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BRL

TECHNIQUES FOR MEASURING BURN TIMES FOR M864 BASE-BURN PROJECTILES

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Techniques using telemetry and Doppler radar were used to obtain measurements of the burn time of the propellant in the 155mm M864 base-burn projectile system. The telemetry technique ~~utilized~~ used a simple radio frequency ~~(RF)~~ transmitter which was mounted in the fuze well of the projectile. The resulting frequency modulation of the RF transmitter indicated propellant burn-out. The radar technique compared discriminated Doppler radar data for a projectile without propellant to that of a projectile with propellant.

Two firing programs were conducted at ~~the~~ Aberdeen Proving Ground, MD: one in September 1988 and the other in June 1989. A total of 18 rounds were fired with different Mach numbers and quadrant elevations. Data from these firings indicate that the burn-out time varies significantly with quadrant elevation. Temperature conditioning the propellant grain with dry ice (-78 degrees centigrade) increased the burn-time.

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I. Introduction

A base-burn projectile system utilizes subsonic mass injection into the near wake (base region) of the projectile to increase base pressure and thus decrease base drag. The reduction on base drag increases the range of the projectile by 18-20 percent. The prediction of the time dependent drag history for a base-burn system for a wide variety of launch conditions, such as different quadrant elevations and muzzle velocity (spin rates), requires that the ignition time and extinction time of the base-burn propellant be quantified. These burn-time processes may also involve transient effects since the ignition, steady state burn, and burn-out processes may be complex.

A non-intrusive and relatively inexpensive technique or capability for making measurements of burn-time is required for development and testing of the base-burn system. Burn time measurements are also needed for the development of computations that model the base burn process.[1]

The 155mm M864 projectile utilizes the base-burn technique for extending the range of the projectile. Figure 1 shows a sketch of the M864 along with a listing of its physical properties. The propellant grain of the gas generator for the M864 is housed in the afterbody of the projectile.

Several techniques for making in-flight measurements of M864 projectile propellant burn time have been developed. One such technique is to instrument the projectile with temperature and pressure sensors in the propellant chamber and transmit the data to a ground receiving station via standard telemetry techniques. [2,3] Another technique is to instrument the projectile with a simple radio frequency (RF) transmitter and antenna, and to monitor the effect that the hot gases, produced by the burning propellant, have on the transmitter frequency. A third technique is to process raw Doppler radar return signals with a proportional bandwith frequency discriminator. Discriminating the Doppler return produces a voltage signal that is proportional to velocity. Comparing the discriminated Doppler signals for projectiles with and without propellant provides a determination of when burn-out occurs.

This report will describe the RF and radar techniques for making in-flight burn time measurements. The results of using these techniques for firing tests at the Ballistic Research Laboratory (BRL) at Aberdeen Proving Ground (APG), Maryland will be reported also. Two series of APG firing tests were conducted to measure M864 propellant burn times under a variety of conditions that included different initial spin rates and different gun elevations. In addition, some propellant grains were removed from the projectile, were temperature conditioned, and reloaded into ambient temperature projectiles to see if there was an effect upon the burn time.

The first series of flight tests were fired in September, 1988 and consisted of eight projectiles instrumented with an RF transmitter and antenna located in the fuze well of the projectile. Four rounds had propellant. The second series occurred in June, 1989 and consisted of firing ten rounds, of which eight had propellant.

II. Measurement Techniques

The FM telemetry technique takes advantage of the effect that the hot gaseous products, resulting from the burning process, have on the frequency of the transmitter. The other technique uses a special processing technique in determining velocity from raw voltage signals obtained from a HAWK Doppler radar that is used to track the projectiles. Results from the two test firings were obtained by utilizing both techniques.

These two techniques are not direct measurements. Careful examination of the data is required as there are conditions that make the results ambigous. In order to minimize confusion and to verify results, information from several signal sources has to be examined for each techniques. Indeed, the techniques need to be checked against each other for consistency.

1. RF Technique

Miniature RF transmitters have been used for years in telemetry packages with gun-launched projectiles at the BRL for a variety of high-G telemetry programs. The transmitter is designed to operate at 243-245 MHz (P-band) and consists of a simple oscillator circuit whose frequency can be altered by applying a voltage to the modulation input. There is a linear amplifier stage with a dynamic range of +20 DB that provides isolation between the RF output load and the oscillator and minimizes shifts in frequency that are caused by output load variation (frequency pulling). The circuit for this transmitter is shown in Figure 2. The transmitters have, on the average, a power output of 100 milliwatts with a 50 ohm output load. The unit is fabricated using hybrid thick-film devices as well as discrete components on an alumina substrate. The antenna used with the P-band telemeters is a piece of number 12 copper wire cut to a length of about 0.3 meters (1/4 wave) and wound into the shape of a tapered helix in order to conform to the inside surface of the projectile fuze windshield. The interior of the windshield is encapsulated to form a rigid unit to protect the antenna and transmitter from the high launch accelerations when fired from a gun.

While the amplifier stage provides isolation, it only minimizes frequency pulling. Typically, the frequency varies 100-200 KHz about the operating frequency with the output load varying from a short circuit (zero output load) to an open circuit (infinite output load). For a 5:1 antenna impedance mismatch (i.e. a 250 ohm output load), the frequency pulling is about 78 KHz.

The transmitter's electrical ground is physically connected to the fuze body when the units are assembled. This makes the projectile body part of the antenna. Experience has shown that the frequency of this transmitter is sensitive, to a small degree, to the length of the projectile to which it is attached. This is because the effective oscillator output load is altered slightly as projectile length changes. In most telemetry applications, this loading can be ignored because the frequency shifts are very small and they can be accomodated easily with the telemetry receiving equipment that is used.

This frequency sensitivity is used to advantage in the measurment of the burn time for the 155mm M864 projectile. The hot gas from the base-burn process produces an ionized trail which effectively changes the length of the projectile and hence modulates the transmitter frequency. If the trail is variable in length, then this frequency pulling would look like noise modulation on the transmitter. A standard FM telemetry receiver demodulates the received RF carrier signal transmitted from the projectile and provides this modulation at its video output connector.

Projectiles instrumented only with transmitters were fired at APG by the BRL in September 1988 and June 1989. The modulation input to the transmitters was left unconnected. If a fixed DC voltage were applied at the modulation input, it would tend to stabilize the transmitter frequency or make it less sensitive to output load changes. This was not desired for these tests. The details of the firing tests and the results from the telemetry will be reported in the ensuing sections of this report.

