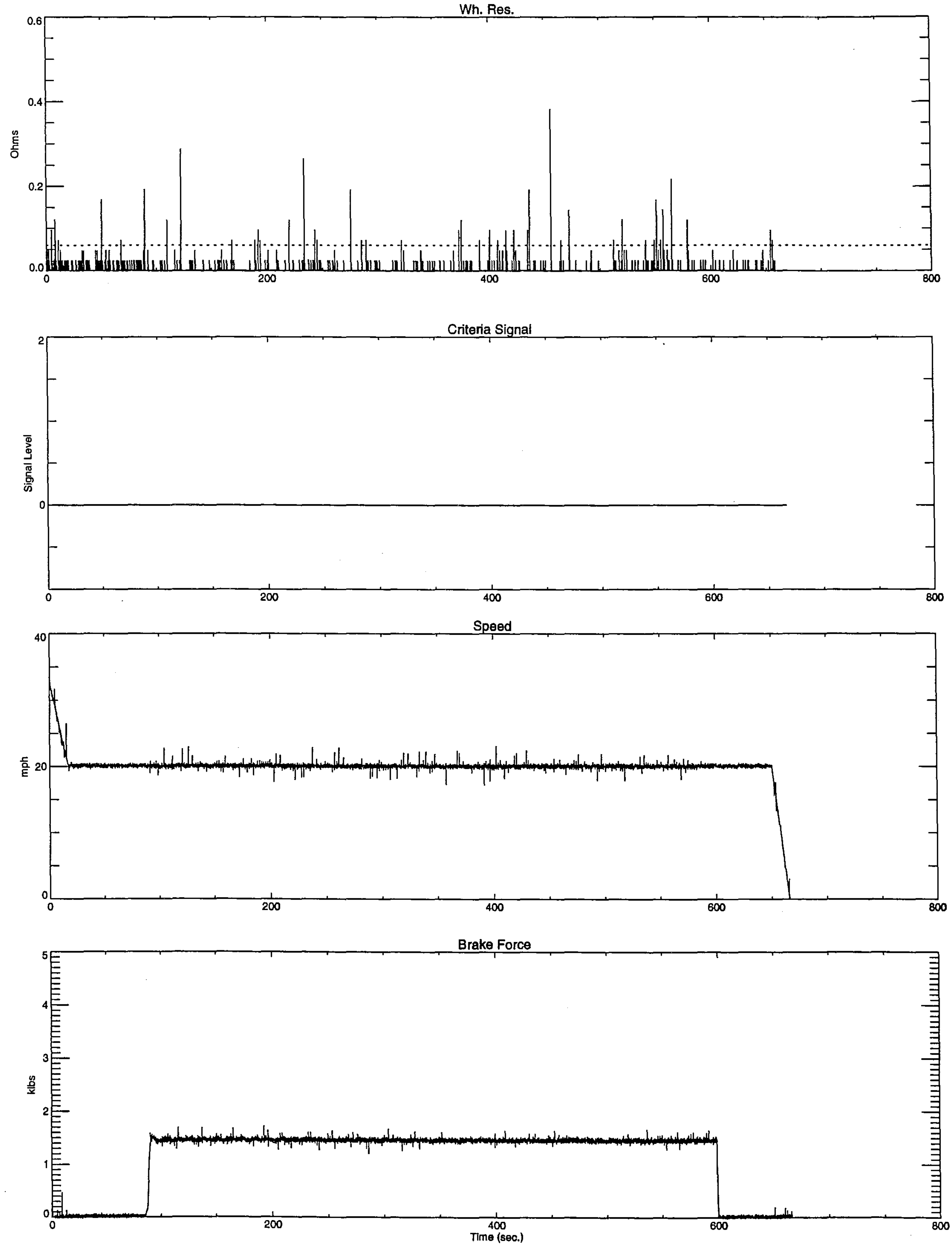
Run 009 B - Wheel Load 6,300 lbs.



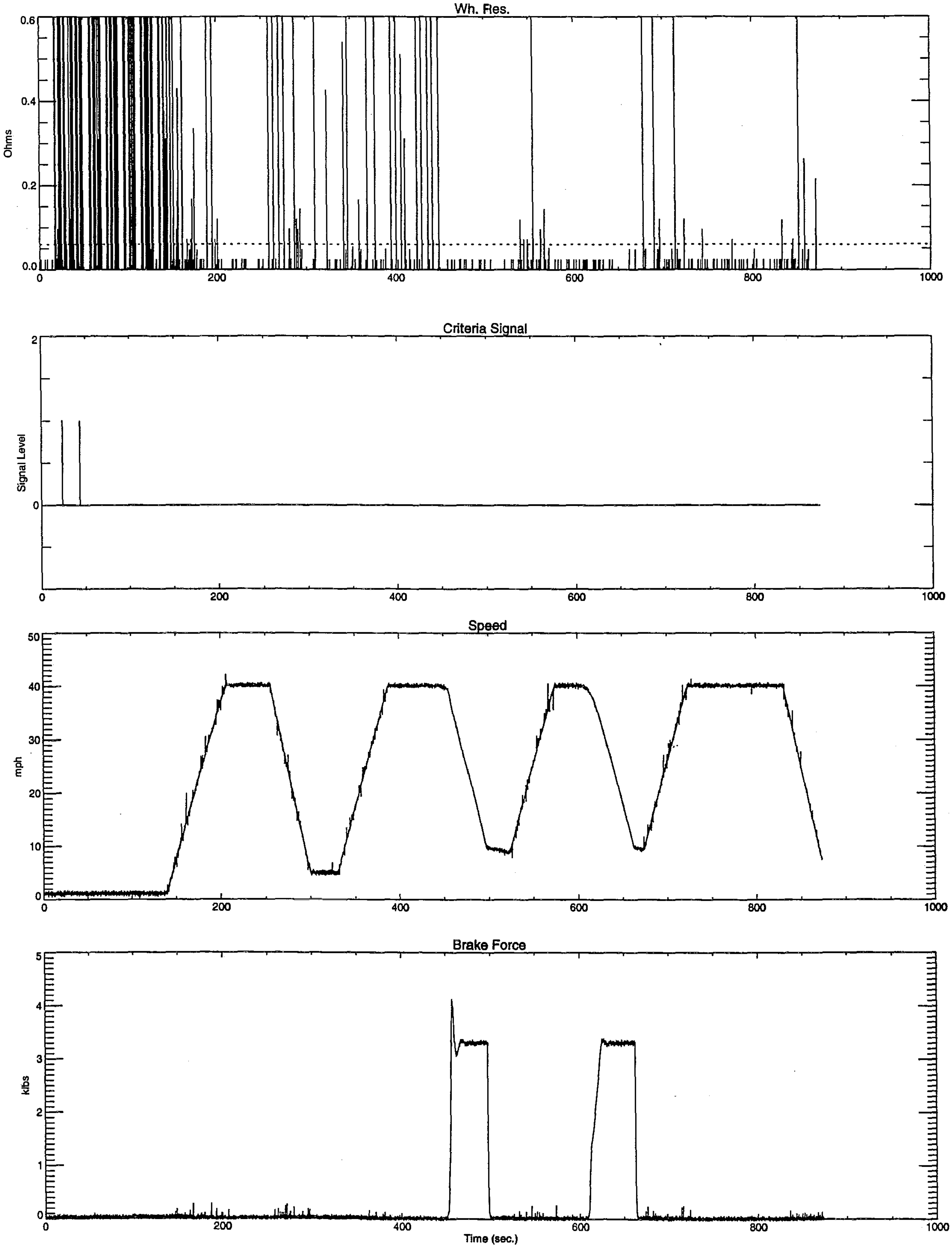
Run 010 B - Wheel Load 6,300 lbs.



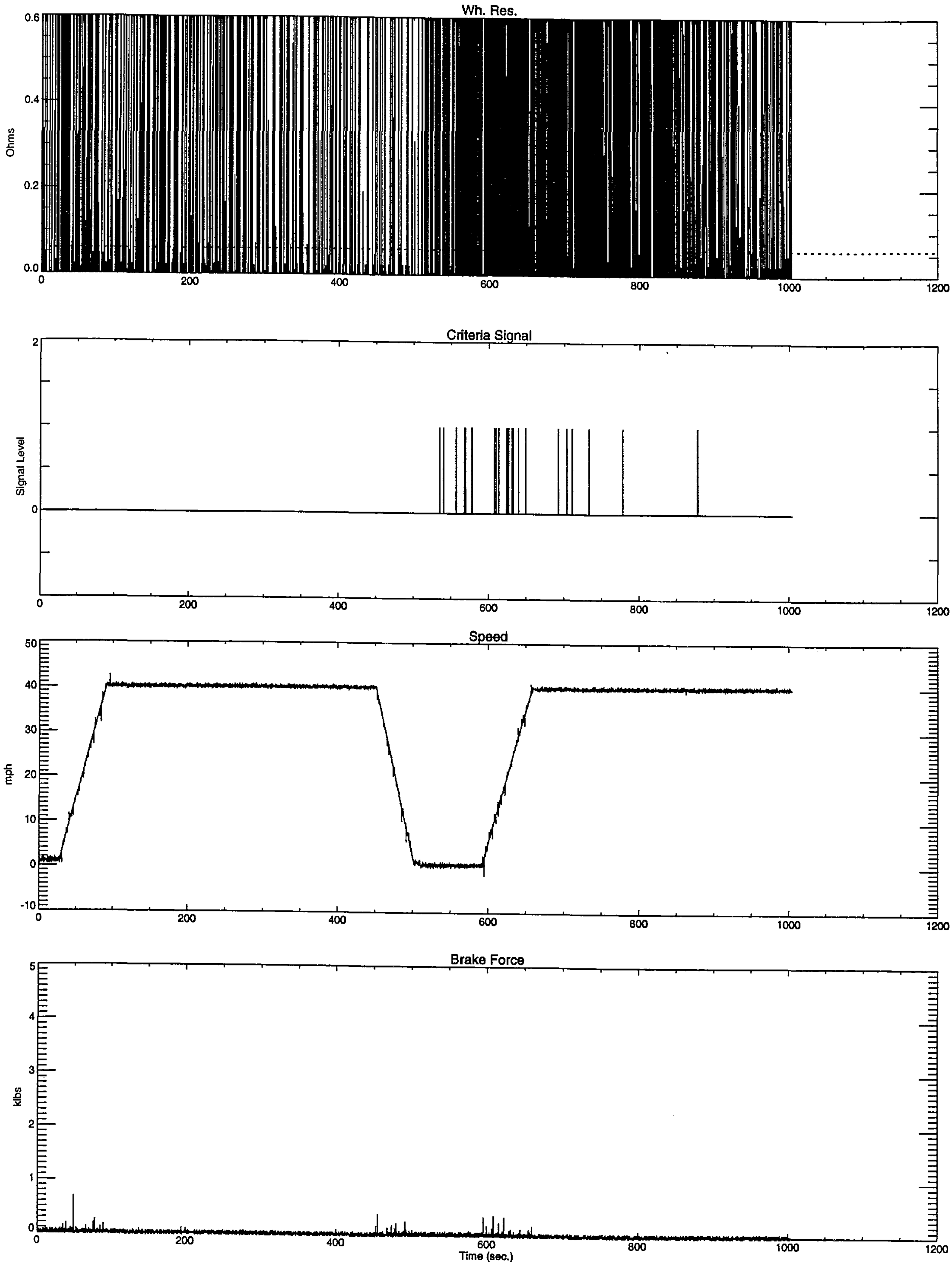
Run 011 B - Wheel Load 6,300 lbs.