2. Discriminated Doppler Radar Technique

HAWK Doppler radar coverage was provided for both series of firings that are described in this report. There are many methods used to process the HAWK Doppler signals to obtain slant velocity as a function of time. The main method is to digitize the raw Doppler voltage signal and then to perform a fast Fourier transform (FFT) on sections of the data to look for frequency content. The frequency spectra are a function of projectile velocity.

Doppler signals can also be processed with a standard telemetry discriminator which is used to demodulate subcarrier oscillator signals obtained from telemetry. The discriminator uses a phase lock loop (PLL) circuit to track the frequency of the input signal. The discriminator is tuned to a center frequency and the input is bandpass filtered at 40 percent above and below the set center frequency. The output of the discriminator is a voltage that is proportional to the difference between the input signal frequency and the set or tuned center frequency. The discriminator can be calibrated for dc voltage output as a function of input frequency. Putting Doppler signals into the discriminator produces an output voltage that is proportional to velocity.

If there is an event that produces a complex Doppler return signal, (multiple frequencies in the return signal), then the discriminator will produce what looks like a noise burst in its output signal. This is because the discriminator is trying to lock onto a single (albeit changing) frequency. A complex signal with multiple frequencies within the input bandpass filter setting will cause the discriminator to lose lock and the output to oscillate, producing a noise-like signal.

In using the discriminator method to process HAWK Doppler data from the September firings, it was noticed that the output of the discriminator produced a noise burst at the expected burn-out time. The time correlated well with the telemetry method. There are, however, a variety of conditions that can produce a complex Doppler return signal. It was felt that the technique of determining burn time by discriminating HAWK Doppler return signals required the comparison between base-burn rounds with and without propellant which were fired under the same conditions. The results of doing this are presented later.

III. Test Program and Instrumentation

Two 155mm M864 firing programs were conducted at the APG by the Free Flight Aerodynamics Branch (FFAB) of the Launch and Flight Division (LFD) of the BRL to make in-flight measurements of the burn time for the base-burn system.

1. Test Programs

There were eight rounds fired in September of 1988. Each of these rounds were instrumented with a transmitter operating at a frequency of 245 MHz. Four of the projectiles had propellant. The rounds without propellant were included to make a comparison of both the telemetry data and the radar information. It was felt that this would facilitate the analysis of the results. All eight rounds in the September tests were fired at a quadrant elevation (QE) of 400 mils. Four of the rounds were fired at a zone 7W (M4A2 propelling charge) and four were fired at zone 8R (M203 propelling charge). All the rounds were fired at ambient conditions.

There were ten rounds fired in the June 1989 test program. The June program included rounds fired at quadrant elevations of 400 mils and 1220 mils. Both zone 7W and 8R propelling charges were used. In addition, some base-burn propellant grains were independently temperature conditioned. All this was done to see what effect the launch velocity (initial spin rate), the propellant grain temperature, and the pressure changing with elevation had on the burn-time of the propellant.

The tests conditions for the two test programs are summarized in Tables 1 and 2 below.

Table 1. September 1988 Test Program Summary

Round No.	QE (mils)	Charge	Propellant	propellant Temperature (degrees Centigrade)
S1	400	M4A2	yes	32
S2	400	M4A2	yes	32
S3	400	M203	yes	32
S4	400	M203	yes	32
S5	400	M203	no	–
S6	400	M203	no	–
S7	400	M4A2	no	–
S8	400	M4A2	no	–

Table 2. June 1989 Test Program Summary

Round No.	QE (mils)	Charge	Propellant	Propellant Temperature (degrees Centigrade)
J1	1220	M203	yes	44
J2	1220	M203	yes	-78
J3	1220	M203	yes	32
J4	1220	M203	no	–
J5	400	M203	yes	44
J6	1220	M4A2	yes	44
J9	400	M4A2	yes	44
J10	1220	M4A2	yes	-78
J11	1220	M4A2	yes	32
J12	1220	M4A2	no	–

2. Instrumentation

The ground instrumentation for both test programs included HAWK Doppler radar support for velocity and trajectory data, and a Weibel Doppler radar system used mainly to obtain muzzle velocity. In addition, a smear photograpic camera was used to check for structural integrity of the projectile as it exited the gun tube. Time zero indication was provided by an infrared muzzle flash detector.

An instrumentation van was located behind the gun tube in order to provide a ground receiving station for the telemetry units on board the projectile. The instrumentation van included two FM/FM telemetry receivers, an analog Honeywell model 101 tape recorder and auxillary electronics needed to provide telemetry coverage. The Weibel Doppler radar processor was also housed in the van and provided muzzle velocities for the test. Two six-turn, helical receiving antennae were used in order to cover the entire trajectory for the higher quadrant elevations.

The telemetry receivers demodulate the received RF carrier signals and provide the modulation signals at the receiver's video output. It was expected that the amount of frequency modulation of the RF transmitter caused by the burning process would be small. Therefore the gain associated with the receiver's video outputs was set to maximum, which is a non-standard procedure when compared to a normal telemetry system that utilizes sub-carrier oscillators. A telemetry package that would include subcarrier oscillators would make the detection of the noise modulation produced by the base-burn process very difficult, if not impossible. The presence of the subcarrier signals would require that the video gain be lowered or adjusted so that the signals are not distorted at the video output. This makes the receiver insenstive to the small amount of noise modulation caused by the base-burn process. The video output signals were recorded on FM channels of the tape recorder.

The receiver's automatic gain control (AGC) outputs were recorded on FM channels as well. The AGC is an indication of the strength of the received RF signal. It often contains information on the spin rate and yawing motions of the projectile. Analysis of the AGC signal aids in the identification of the source of the video signals. For example, if the video signal is noisy and the AGC is very low, then the source of the noise is probably the receiver itself. If the AGC signal is high then the source is in the RF carrier and it is probably caused by modulation of the carrier itself.

IV. Results

The burn time measurement results from the September 1988 and June 1989 test programs at the Aberdeen Proving Ground are summarized in Table 3.

Table 3. 155mm M864 Burn Times

Round No.	QE (mils)	Muzzle Velocity (m/s)	Launch Spin (Hz)	Propellant Temperature (degrees Centigrade)	Burn Times (sec) *	
					Telemetry	Radar
September 1988						
S1	400	555	179	32	30†	29
S2	400	554	179	32	no RF	30
S3	400	828	267	32	27	26
S4	400	827	267	32	27	27
June 1989						
J2	1220	824	266	-78	62	no data
J3	1220	826	267	32	54‡	no data
J5	400	817	264	44	28	no data
J9	400	557	180	44	28	29
J10	1220	556	179	-78	51	no data
J11	1220	554	179	32	38,45	no data

* times rounded to the nearest second
†obtained by frequency analysis
‡measurement is questionable

The times for burn-out to occur were obtained from the recorded video output of the telemetry receiver and, for the September test series, the discriminated HAWK radar Doppler return signals. The HAWK radar data yielded only one measurable burn time for the June, 1989 series. This was because a time-zero reference pulse was not recorded on the tape recorder (rounds J1- J5) or the HAWK radar did not track the projectile through the time for burn-out to occur. There was a power failure in the instrumentation van that caused the loss of data for the first round of the June series. There was no RF transmission for Round S2 of the September series or for Round J6 of the June series.

1. Telemetry Data Plots

Figures 3, 4, and 5 are typical plots of the video and AGC signals from instrumented rounds with live base-burn systems. The video traces show a noise modulation that persists for a period of time and then, rather abrubtly, goes away. Figure 3 is for Round S4 of the September firings. Figures 4 and 5 are for Rounds J9 and J10 respectively of the June test series. Burn-out is taken to occur at the time when the video signal amplitude reaches its minimum level. Examination of the AGC traces before and at the time burn-out occurs shows that the received signal strength is high and that the noise on the video trace is from frequency modulation and not from receiver noise. The large, short duration voltage spikes that are visible in Figures 3 and 5 are due to the tuning of the telemetry receiver. The receivers are manually tuned to keep the RF carrier centered and any tuning produces a momentary shift in the video output. Since the video gains are at a maximum, a large voltage pulse is produced any time a tuning adjustment is made. The noise at the end of the video traces for Figures 4 and 5 is receiver noise. This is evident from the rapid drop in the AGC signal that occurs at that time.

The video and AGC traces for M864 projectiles without propellant are shown in Figures 6 and 7. Figure 6 is for Round S6 of the September, 1988 series, and Figure 7 is for Round J12 of the June 1989 series. The video traces show a very clean baseline. Again, the sharp voltage spikes are the result of periodically tuning the receiver. The noise at the beginning of Figure 7 is partly due to initially low signal strength and also to tuning adjustments of the receiver. The clean baselines, however, are expected for a round with an inert base-burn system.

Figure 8 is a plot of the video and AGC signals for Round S1 of the September series. This round had a propellant grain. The initial data loss in the first seven and a half seconds is due to acquiring the RF signal, but the remainder of the trace shows noise for the duration of the flight. The AGC shows that the received signal strength starts dropping significantly at about 25 seconds. When this happens the receiver starts filling with noise, and it is difficult to tell from the video trace where base-burn induced noise modulation of the transmitter stops. However, frequency analysis of the video signal shows a definite change in the nature of the frequency content at approximately 30 seconds into the flight. This is shown in Figure 9 which is a waterfall spectral plot of the video signal for this round. The first trace of the waterfall starts at 27.8 seconds. The time increment between traces is 0.16 seconds. It can be seen from Figure 9 that the frequency content of the signal changes from small frequency spikes distributed across the frequency band to a very low amplitude frequency trace at 30 seconds. This quieting is assumed to be when burn-out occurs. Examination of Figure 8 shows that the video signal does show a subtle change at 30 seconds.

Figure 10 is a plot of the video and AGC signals for Round J3 in the June, 1989 series. This round had base-burn propellant, and it would appear that burn-out occurs at 54 seconds into the flight. However, the received signal strength was low for this round as shown from an examination of the AGC signal for the first part of the flight. The quieting of the video signal at 54 seconds is most probably the decrease in receiver noise that results as the signal strength increases. The actual burn-out is masked in the receiver noise.

Figure 11 is a plot of the telemetry signals for Round J11 of the June, 1989 tests. The video signal shows a major quieting in noise at 38 seconds into the flight and a further quieting at 45 seconds. The second quieting in the data trace is very minor but it leaves a question as to where burn-out really occurs. Which of the two times is correct cannot be determined here.

Figure 12 shows the telemetry signals for Round S7 of the September, 1988 series. This round did not have a base-burn propellant grain and still shows noise on the video signal. The AGC shows good signal strength for the entire flight, after carrier acquistion, so that the noise is a modulation on the transmitter rather than receiver noise. Figure 13 is a waterfall plot of the video signal for this round, beginning at 26 seconds. It shows that the video signal contains a major frequency component at 145 hertz. This frequency is the spin rate of the projectile at 25 seconds into the flight. Figure 14 is a plot of spin versus time for this round. It was obtained by frequency analysis of the AGC signal. This suggests that the modulation for Round S7 is associated with and perhaps caused by the motion of the projectile. The AGC signal indicates that the projectile is undergoing some yawing motion, but this cannot be quantified. It also suggests that yawing motion during burn-out could mask the effect of burn-out on the video signal and influence the determination of burn time from the video signal.

2. HAWK Radar Data Plots

Figures 15, 16, and 17 are plots of projectile velocity versus time obtained by discriminating the HAWK Doppler return signals. These are all for the September test program series. As mentioned previously, burn time measurements from the radar signals were not made for the June 1989 tests either because of a lack of time zero indication or because the radar did not track the projectiles long enough.

Each of the plots shows a comparison of discriminated HAWK velocity for a live round and an inert round fired at the same charge and quadrant elevation. In Figure 15, burn-out for the live round is taken to be at the end of the first noise burst in the discriminator output, as indicated on the plot. Note that there is not a corresponding burst on the inert round fired at the same conditions. For live and inert rounds, noise bursts occurred at similar times as shown in Figures 16 and 17. The times at which burn-out occurs are indicated on the plots. The velocity curves for the inert rounds in Figures 16 and 17 do not show any bursts at a time corresponding to the burn-out time for the live rounds.

As is evident from the plots of the discriminated HAWK velocity profiles there are other events occurring that produce a disturbance in the output of the discriminator. These disturbances could be caused by a significant drop in signal amplitude that could occur if the radar cross section changes as the projectile goes through apogee or by a decrease in signal to noise ratio as the projectile gets farther away. A decrease in the signal to noise ratio at the end of the flight could cause a disturbance in the discriminator output.