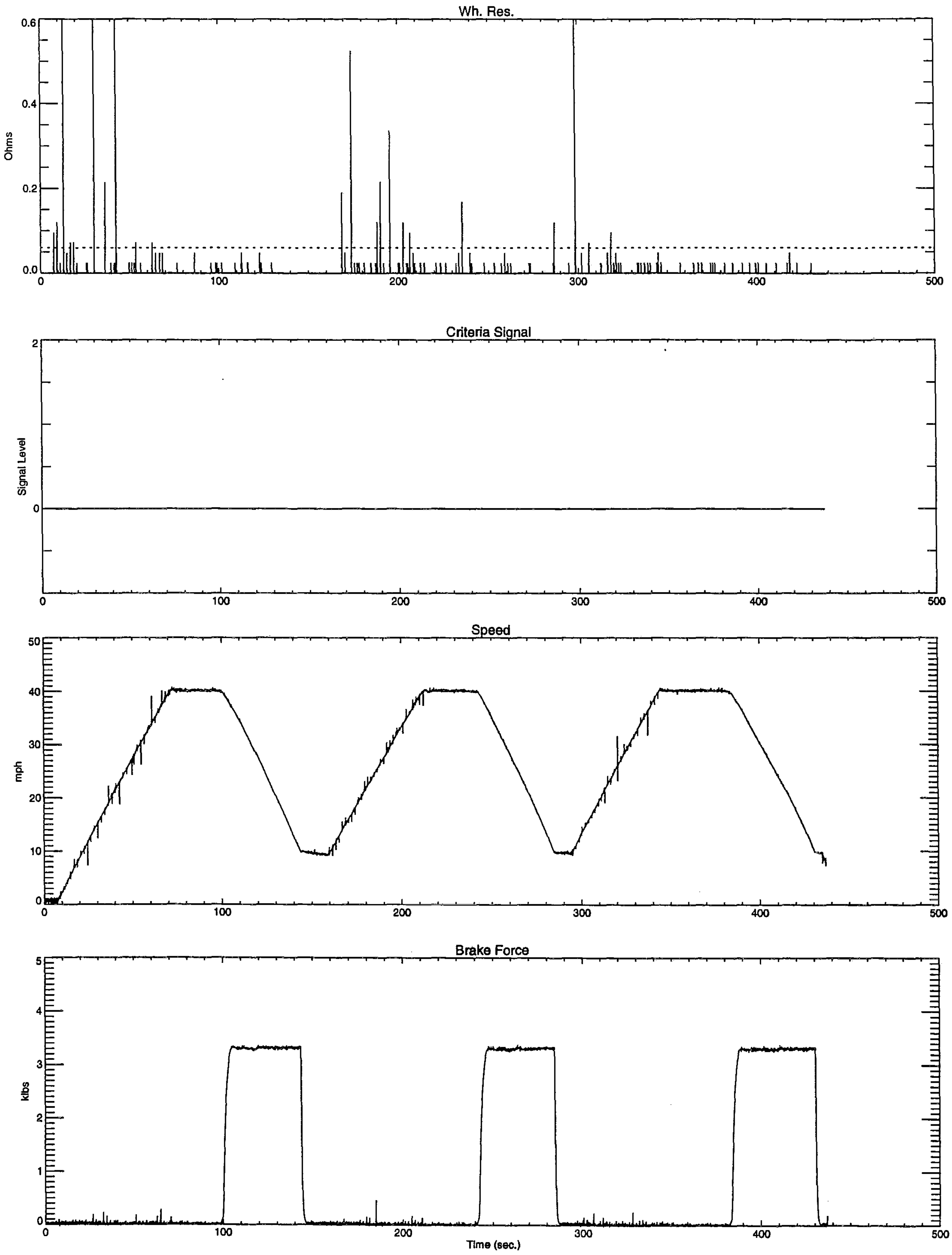
Run 012 B - Wheel Load 6,300 lbs.



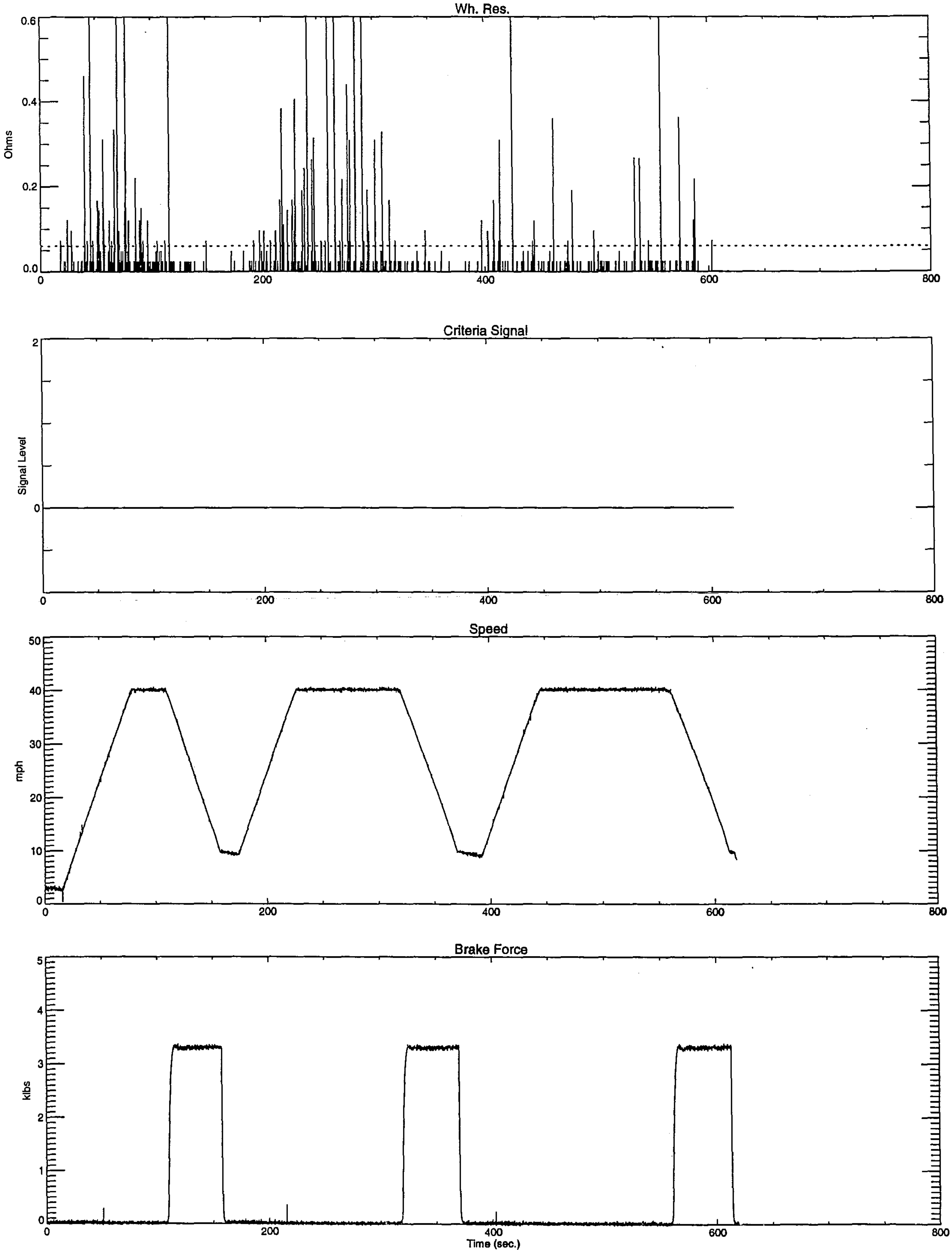
Run 013 B - Wheel Load 6,300 lbs.



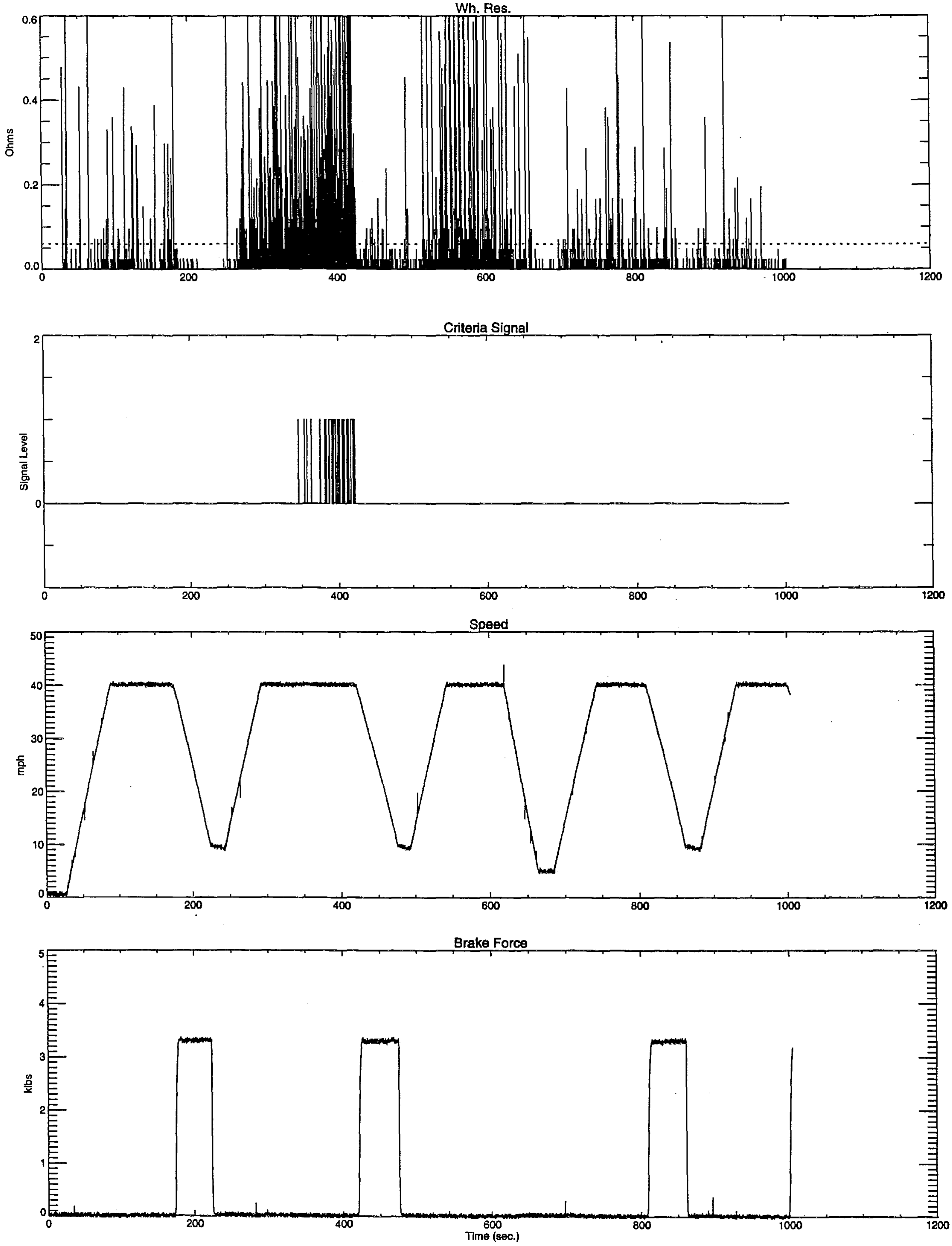
Run 015 B - Wheel Load 6,300 lbs.



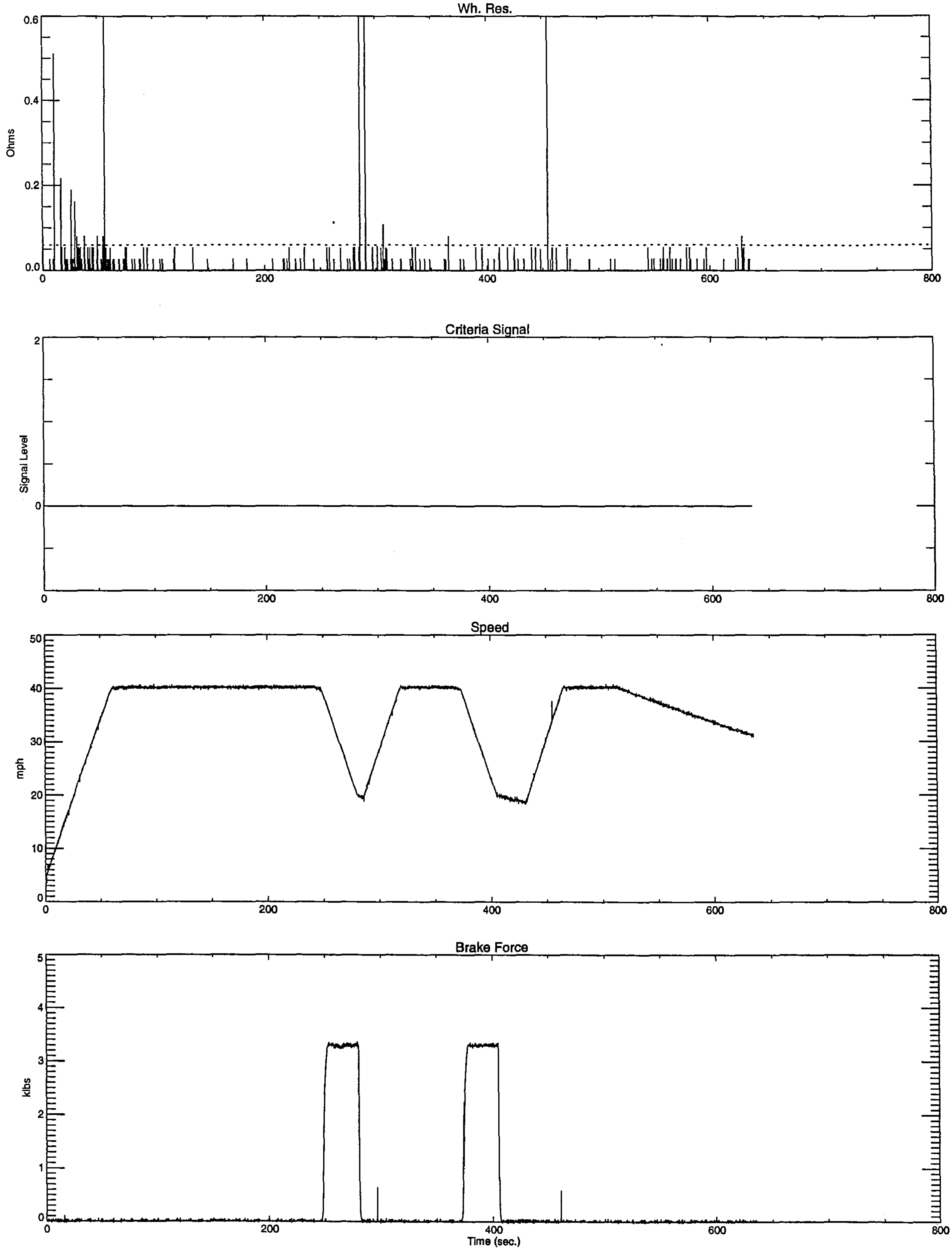
Run 017 B - Wheel Load 6,300 lbs.



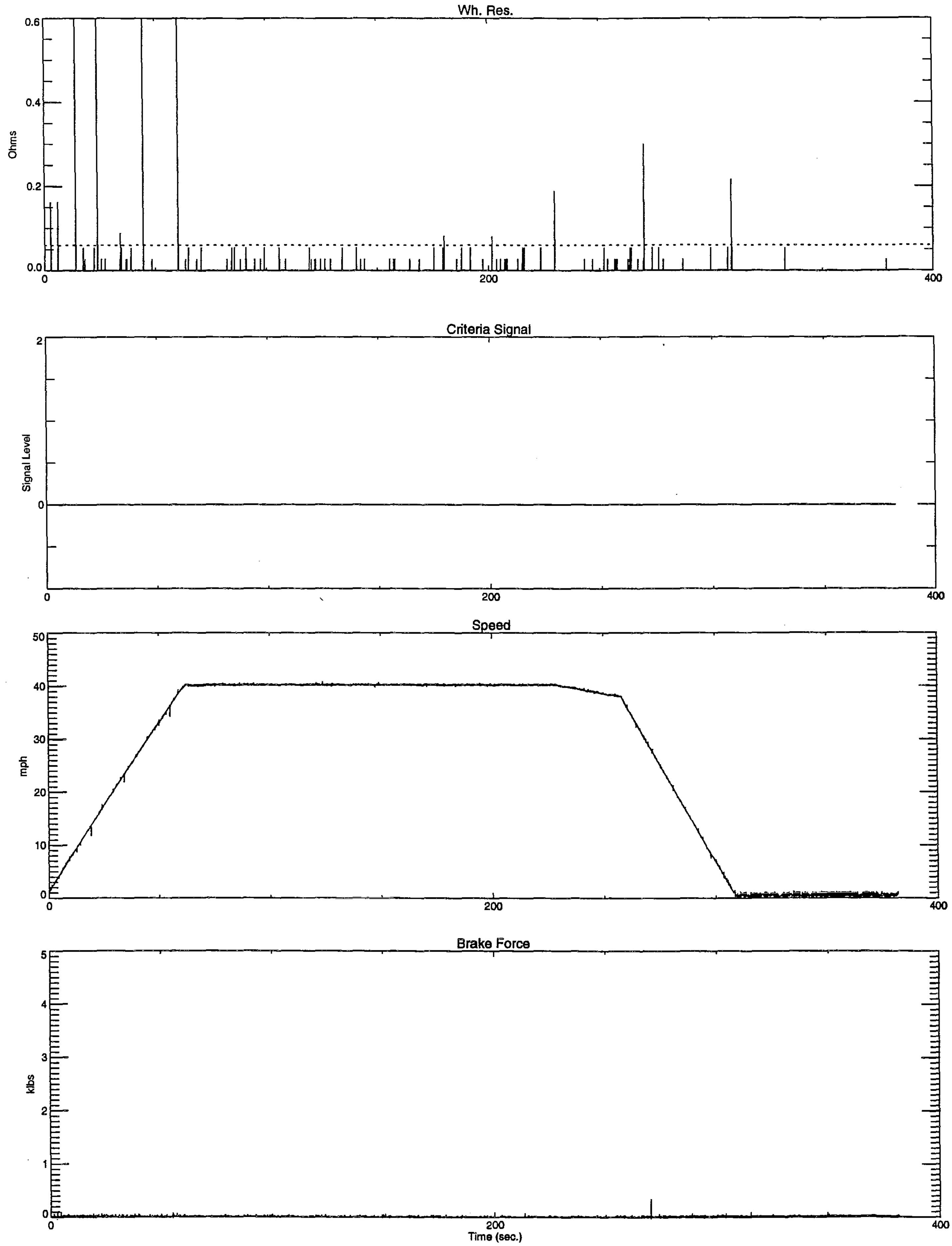
Run 019 B - Wheel Load 6,300 lbs.



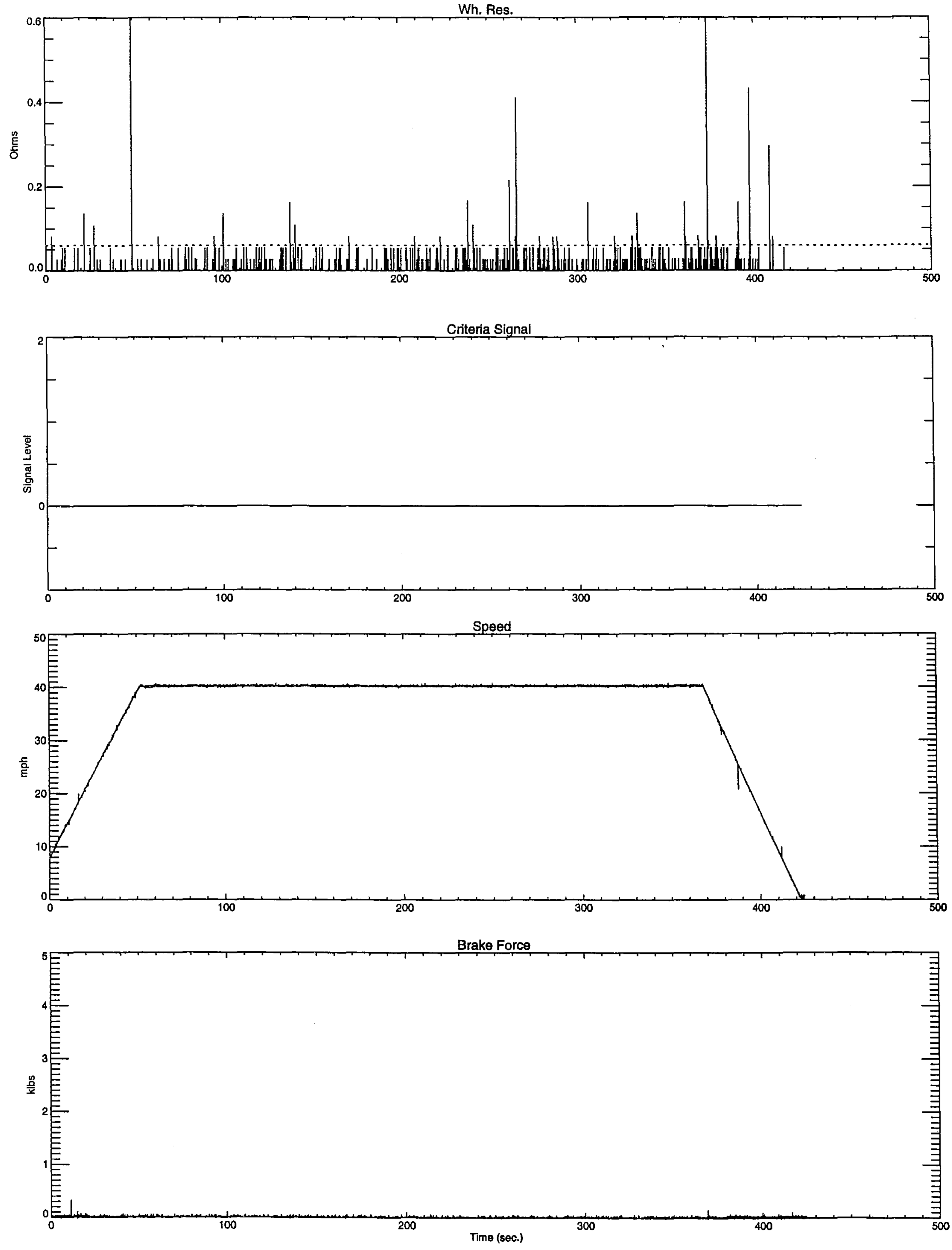
Run 013 C - Wheel Load 6,300 lbs.



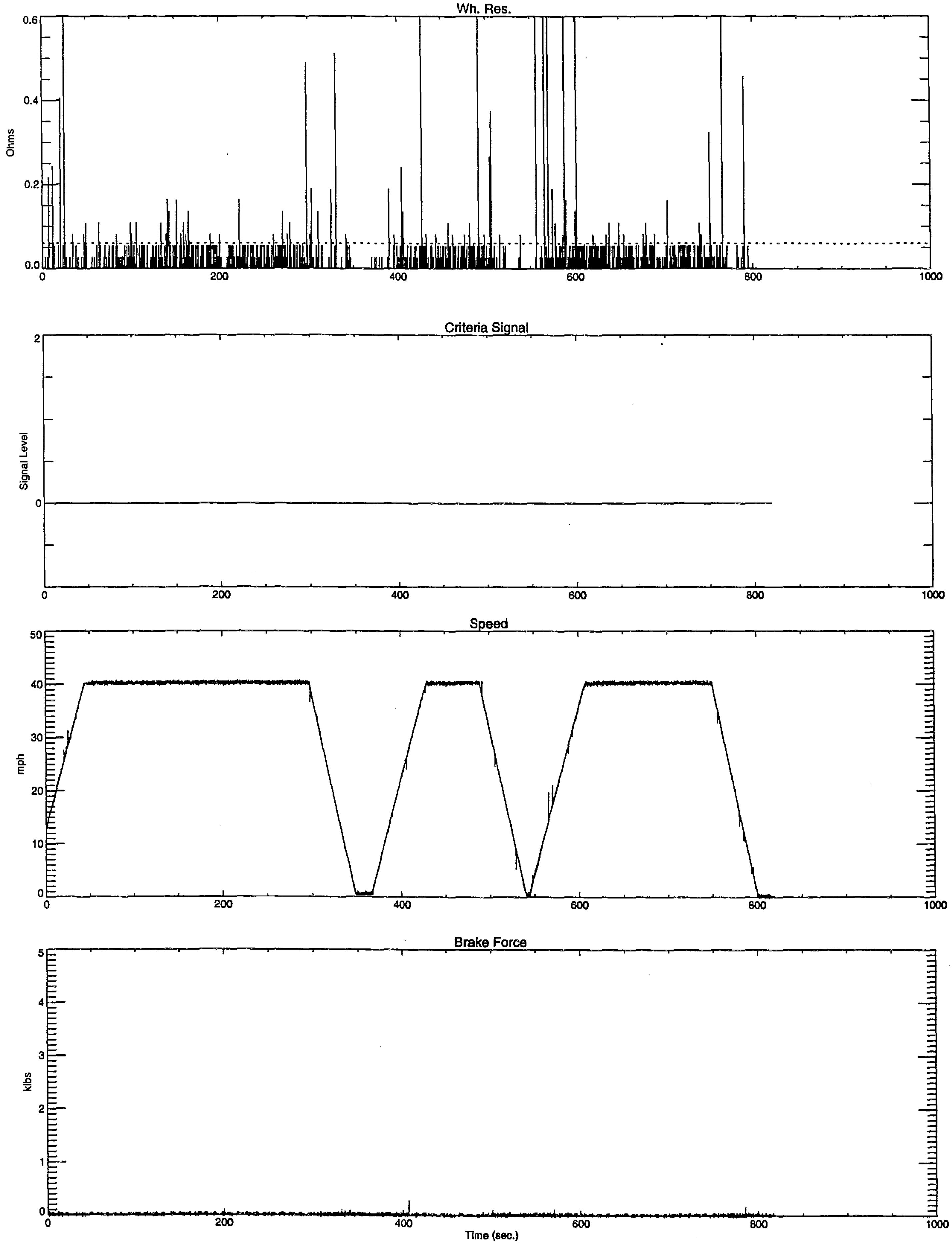
Run 014 C - Wheel Load 6,300 lbs.