It would be impossible, at this time, to determine when burn-out occurs using discriminated HAWK Doppler returns from only a live base-burn round. At a minimum, it is necessary to have data from an inert round shot under the same firing conditions. This allows the burn-time to be determined by comparisons of data as is done in this report. It will be necessary to understand the details of base-burn signal process as it nears burn-out. Studies on what other phenomena could cause a similar signature in the discriminated HAWK data are also necessary.

3. Data Analysis

The burn times presented in Table 3 from both the RF and radar techniques are rounded to the nearest second. The differences in time as measured by the two techniques can be attributed to some extent to this rounding off as well as to the transient nature of the burn-out process. Additionally, the HAWK radar data was recorded on a different tape recorder than were the telemetry signals and the radar used an independent time-zero detector.

The effects of different launch conditions are summarized in Tables 4, 5 and 6 below where results are presented side-by-side so that the comparisons are easy to make.

Table 4. Effect of Launch Velocity and Launch Spin on 155mm M864 Burn Times

Round No.	QE (mils)	Muzzle Velocity (m/s)	Launch Spin (Hz)	Propellant Temperature (degrees Centigrade)	Burn Times (seconds)
S1	400	555	179	32	30
S3	400	828	267	32	27
J9	400	557	180	44	28
J5	400	817	264	44	28
J10	1220	556	179	-78	51
J2	1220	824	266	-78	62

Table 5. Effect of Quadrant Elevation on 155mm M864 Burn Times

Round No.	QE (mils)	Muzzle Velocity (m/s)	Launch Spin (Hz)	Propellant Temperature (degrees Centigrade)	Burn Times (seconds)
S1	400	555	179	32	30
J11	1220	554	179	32	37,45

Data from ground instrumentation tests [2] in which the M864 base-burn system was mounted in a rotating test fixture show that the burning rate of the propellant increases and burn time decreases with increasing spin rate. Computations by Danberg [1] show similar results. An increase in muzzle velocity should decrease the base pressure and result

Table 6. Effect of Temperature Conditioning on 155mm M864 Burn Times

Round No.	QE (mils)	Muzzle Velocity (m/s)	Launch Spin (Hz)	Propellant Temperature (degrees Centigrade)	Burn Times (seconds)
S4	400	827	267	32	27
J5	400	817	264	44	28
J10	1220	556	179	-78	51
J11	1220	554	179	32	37,45

in an increase in the burn time. In flight tests such as reported here, the effects of spin and muzzle velocity cannot be isolated. As muzzle velocity is increased, so is the launch spin rate of the projectile and the two effects tend to oppose each other so all that can be determined by these techniques is an overall combined effect. An additional complication is the fact that projectiles fired at different velocities, even at low quadrant elevation, will have different trajectories and experience different ambient pressures.

A comparison of the burn times for the rounds fired in September, 1988 indicates that the combined effect of spin rate and muzzle velocity has a measurable effect on the burn time. The first two rounds were at a lower zone and initial spin rate than were the last two rounds . The rounds fired at the lower zone burned for about 3 seconds longer than the high zone rounds. It is not clear at this time whether this is a combined muzzle velocity-spin effect or whether the three seconds is due to the accuracy of the technique only. All of the September firings were at a quadrant elevation of 400 mils.

The effect of spin for the rounds fired in the June series cannot be determined. Rounds J5 and J9 were both fired at 400 mils elevation with their propellant grains conditioned hot (44 degrees centigrade). The measured burn times were the same for both rounds. Rounds J2 and J10 were fired at 1220 mils elevation and had their propellant grains conditioned at -78 degrees centigrade The high zone round actually burned for about 7 seconds longer than the low zone round. The combined muzzle velocity-spin effect, if any, is probably masked by the fact that the higher charge round fired at 1220 mils quadrant elevation is spending more time in a less dense atmosphere than are the lower charge rounds. The effect of being in a less dense atmosphere is to increase the burn time which is probably the overriding condition.

The effect of quadrant elevation on the burn time is evident. This can be seen in the results by comparing any of the lower elevation rounds with the higher elevation rounds that were fired under similar conditions. For example, a comparison between Round S1 in September and Round J11 in June shows that there is a significant increase in the burn time of the propellant at the higher quadrant elevations.

The measurements indicate that temperature conditioning of the propellant grain has some effect on the burn time. A comparison of Round S4 in September 1988 and Round J5 of the June 1988 tests show similar burn times. One was ambient and the other was at 44 degree centigrade. A comparison between Rounds J10 and J11 in the June 1989 program shows that the cold conditioned rounds burned for about 8 seconds longer than the rounds fired at ambient temperature.

V. Summary and Conclusion

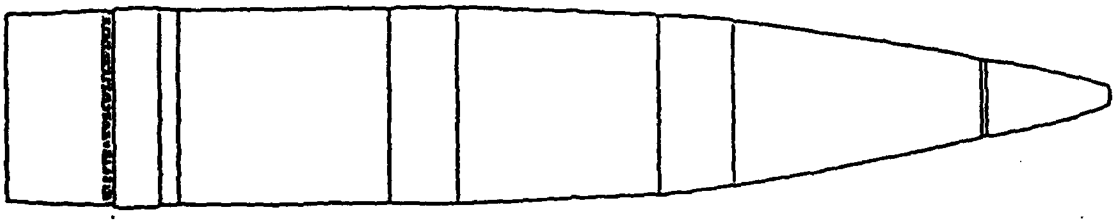
Several techniques have been used to make in-flight burn time measurements on the propellant in the 155mm M864 base-burn projectile. A telemetry technique examines the frequency modulation of RF transmitter data. A technique of detecting burn-out by discriminating the Doppler return signals from a HAWK radar system was used as an alternate method. This second technique requires the comparison of Doppler data between live and inert base-burn projectiles. The inert projectile must be fired at the same conditions as the live round so that data comparisons can be made.

Both methods provided burn times that correlated with each other. The results obtained via telemetry were more readily analyzed in most cases. However there were some situations where the telemetry data was ambigous. If burn-out occurred near the end of the flight, which is the case for a low zone firing, then receiver noise masked the burn-out effect. Likewise, there was a modulation of the transmitter frequency produced by the yawing motion of the projectile would confuse the results. The use of an AGC signal and frequency analysis helps to isolate these effects.