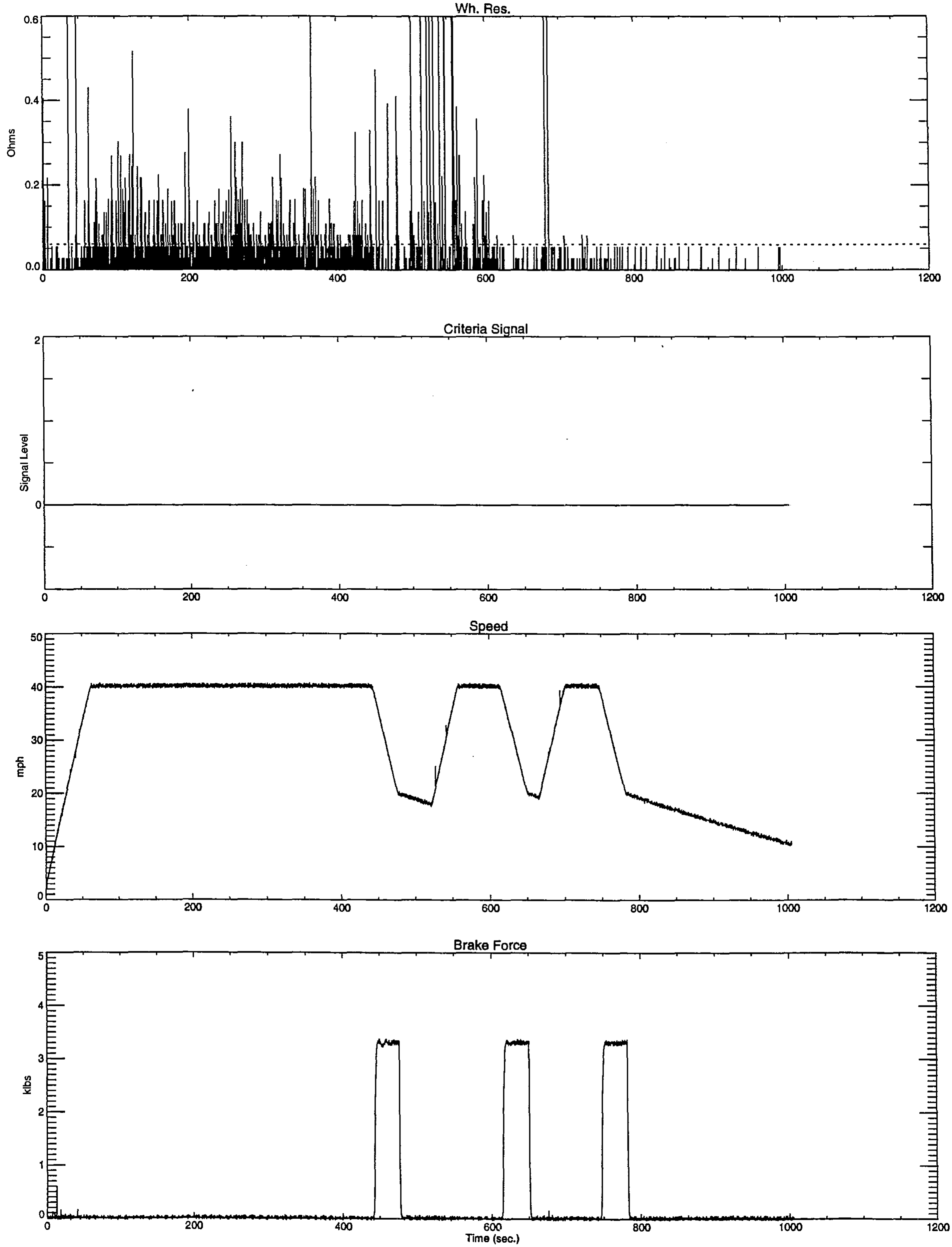
Run 015 C - Wheel Load 6,300 lbs.



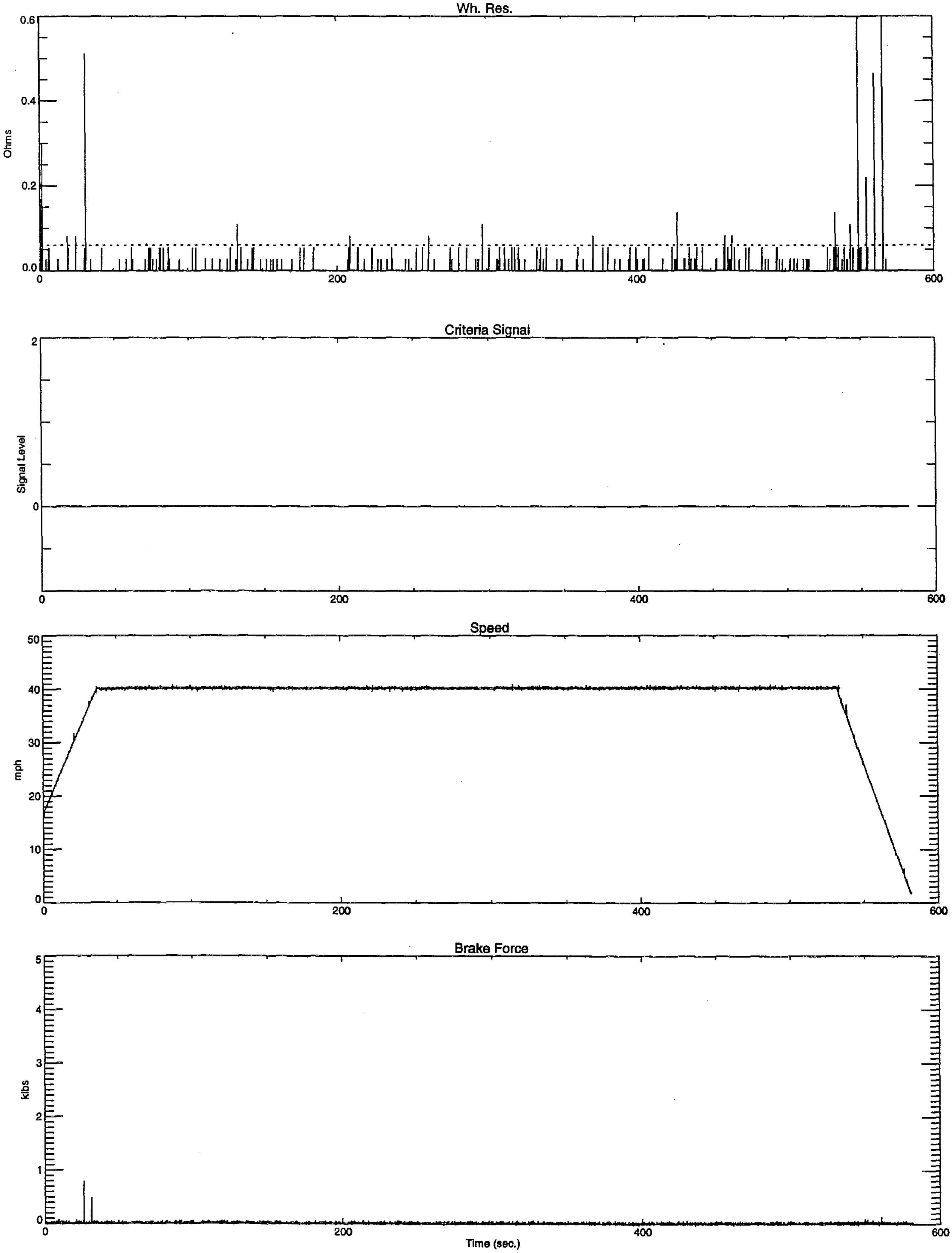
Run 016 C - Wheel Load 6,300 lbs.



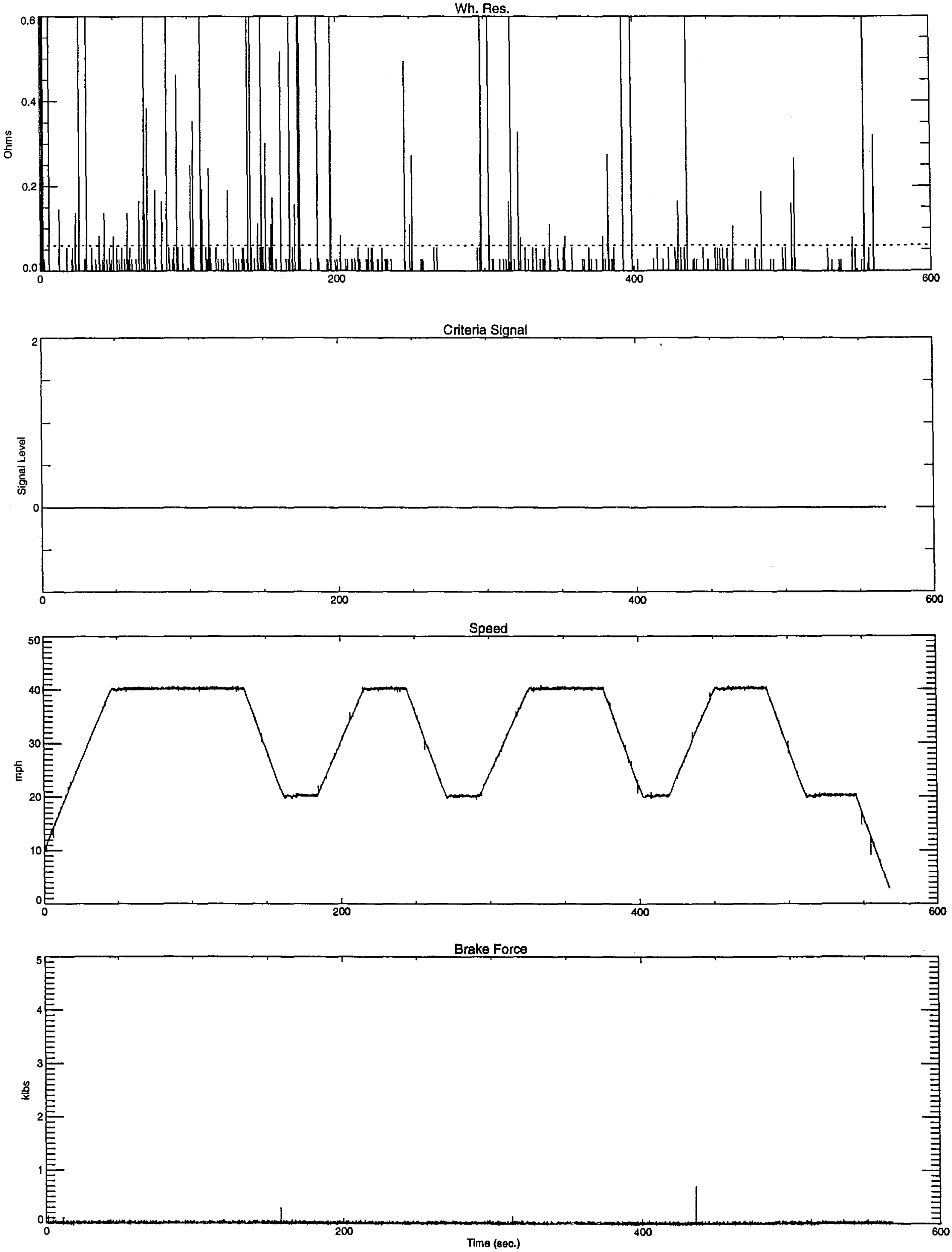
Run 017 C - Wheel Load 6,300 lbs.



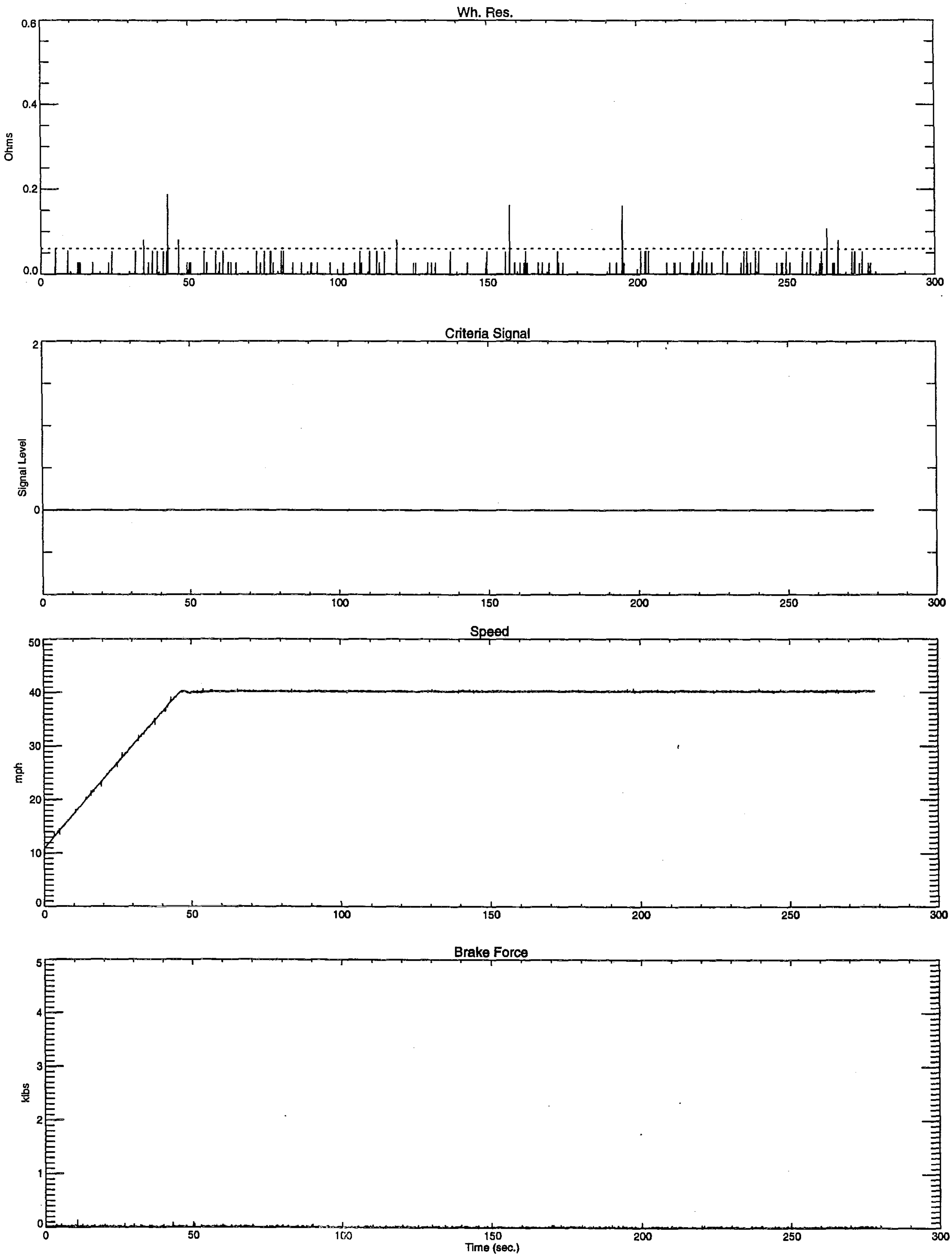
Run 018 C - Wheel Load 6,300 lbs.



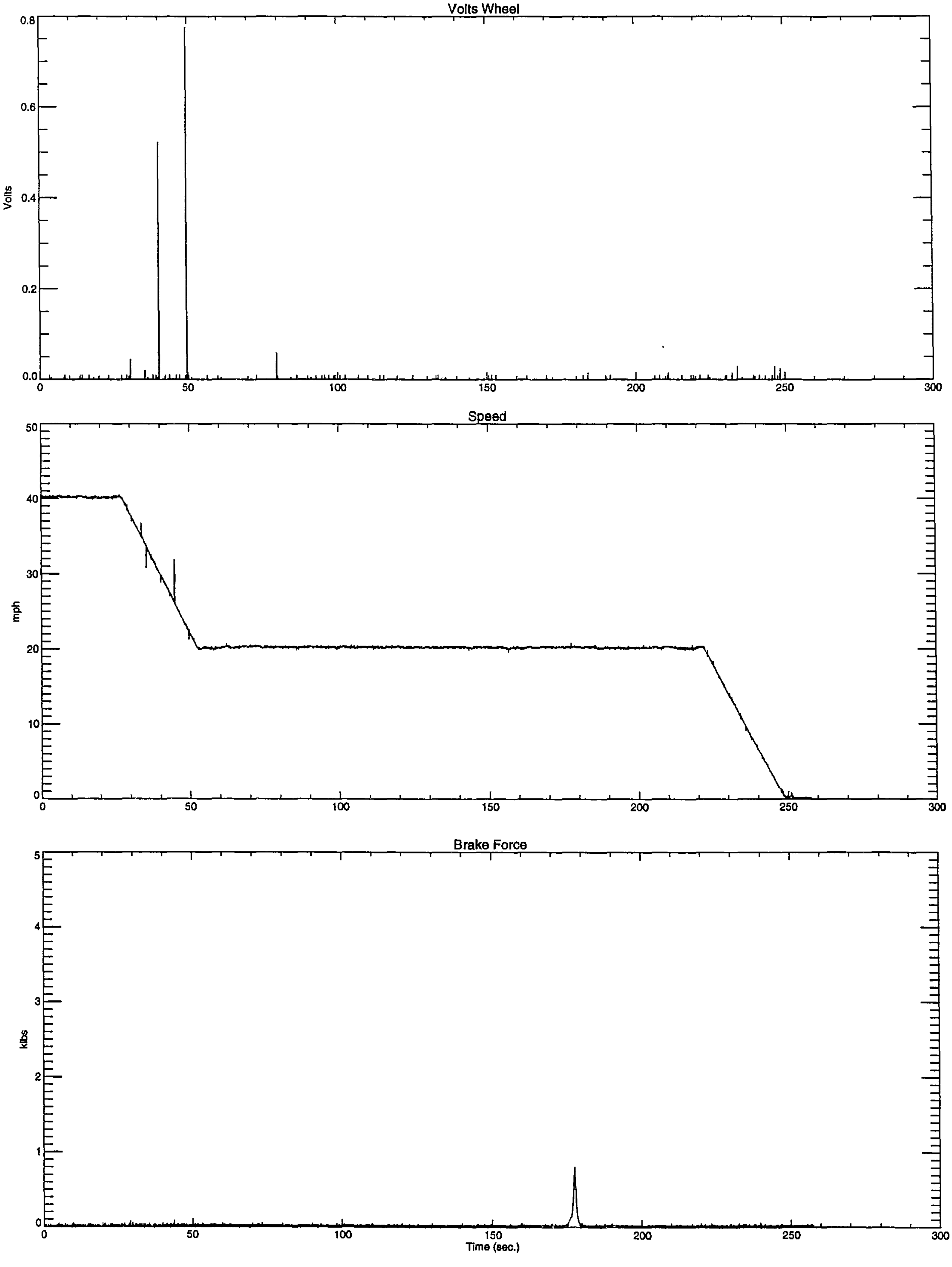
Run 019 C - Wheel Load 6,300 lbs.



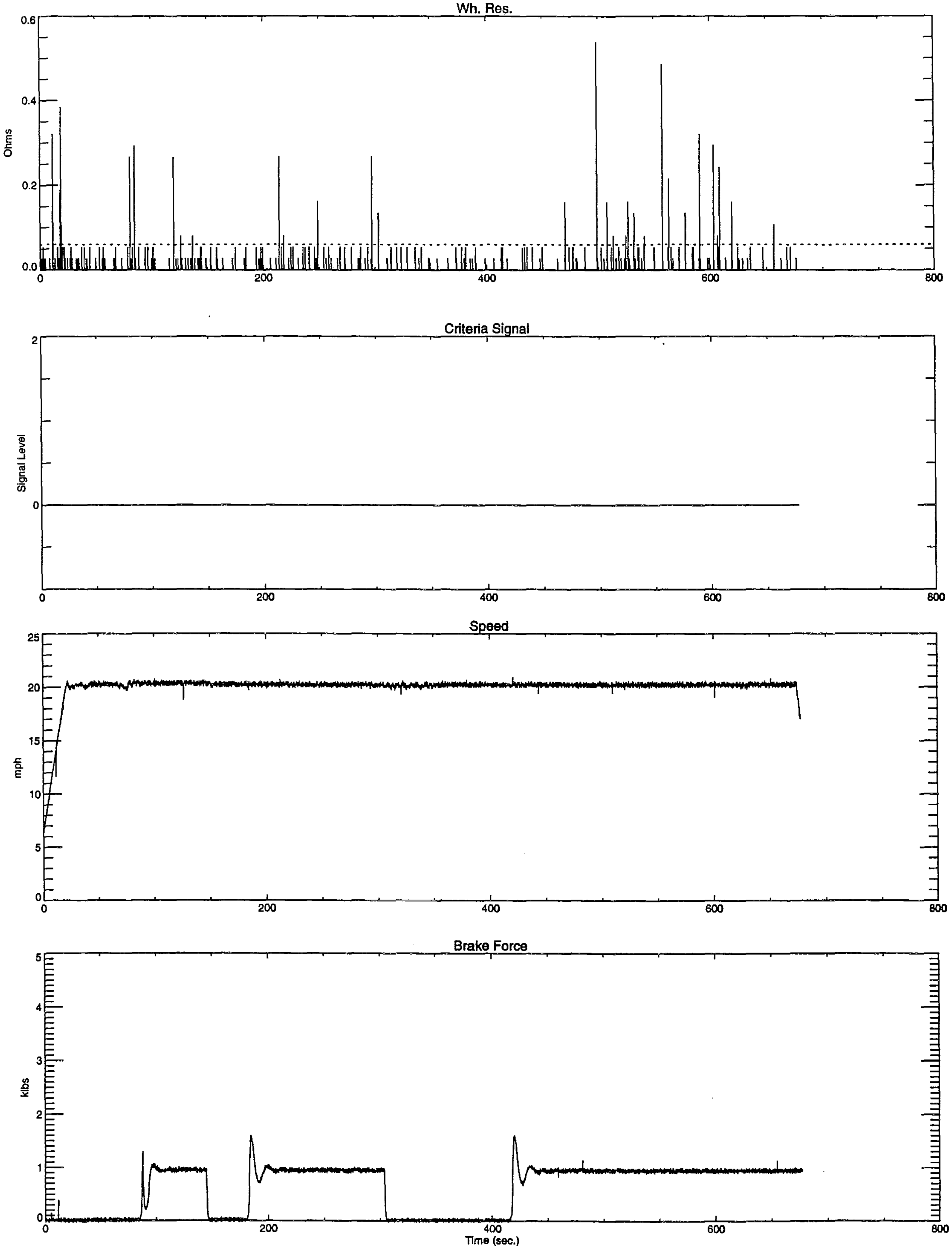
Run 020 C - Wheel Load 6,300 lbs.