Results using the HAWK radar data were more difficult to interpret because of ambiguities in the data. The ambiguities were disturbances in the discriminated Doppler signals that resemble those that occured at burn-out. The causes of the ambiguities have not yet been indentified in any quantitative manner. The use of inert rounds as in the September, 1988 tests showed the presence of an extra disturbance that occurs at burn-out for only the live round. Additional work is needed with this technique in order to be able to confidantly use it alone to make burn time measurements.

The results of measurements made with these techniques show a definite effect of ambient pressure on burn time of the 155mm M864 base-burn projectile. The rounds fired at the higher elevations show a considerable increase in burn time over the lower elevation firings. The measurements show that, at low quadrant elevations, rounds with higher initial spin rate and muzzle velocity had slightly shorter burn times. For the higher quadrant elevations, the combined effect of spin and muzzle velocity is probably masked by the effect of ambient pressure.

The effects of the various parameters were obtained by comparing burn-times between firings that had similar launch conditions. The data are sparse for some of these comparisons. It is recommended that further firings be conducted to better define the effects of spin, muzzle velocity and temperature on burn-time.



Dimensions

Length of Projectile	calibers	5.79
Nose Length	calibers	3.42
Cylinder Length	calibers	1.86
Boattail Length	calibers	.50
Boattail Angle	degrees	3.00

Mass Properties

Mass	kgs	46.95
	(lbs)	103.5
Mass of Fuel	kgs	1.21
	(lbs)	2.67
Center of Gravity	cm from nose	58.8
	(in from nose)	23.16
Moments of Inertia		
Axial	$kg\text{-}m^2$	.158
	$(lb\text{-}ft^2)$	3.75
Transverse	$kg\text{-}m^2$	1.657
	$(lb\text{-}ft^2)$	39.32

Figure 1. Physical Properties of the 155mm DPICM, M864 Projectile

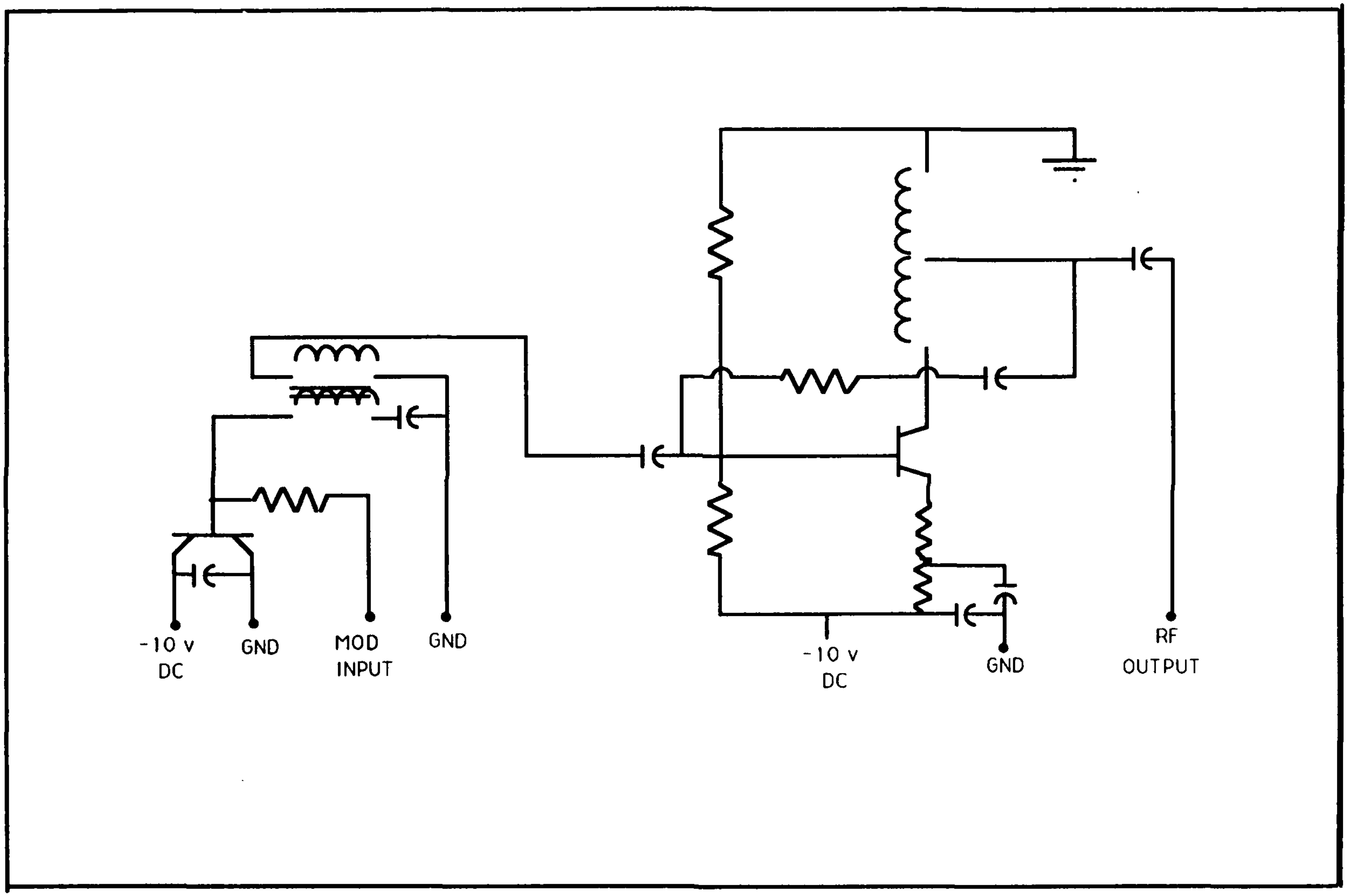


Figure 2. 245 Mhz Two-Stage Oscillator Circuit

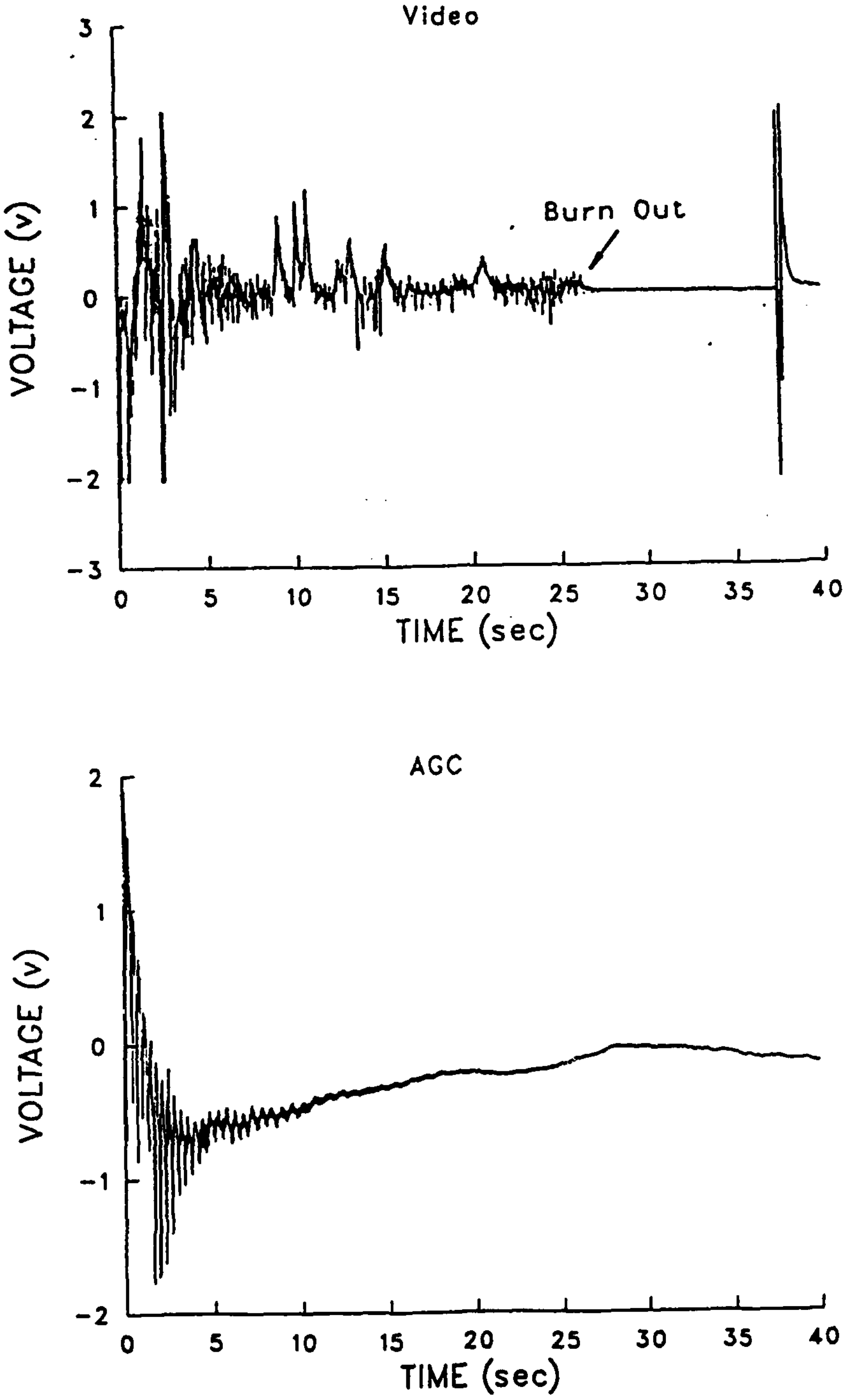


Figure 3. Video and AGC signals for Round 4. September 1988. (live)

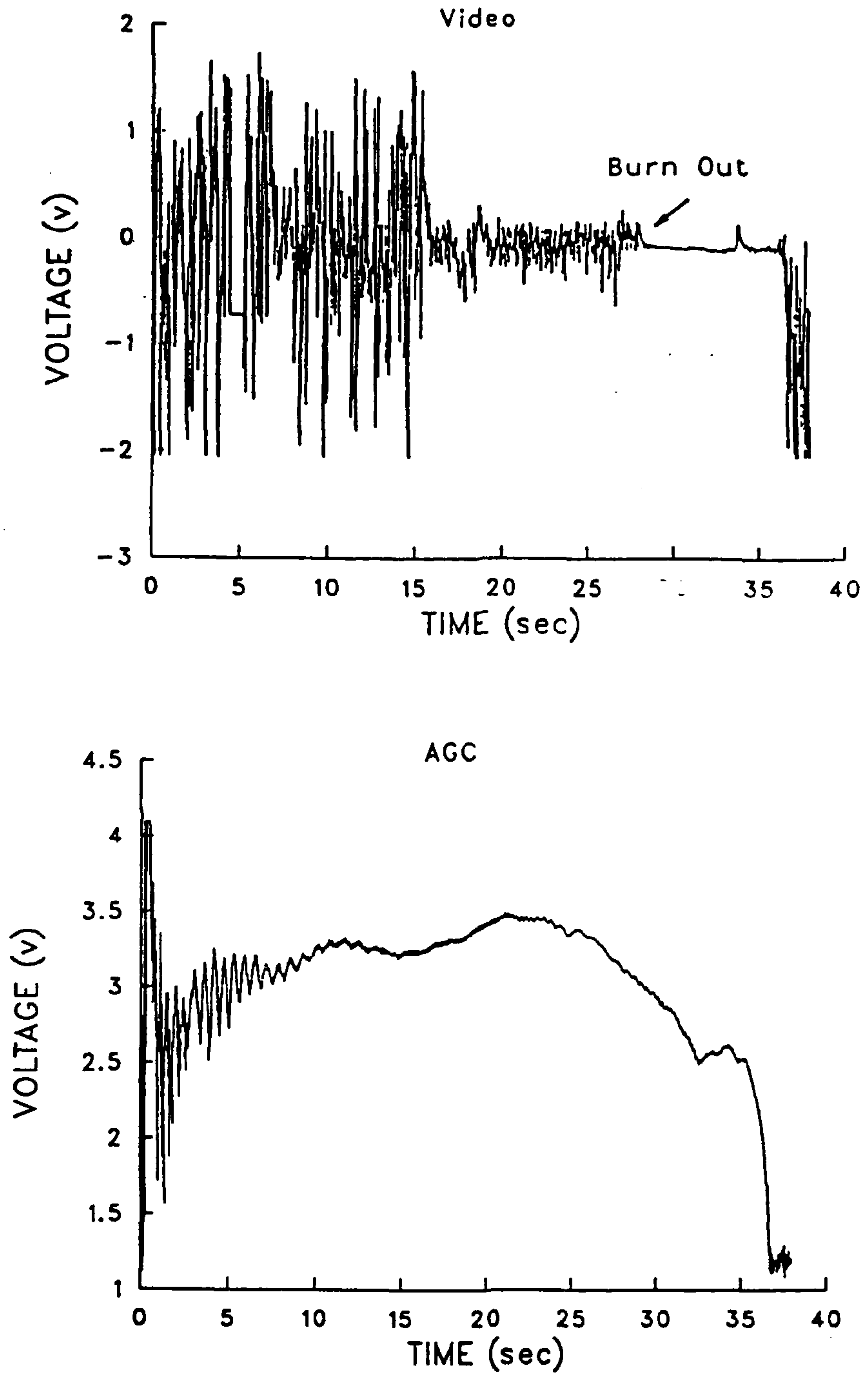


Figure 4. Video and AGC signals for Round 9, June 1989. (live)