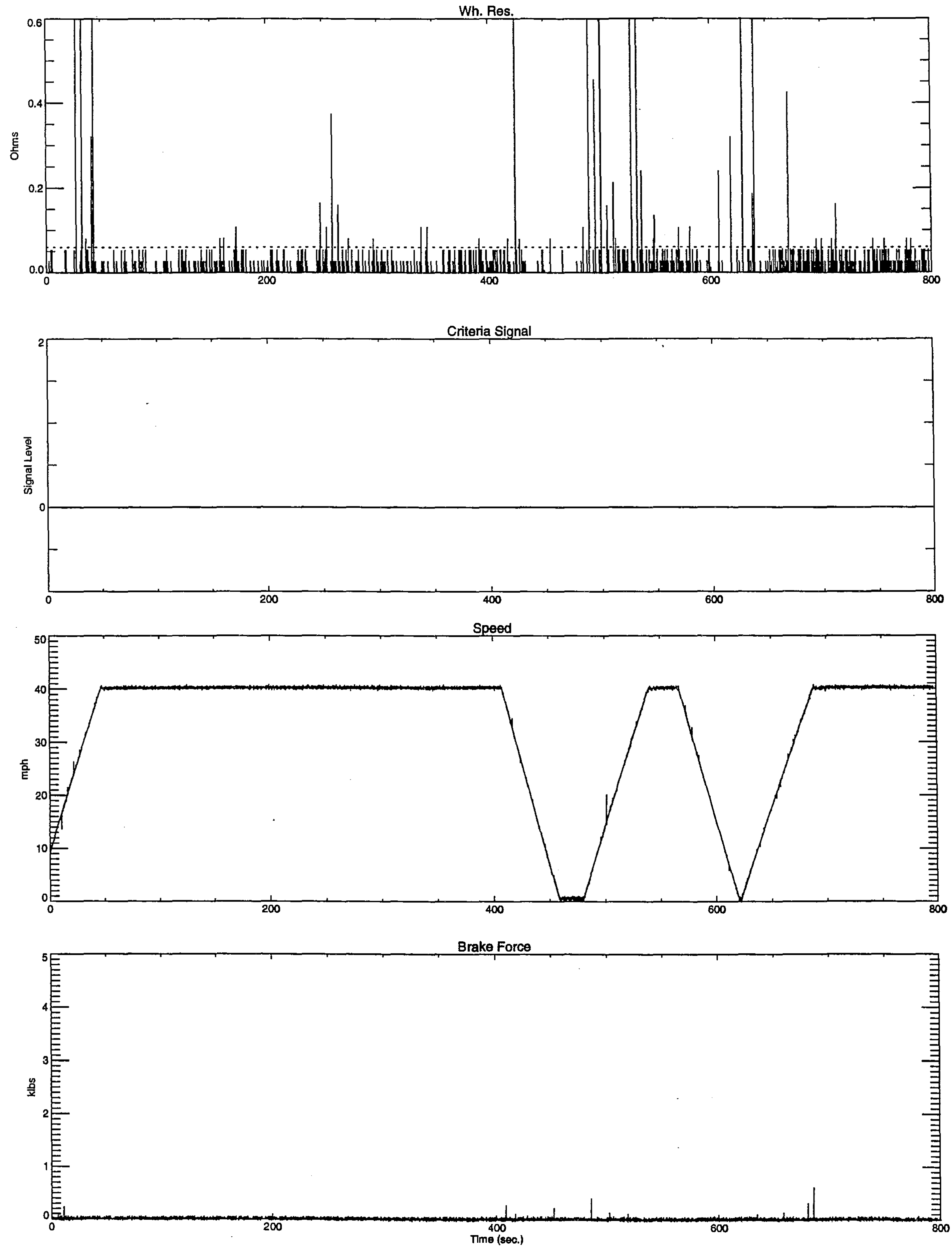
Run 021c - Wheel Load 6,300 lbs



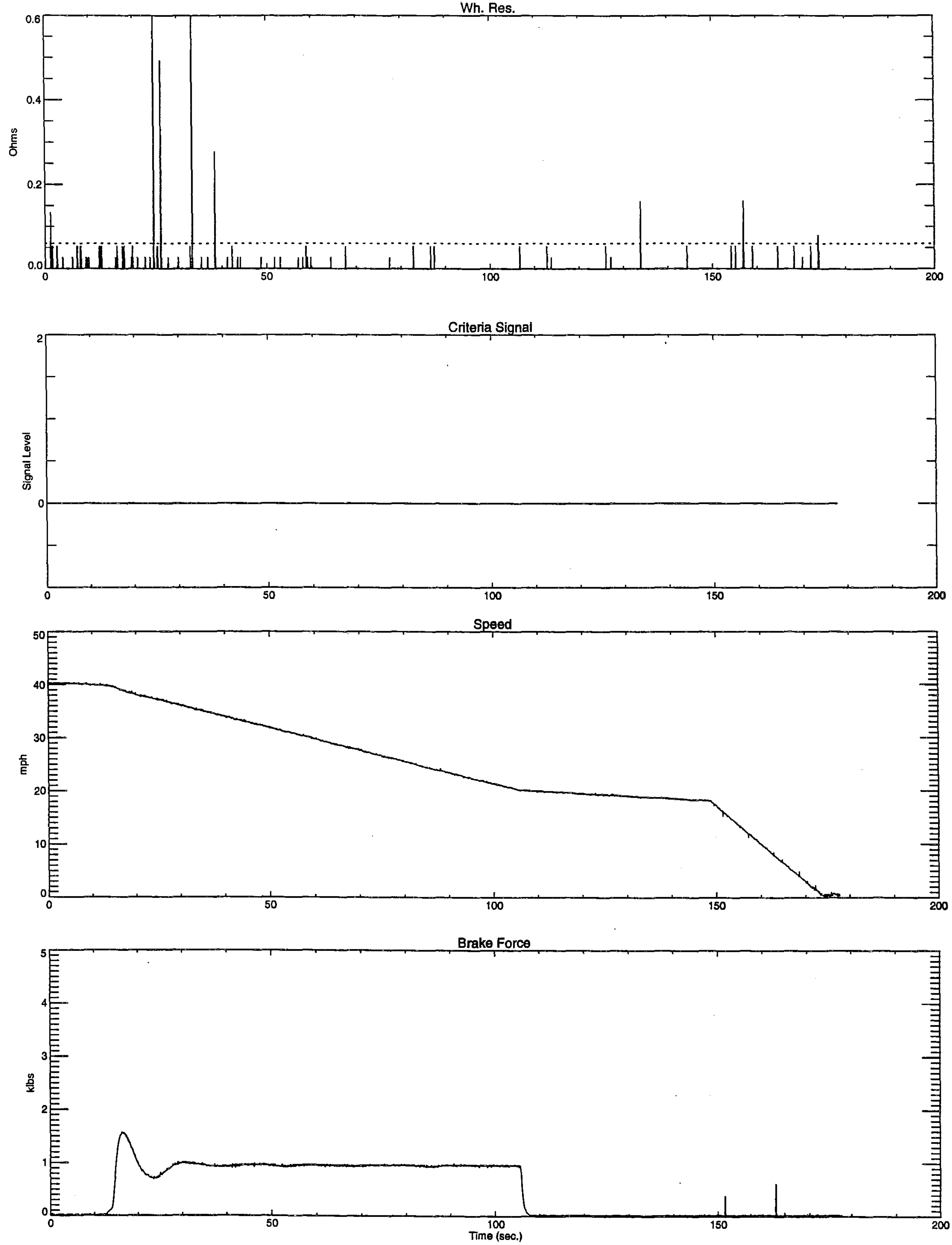
Run 022 C - Wheel Load 6,300 lbs.



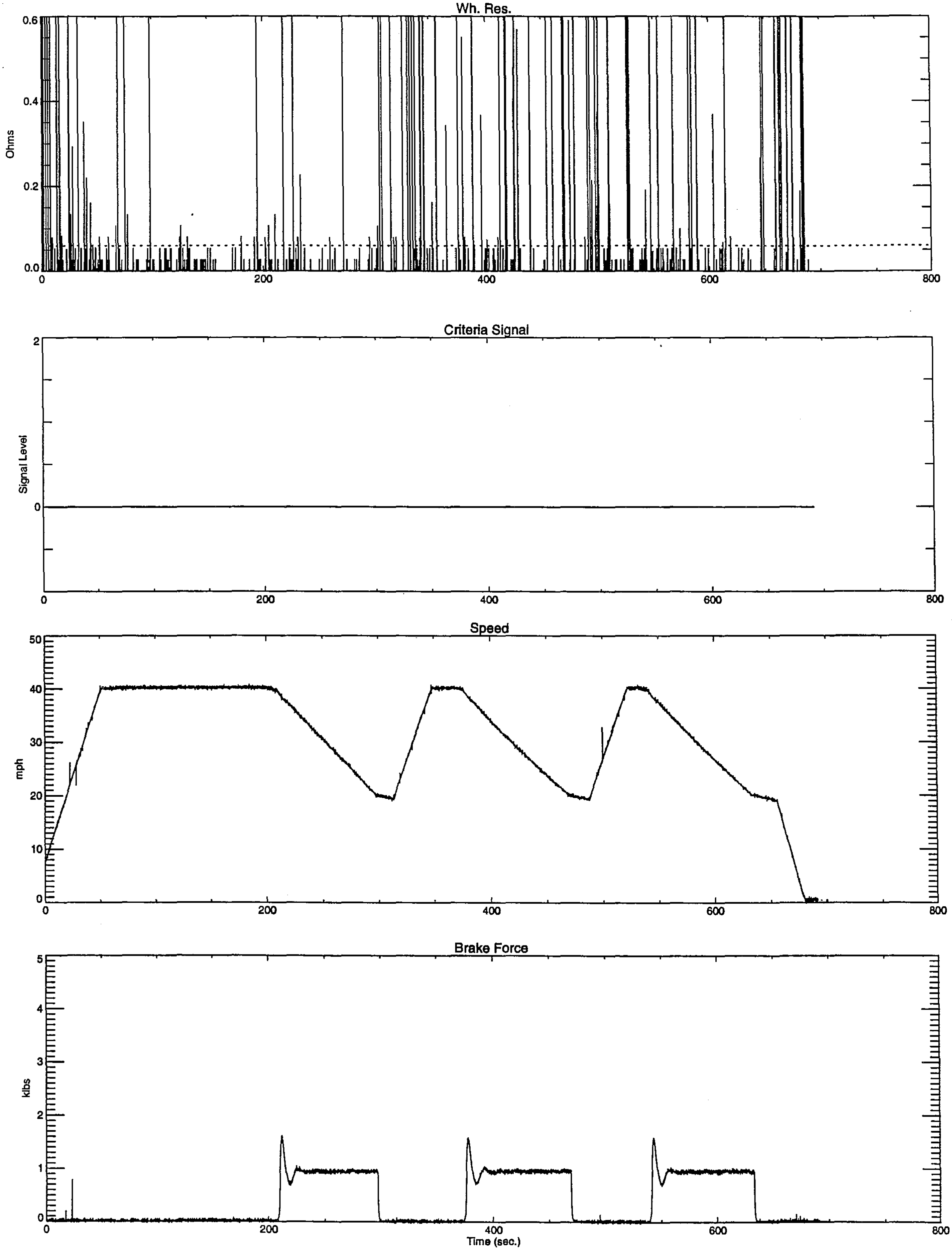
Run 023 C - Wheel Load 6,300 lbs.



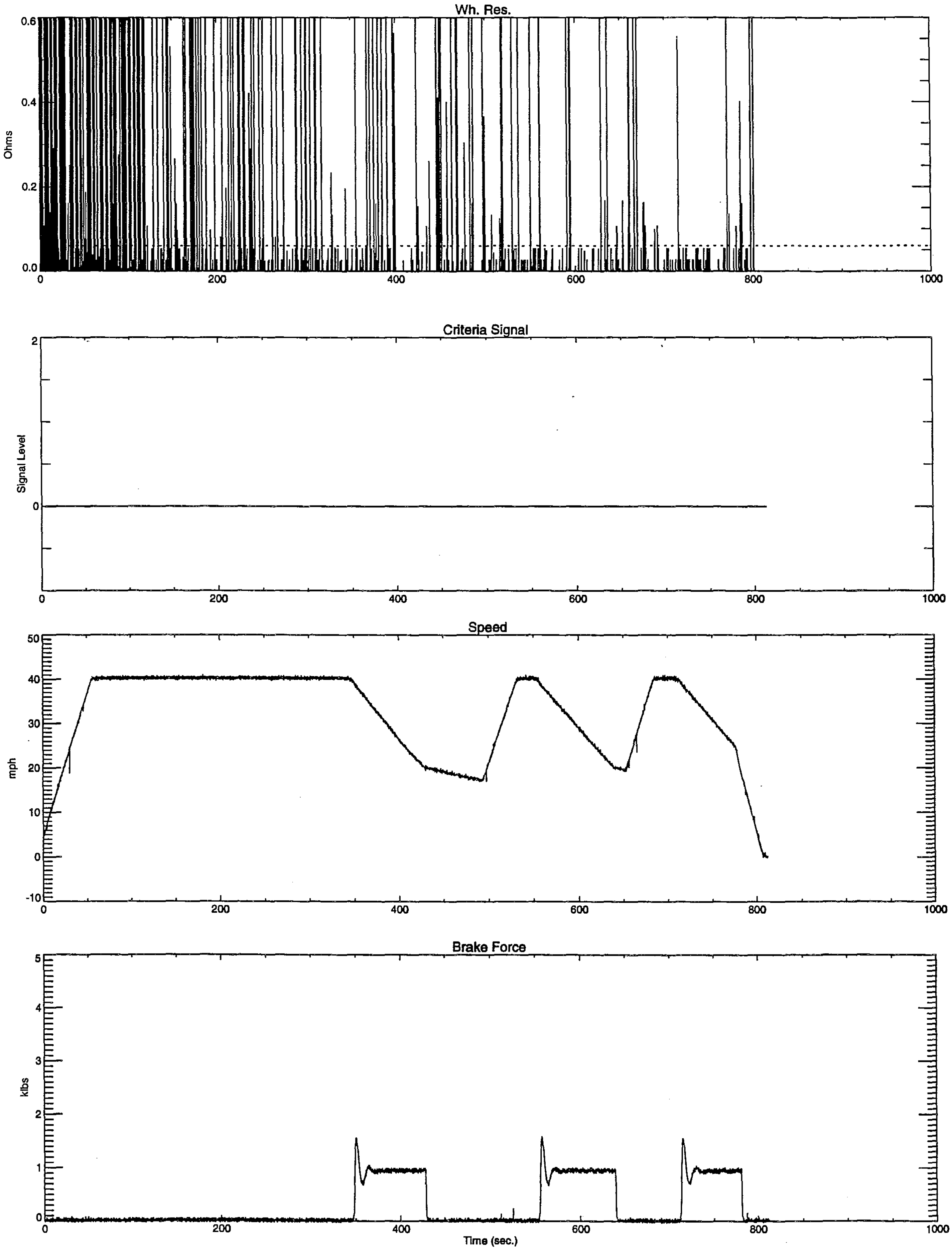
Run 024 C - Wheel Load 6,300 lbs.



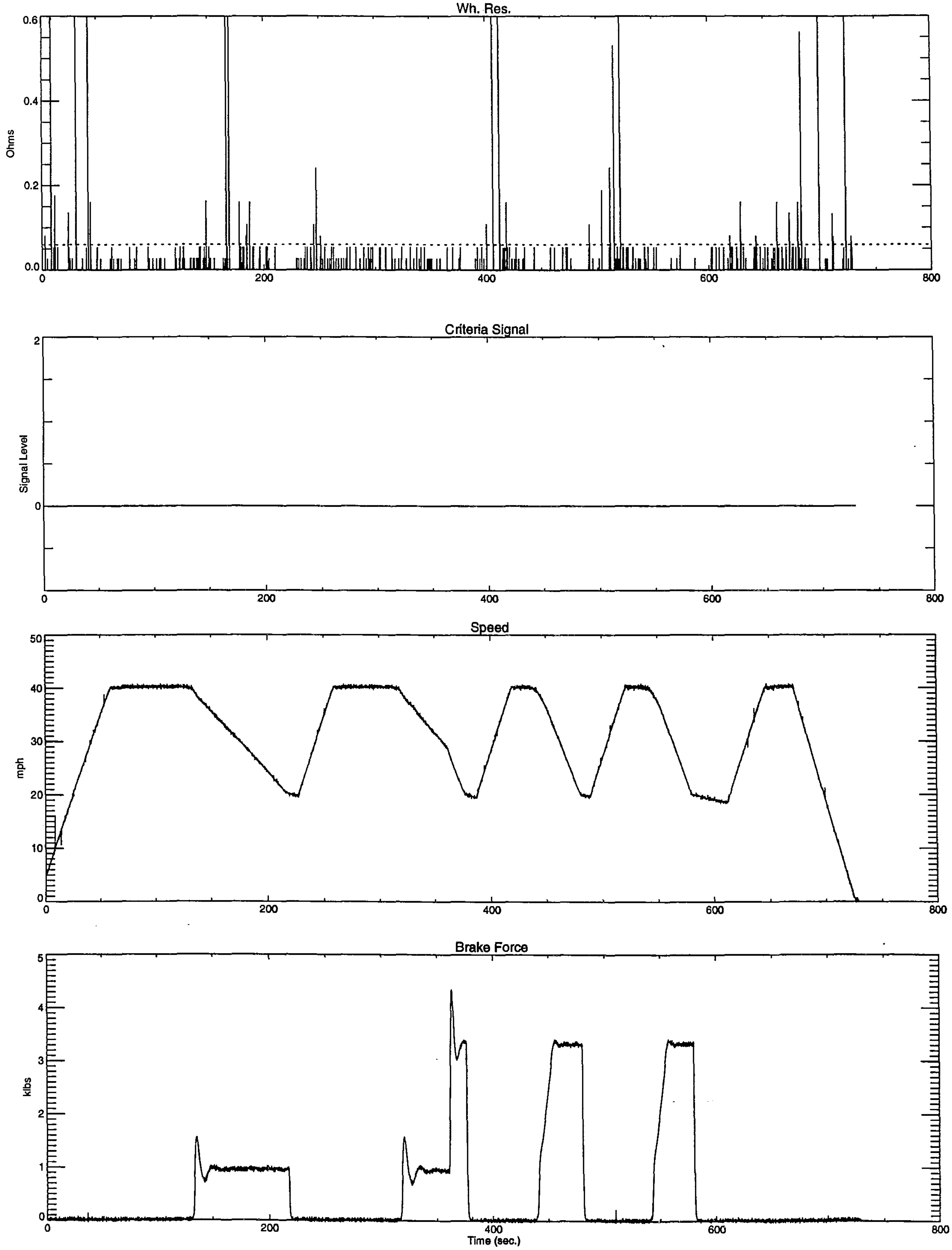
Run 025 C - Wheel Load 6,300 lbs.



Run 026 C - Wheel Load 6,300 lbs.



Run 027 C - Wheel Load 6,300 lbs.



APPENDIX E

Task Force Comments

February 28, 1996

File: C&S 3.12.1

To: R. Reif
From: W. Etter

Ref. LOS Plots and response analysis

Attached are synopsis of the committees observations and comments given by J. Murphy of UPRR and CN Labs. It is my understanding that CN Labs may submit more information, however Terry Therrien will be vacationing for the next three weeks. Therefore, I'm not certain when their report will be available. Jim Moe will also be submitting his comments which I believe sometime this week.

As you can read, the perspectives given in each paper is quite diversified and tends to keep the research results in a questionable flux. Quite a few view points are given and for honesty of analysis, all have merit.

Attachments:

1. Committee Synopsis
2. CN Rail Labs report
3. UPRR, J. Murphy report

Track Circuit Parameter (Loss of Shunt)
Evaluation of Wheel Dynamometer Plots
Highway Railroad Grade Crossing Committee Synopsis

The following listed members of Committee D who are assigned to the Task force held a teleconference on January 29, 1996 to review the revised wheel dynamometer plots supplied under Richard Reif's cover letter of December 19, 1996.

J. Murphy - chairman, UPRR
T. Therrien - CN Rail
M. McNichols - CSXT
F. Ballinger - Harmon
J. Moe - Consultant Safetran
W. Etter - AAR
C. Johnson - NS

The re-drafted plots with the consistent and equal scale readings and .06 ohm scale eliminated the discrepancies of interpretations as found on the previous plots.

Go-no-go feature

This feature which was added per the Signal Committee's recommendations and specifications appears to have eliminate questionable shunt loss areas as compared with earlier plots. The go-no-go parameters recommendations are arbitrary. In certain plots such as #13b where the resistance and time durations appear as a full loss of shunt, the signal level (go-no-go) indicates that the sample rate may be set to tight and not accurately replicate true conditions. Nevertheless, we believe changing the go-no-go parameters will not expand the findings or prove any new conclusions.

60 mili-ohm scale

This scale reveals the presence of resistance which hovers just below or above the 60 mili-ohm level during or following the application of lubrication and also following cyclic braking activity when insignificant amounts of lubrication are on the wheel. This is significant in itself because the wheel rail interface resistance is consistently at the threshold level. A small increase of resistive elements can raise the threshold level above the Loss of Shunt level.

Run A

The most unique discovery is that the plot patterns are basically the same and are fairly consistent and repeatable such as found in plots 15a, 17a, 18a, 19a, 20a, 21a, 22a. These patterns reveal intensified resistance and full LOS under braking applications plots 23a and 24a, and repeated again during cyclic braking in plots 25a, 26a, and 36a, 38a. The patterns indicate less shunt loss with the heavier axle loads. It should be noted that these heavy axle load patterns are similar and consistent to the light load patterns.

Run B - Brake shoe #1

The members determined that run B can not be accurately compared with run A or C due to the differences of brake shoe manufacturers, irrespective if this a conformal brake shoe. Also the members observed that the MPH braking cycles patterns are different than run A. Although the brake shoe types are not the same as in run A, the pattern can again be observed. Braking cycle patterns 8b, 9b and 15b, 17b, 19b are again similar to braking cycles in Run A. The signal level (go-no-go) sampling rates in Runs 13b & 19b appear tight. The resistance remains above the threshold for long time durations.

Run C - Brake Shoe #2

The members again concluded that this test could not be accurately compared with runs A & B because of the brake type differences. Also the MPH braking cycles patterns are different than run A and B. Although the brake shoe types are not the same as in run A or B, the pattern theme continues to be evident for the braking cycles with lubrication present on the wheel. See runs 16c, 17c and 27c.

Conclusions:

- Los of shunt occurs within the same plot patterns.
- There are significant problems with small residue of grease with repeated braking cycles.
- Does this LOS only occur with a particular brake shoe, IE: manufacturer, conformal?
- Does LOS occur only with a given manufactures lubricant?
- Were brake shoes 1& 2 in run B & C the significant factors for not replicating the cyclic braking shunt loss as found in the first run?
- What did occur at the wheel rail interface to cause LOS during cyclic braking?
- Cyclic braking LOS was repeatable in run A, but not in run B & C. Why the inconsistencies? Note: Runs B & C did show cyclic braking LOS tendencies but not to the extent as found in run A.
- What extent does conformal and non-conformal brake shoes contribute to LOS?
- The collected data has indicated unique correlations between brake cylcles and lubrications. Unfortunately the research could not be carried out to satisfy or clarify these distinct findings with the rail/wheel contact patch phenomenon. The research has been left open ended.

Date: Friday, 2 February, 1996 1:21pm ET
To: THERRIEN
Cc: CHAPMAN, TRUONG02
From: TRUONG02
Subject: TTC L.O.S. Test & Comments

Terry,
After going through your thick memo, I have come up with several observations

1. First of all, the LOS criteria developed by TTC is a very precise one to track resistance. Out of 64 graphs, I have seen 12 cases of LOS but we should only discuss the 5 cases whose duration is higher than 5 seconds.
These 5 cases are: 017A, 022A, 023A, 024A, 026A, and 019b of the report. The causes of LOS can be grouped into two category:

a. Main cause: sand, leaves, grease and lube. An EXCESSIVE amount of any of this material can cause LOS when the wheel equipped with new brake shoes is:
a. Accelerating;
b. At constant speed; or
c. At low speed (skidding at less than 0.1mph).

b. Secondary cause: wheels with new brake shoes are more likely to cause LOS if condition (a) exists. Braking can help deminish LOS.

2. Conformal brake shoes tend to remove grease/debris from wheel/rail interface and reduce chances for LOS to occur.

By observing so many test results, I would like to conclude that the LOS is not prevalent. Braking tends to deminish LOS caused by big chunk of grease as per graph 015A. Nevertheless, this test was done for one type of wheels, I'm not sure whether one can generalize his observation. I believe that LOS depends on the rail/wheel oval footprint. If we perform the same test for two types of wheels (the smallest and the biggest one), we may be able to derive something out of it.

Duy(7043)

TO: WAYNE ETTER

FROM: JIM MURPHY

DATE: FEB 27, 1996

SUBJECT: DYNAMOMETER - LOSS OF SHUNT TESTING

DURING BRAKE CYCLE TESTING, WITH CERTIAN AMOUNTS OF GREASE ON THE RAIL, THERE WAS SUBSTANTIAL LOSS OF SHUNT WHEN THE BRAKE WAS RELEASED. THEN LOSS OF SHUNT IMPROVED DURING THE BRAKING, AND THEN WENT BAD AGAIN WHEN THE BRAKE WAS RELEASED. THIS CYCLE REPEATED SEVERAL TIMES.

WHEN THE BRAKE WAS APPLIED TO THE GREASY WHEEL, I BELEAVE A FILM WAS CREATED WHICH WOULD CAUSE LOSS OF SHUNT. AT THE SAME TIME THE FRICTION BETWEEN THE BRAKED WHEEL AND THE RAIL WHEEL, CAUSED BY THE BRAKED WHEEL SLOWING THE RAIL WHEEL DOWN, CREATED GOOD SHUNTING. THEN AS SOON AS THE BRAKE WAS RELEASED, THE SLOWING FRICTION WAS GONE AND THE FILM THAT WAS CREATED FROM THE BRAKING CAUSED LOSS OF SHUNT.

YOU REPORT OF OUR TELECONFERENCE WAS GOOD, AND I BELEAVE WE ARE ALL IN AGREEMENT THAT FURTHER TESTING IN THIS AREA SURELY WOULD BE MERITED, AS WE HAVE FINALLY FOUND A CAUSE OF LOSS OF SHUNT THAT COULD BE CONTROLLED.

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FAX Message

To: Wayne Etter

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Date: March 4, 1996

Re: Track Circuit Parameters Task Force - Dynamometer tests

The following are my observations concerning the data developed during the Chicago Test Center tests and subsequent data reduction using criteria developed at the last Task Force meeting in Columbus:

Run 000A

This run with the rusty track wheel is typical of what we see in the field with rusty rail conditions and indicates that the test method used at Chicago appears to be duplicating actual field conditions fairly well. It also shows how effective our modern island circuit equipment is in rejecting "noise" voltages due to loss-of-shunt. This is based on the island circuit criteria that we supplied at Columbus which is typical for state-of-the-art conventional island circuit design.

However, note that there are a number of island relay pick-ups during the run. While of short duration, any one of these could result in a gate "pump" which could encourage a motorist to start out toward the tracks. Further, if the crossing warning is circuited to either provide a time delay or force the gate to rise to its vertical position upon island recovery (as many are), each of these island relay pick-ups would result in a gate-up situation.

Runs 003A - 010A

These runs with relatively clean and close to ideal conditions still show some loss-of-shunt "spikes" in the wheel-rail voltage. Despite these, a modern island circuit would not pick up.

Run 011A

This run with constant braking shows quite a bit more momentary loss-of-shunt events. While none of these result in an island pick-up, it does indicate that something is happening to deposit brake shoe material on the wheel that results in periodic loss-of-shunt. This is not too significant in itself, but is significant in view of what occurs in subsequent braking tests.

Run 015A

With a significant amount of lubricant present, there is also significant loss-of-shunt. In the 0-200 second time frame, there are loss-of-shunt events which result in fairly long island pick-ups. The time scale is too tight to determine the actual time, but it appears that some of these could be as much as 5-10 seconds in duration.

The loss-of-shunt mitigation in our "ideal" theoretical island circuit deals very well with the "firestorm" of loss-of-shunt spikes in the T=400 second time frame. Nevertheless, this still shows the significant effect on high levels of wheel-rail lubrication, at least with the grease which was used in this test.

Run 017A

Even with a higher wheel loading, the addition of heavy lubrication resulted in significant loss-of-shunt. The island pick-up at around T=250 seconds appears to be around 10 seconds or more in duration which would result in a gate-up situation, or very noticeable cessation of flashing light operation, at any crossing.

Runs 018A-020A

As wheel loading is increased, the effects of lubrication are, as would be expected, reduced. However, there is still significant loss-of-shunt even with the higher wheel loading and the tests indicate that high wheel loading does not eliminate loss of wheel-rail contact due to high levels of lubrication.

Runs 021A-022A

Here again, heavy lubrication resulted in a very significant loss-of-shunt. In run 021A there is an island pickup which is well in excess of 10 seconds at around T=480-490 seconds. Note that the time scale here is 800 seconds for the total run, so an island pickup which shows any width at all is of very significant duration. Even with wheel loading increased to 12,000 lbs in run 022A, we still have an island relay pickup of several seconds around T=150 seconds.

Runs 023A-024A

These are perhaps the most significant of all the testing done in this series as it is the first that appears to explain and quantify some of the loss-of-shunt phenomena which we are experiencing in the field in the absence of heavy lubrication or obvious contaminants. When the tests were being run, it was obvious that we were experiencing the sort of dramatic loss-of-shunt that has shown up at several locations around the country over the past few years.

The physical parameters should be noted: First, a small residue of lubricant on the wheel (and rail wheel) which is what we would expect to find in the field if a rail mounted lubricator is some distance away or an onboard lubricator is metering a small amount of lubricant. Second, braking with a composition brake shoe. Third, everything else is clean and would otherwise give the expectation of excellent shunting.

In run 023A, there is good shunting from the start of the run until braking occurs at around T=150 seconds. There is no loss-of-shunt during braking. However, after the brake has been released at T=180 seconds, significant loss-of-shunt occurs about 20 seconds later. Shunting becomes progressively poorer over the next minute as speed increases, resulting in an island relay pickup at T=260 seconds which lasts continuously until T=310 seconds. This is a track circuit pickup of 50 seconds which could occur at an island circuit, detector section or, if a locomotive or short train were affected, result in losing a train entirely in signal territory.

Only when the brake was reapplied at T=305 seconds did the shunting return to normal as the brake shoe apparently cleaned whatever film was present from the wheel. Unfortunately, the test was not continued beyond this time without reapplication of the brake as it appeared that whatever was causing the loss-of-shunt incident was continuing to get progressively worse. Cèrtainly, only the cleaning action of brake reapplication was responsible for achieving a shunt again and it is reasonable to assume that loss-of-shunt and track circuit pickup would have continued for some longer time otherwise.

This was no isolated phenomena, as the same thing was repeated following the second brake application and started to occur after the third brake application. Unfortunately, again the run was terminated before the longer-term effects could be determined.