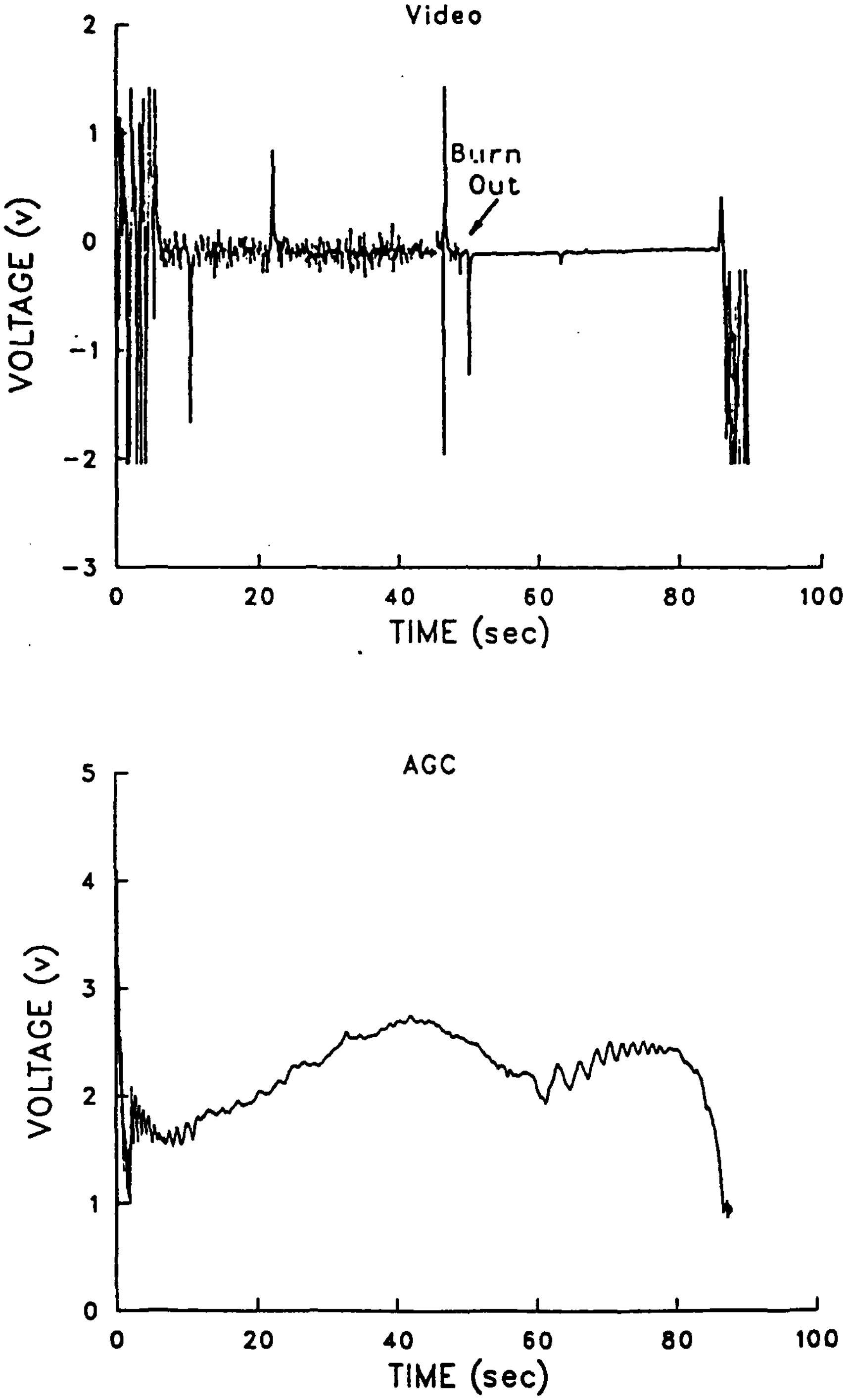


Figure 5. Video and AGC signals for Round 10, June 1989. (live)