While in retrospect one could conclude that the testing should have been continued at the time to determine the longer term effects of these phenomena, it must be realized that we were at the time somewhat blindly trying different possibilities and combinations of lubrication, contaminants and braking to see what contributed singly and collectively to loss-of-shunt. The significance of what we saw in run 023A was immediately apparent, but we did not have time to do any analysis on the spot to fully realize what was unfolding. Also, time available for the tests was running out and we still had many more runs to make to carry out our original test plan.

Run 024A was a continuation of run 023A with the same parameters present at the start. The loss-of-shunt event during the first cycle from T=10 to T=190 was essentially the same as run 023A and corroborates data collected from that run. Loss-of-shunt was even more severe, resulting in a track circuit pickup of around 125 seconds. Also, on this cycle, although the brake was applied at T=150 seconds, severe loss-of-shunt continued, though somewhat diminished, and track circuit pickup continued throughout the brake application portion of the cycle. Apparently the non-conductive film had become more difficult to clean off during brake application.

It is not clear just where the addition of more lubricant occurred, but it was likely at around the T=190 to 200 second point as there is a marked change in shunting characteristics at that point. Further, during the brake applications at T=300 seconds and T=480 seconds, there is no loss-of-shunt at all. Evidently, the presence of large amounts of lubricant has the effect of aiding the brake shoe in cleaning any non-conductive film from the wheel.

Runs 025A-026A

We wanted to determine whether or not the results seen in runs 023A and the first cycle of run 024A were repeatable so tried to reconstruct the same wheel-rail parameters. In run 025A, the loss-of-shunt phenomena previously observed were less pronounced, but grew progressively more noticeable in subsequent braking cycles.

Consequently, run 026A was done to see the effect of additional braking and, presumably, leaving only a small residue of lubricant. The results of runs 023A and the first cycle of run 024A were essentially repeated. The island relay showed significant pick-ups in the second cycle and almost continuous pickup during the third and fourth cycles between brake applications. This definitely indicates that the combination of a small residue of lubrication together with repeated braking action can result in a significant loss-of-shunt and track circuit relay pickup and corroborates the data from runs 023A and the first cycle of run 024A.

Runs 027A-030A

Wheel loading was increased to see what effect this had on the loss-of-shunt phenomena seen in runs 023A to 026A. Apparently, heavier wheel loading cut through whatever film was causing the problem in runs 023A-026A, as only minimal loss-of-shunt was noted. Also, once the film had been removed by the heavier wheel load, no loss-of-shunt recurred even when the wheel load was again reduced to 6300 lbs in run 029A. Also, adding a small amount of lubricant in run 030A had little effect on shunting, which remained relatively good with only occasional short "spikes" greater than .06 ohms.

Runs 032A-034A

These runs introduced sand, dirt and leaves with a small amount of lubricant to aid in adhering the contaminants to the wheel and track wheel. In all cases, it was apparent that some contaminant particles did result in loss-of-shunt "spikes," but it was not severe and did not result in island relay pickup. The greatest incidence of these "spikes" was for dirt and leaves. Brake application appeared to quickly clean the contaminant residue from the wheel.

Runs 036A-038A

These runs introduced water after a small amount of lubricant early in run 036A along with braking cycles. Run 038A used significantly higher braking force. In both of these runs, loss-of-shunt events became more numerous with subsequent cycles, as it had in runs 023-A-034A and 025A-026A, but to a much lesser degree and without any island relay pickup. The presence of water did not seem to have any significant effect.

Runs 002B-007B

Run 002B was presumably to determine a "base line" for subsequent tests and the graphical data was not included. In run 003B, lubricant was added. There are a number of loss-of-shunt "spikes" indicating some shunting problems but no island relay pickup. In run 004B, excess lubricant was wiped off which resulted in significantly poorer shunting and heavy loss-or-shunt "spikes." However, no island relay pickup resulted. In run 006B, more lubricant was added and in run 007B the excess was removed.

There appears to be no conclusion to be drawn from runs 003B to 007B, other than to note that with whatever film remained on the wheel from the previous braking tests and the presence of varying amounts of lubricant, quite a few loss-of-shunt "spikes" did occur. Shunting was not generally as effective as it was in the previous "A" series tests under ideal conditions. However, adding lubricant did not have as serious an effect on shunting as it did in the "A" series tests with the same wheel loading.

Runs 008B-009B

Both of these runs utilize regenerative braking to decelerate. In run 009B, lubricant was added. There is significant loss-of-shunt in run 008B, particularly in the second cycle. Also, there are more "spikes" of higher amplitude during acceleration and deceleration than at a steady speed and almost no loss-of-shunt at low speed between cycles.

Runs 010B-013B

Contaminants were introduced in these runs. In run 010B, sand was used with some lubricant as a binder, presumably at the start of the run at very low speed rather than during the run at speed, as was done in the "A" series tests. Loss-of-shunt is significant initially with island relay pickup of unknown duration (though the one at T=100 during acceleration could be fairly long). This cleans itself up after about three minutes and dynamic braking appears to improve shunting quite rapidly. There are loss-of-shunt "spikes" immediately following brake applications at around T=700 seconds and T=850 seconds, but these do not appear to be particularly significant. The continuous brake drag in run 011B has no significant effect.

The lube, sand and dirt applied in run 012B (again apparently applied at low speed at the start) again resulted in significant loss-of-shunt initially. However, it cleaned up quite a bit with dynamic braking and almost entirely with friction braking as it had in run 010B.

When leaves and organic material was added to the mix in run 013B, the effect was significant with a "firestorm" of loss-of-shunt "spikes." Dynamic braking appeared to exacerbate the problem rather than improve it as it did with only sand or sand and dirt. There are significant island relay pickups from T=500 to T=650 seconds which are of indeterminable duration as the time scale of 1200 seconds makes even a 10 second pickup appear as a "spike."

Friction braking was not tried here although it had been in the two previous runs. This begs the question of what would have been its effect? Also, even though the loss-of-shunt event was still very evident at the conclusion of run 013B, no further runs were made using organic contaminants.

Runs 015B-019B

Run 015B was done presumably using a dry wheel and rail wheel without lubricant as it was noted that they had been cleaned in run 016B. Brake application did not appear to have a significant effect on loss-of-shunt. In run 017B, some lubricant was added though the amount and time are not specified. Looking at the resistance graph, it would appear it was applied before the start as there is a distinct increase in loss-of-shunt "spiking" from the previous run with a dry wheel.

In run 019B, which appears to mix friction and dynamic braking, there is a distinct increase in loss-of-shunt following the first friction braking cycle. This is accompanied by island relay pickups of significant duration, particularly during steady-state running just before the second brake application. Although the tight time scale (1200 seconds) used here as opposed to the longer time scale (600 seconds) used in run 023A makes it more difficult to compare, the wheel-rail resistance graphs appear to look very much alike. The dynamic braking applied at T=650 appears as it might have helped to clean up whatever film was causing the shunting problem.

Runs 013C-027C

These runs with light braking loads and other variations on the previous runs do not appear to introduce any further significant information concerning loss-of-shunt phenomena. In run 015C lubricant was introduced with some additional loss-of-shunt "spiking." In run 016C this lubricant was spread around further with friction braking also introduced. The braking did result in some increase in loss-of-shunt spiking, but not nearly as much as it had in runs 023A-034A and 019B.

In run 017C, friction braking appears to have cleaned up the increasing loss-of-shunt problem caused by multiple lubricant applications in runs 015C-017C. The amount of lubricant present is indeterminant, but there apparently was quite a bit of residue.

It is interesting to note that the steady-state conditions observed in run 013B were not repeated in run 018C despite the similar contaminant mix containing organic material and other nominal parameters being the same. However, when this same contaminant mix was merely redistributed in run 019C, it resulted in a significant increase in loss-of-shunt spikes.

Runs 025C-027C appear to show that light braking does not clean a dirt-lubricant (apparently dirt-diesel fuel) mixture nearly as effectively as a heavy brake application as would be expected. Also, when lubricant (I assume grease lubricant) is added to the existing dirt-lubricant mixture in run 026C, there is significant loss-of-shunt "spiking."

General conclusions:

The loss-of-shunt and island relay pickup phenomena which we observed in runs 023A-024A and run 026A is unquestionably the most important finding to come out of these tests. It is further corroborated in run 019B so is not a transient phenomena. This appears to occur with a small amount of lubricant residue following several heavy braking cycles. Neither lubricant nor braking alone produce such significant loss-of-shunt results. However, the actual mechanics and parameter interactions that cause the phenomena remain a question.

Heavy lubrication does have an effect and it is apparent that this can contribute to loss-of-shunt if the amount of lubrication is significant. Wayside lubricators should be located away from short track circuits such as islands and detector sections. However, the small trace lubricant which appears to be highly beneficial in reducing wheel-rail friction does not appear to be itself a problem.

The effect of contaminants is about as would be expected. Gross application of any kind of contaminant is detrimental to shunting but most appear to clean out rapidly, both by running and by braking. Organic material seems to pose the greatest problem and this is what we also see in the field, particularly in the spring of the year when the trees are shedding or if we ever have a grain car leaking.

There is no indication that dynamic braking is a contribution to the loss-of-shunt problem from these tests. In fact, it appeared to have a somewhat beneficial effect when applied where there were contaminants and/or lubricant which caused loss-of-shunt "spiking." However, this is not conclusive and it is possible that replacing friction braking with dynamic braking could result in a film buildup on wheels as occurred with the Amfleet cars before retrofitting tread brakes.

Other considerations:

No distinction was made as to what type of lubricant was used in the tests. A graphite grease was used in the "A" series tests and it is not known what type was used in the "B" and "C" series tests. Certainly it is reasonable to expect that different lubricants would act differently.

The brake shoe used in the "A" series tests was, I have been told, not the same as was used in the "B" or "C" series tests. It is reasonable to assume that if there is some connection between the brake shoe and loss-of-shunt events as these tests strongly suggest, it may well be dependent upon brake shoe composition. If this is the case, this variable should be isolated.

There was a considerable concern during the testing regarding "conformal" and "non-conformal" brake shoes. While some comparative testing was done, it was not established what effect this had upon actual loss-of-shunt results. The new brake shoe used in the first tests had "broken in" by run 023A so there was about 75% contact and the car wheel showed uniformity of contact and no striations indicating missing contact areas. If this is an important parameter, its effect should be isolated. On an actual train, it would be reasonable to expect most shoes to be "conformal" but certainly some could be "non-conformal" either due to newness or wheel and/or brake shoe anomalies.

Another interesting observation made during the "A" series tests was the presence of large flakes of a shiny, black surface deposit on the brake shoe. These appeared coincidentally with the runs 023A-026A, when we experienced our significant loss-of-shunt and had not shown up previously. Whether this is significant or not is unknown.

Definitions:

There seems to be some confusion regarding "loss-of-shunt" and "track relay pick-up." Actually, loss-of-shunt technically occurs anytime the rail-wheelset-rail resistance, when measured at around one volt open-circuit, goes above 0.06 ohms (60 milliohms). It doesn't matter whether an associated track circuit picks up or not. This is a specific industry definition. Consequently, any time the trace on the resistance curve in these test reports rises above the 0.06 ohm line, that is, by definition, a loss-of-shunt.

In the test runs in Chicago, we used a single wheel-rail contact patch. This is electrically equivalent to a series-parallel circuit made up of two wheelsets in parallel, each with two contact patches. Thus, the values in the test report are representative of one two-axle truck in a short track circuit.

Track circuit component manufacturers have long been aware that there are periodic loss-of-shunt events which occur in the field under even normal conditions. This has been taken into consideration in the design of their equipment. Thus, some "spiking" of the resistance curve over the 0.06 ohm level can be tolerated by equipment in service.

When this built-in tolerance is exceeded, a "track relay pick-up" will occur. As there are no industry definitions for the tolerance to loss-of-shunt "spiking," neither in duration or amplitude, any significant loss-of-shunt event could potentially result in a relay pick-up. Thus a loss-of-shunt which results in a track relay pick-up with one track circuit may or may not with another.

The parameters used for the analysis of the contact resistance data in these tests represent industry shunt threshold/persistence criteria used in the best current island track circuit equipment and, as is apparent from the test runs, are very effective in preventing relay pick-up, even under adverse loss-of shunt conditions. However, there are many track circuits in use which are many years old and may not incorporate as effective false relay pick-up mitigation as modern equipment does.

Consequently, any loss-of-shunt event, other than occasional and isolated "spikes," should be regarded as a potential for false track relay pick-up in the context of this test program.

Further action:

The testing done to date on the AAR Test Center dynamometer has provided some valuable insights concerning shunting and isolated a number of variables which have been impossible to determine in other forms of test and evaluation of track circuits. It is essential that these leads be explored to further isolate variables and determine just what it is that caused the severe loss-of-shunt events of runs 023A, 024A, 026A and 019B.

Hopefully, the brake shoe which was used in thee "A" series tests and the one used in the "B" series tests are available for further runs. The same, of course, is true for the insulated car wheel, slip rings and instrumentation.

The effect of various types of lubricants in common use, both alone and in conjunction with friction braking, should be explored further. The previous tests indicate that the types of lubricant (of lubricants) which we used caused some problems when concentrated. However, we should determine the effects of both quantity and lubricant makeup in a controlled test.

A test plan should be drawn up to define further testing and decide how best to follow up on these tests. This must be based both upon the specific areas which look most promising and limitations of the dynamometer and test equipment.