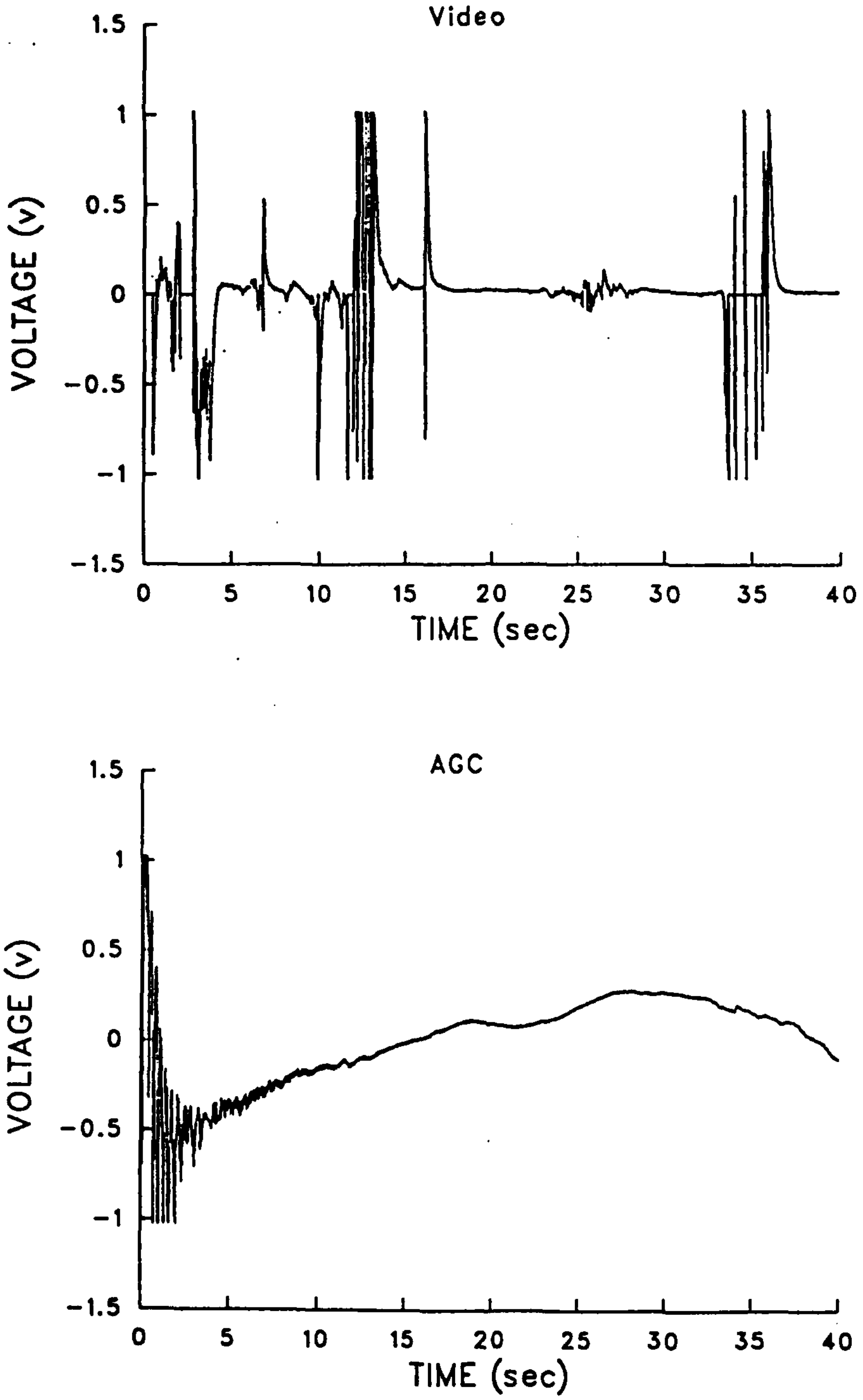


Figure 6. Video and AGC signals for Round 6, September 1988. (inert)

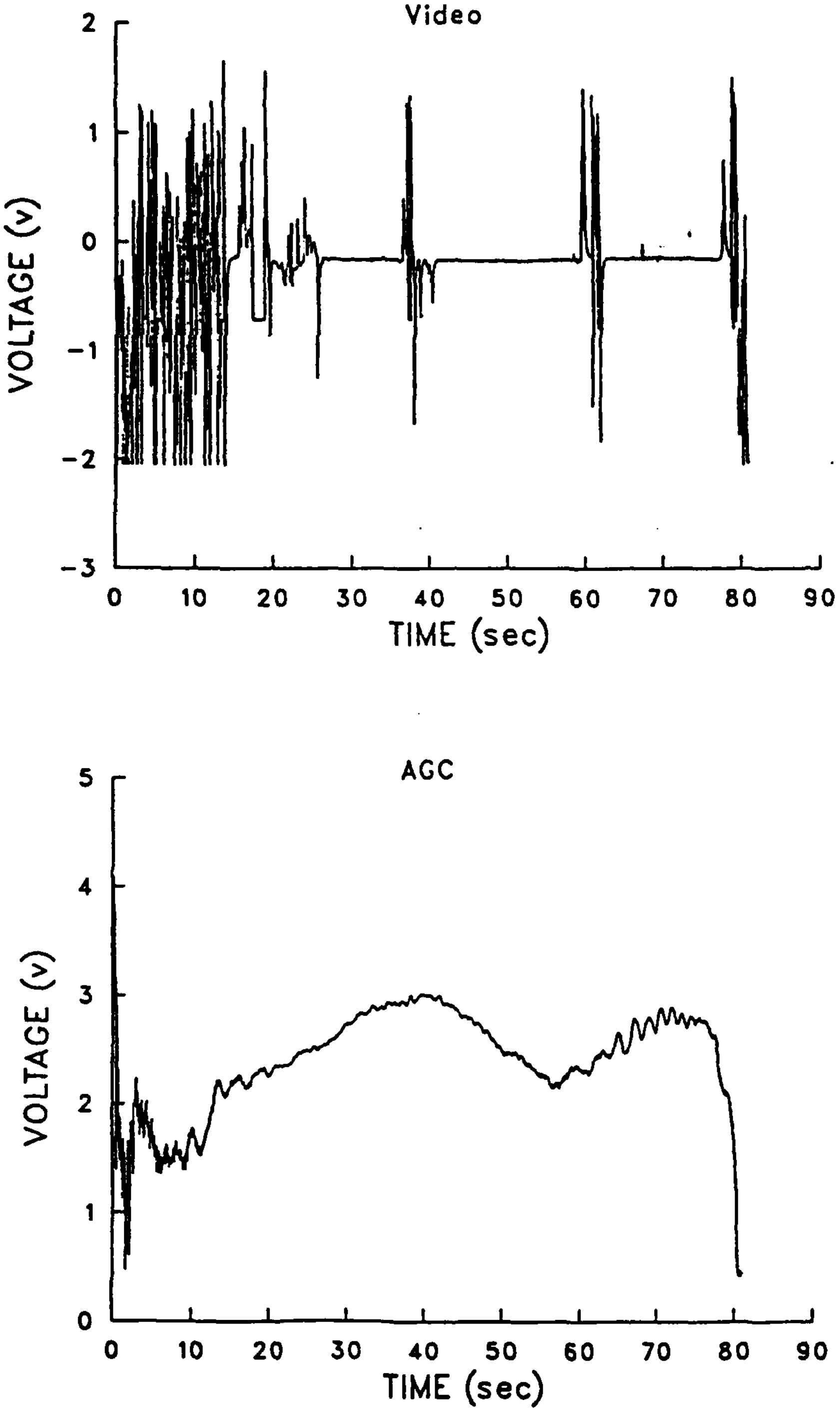


Figure 7. Video and AGC signals for Round 12, June 1989. (inert)

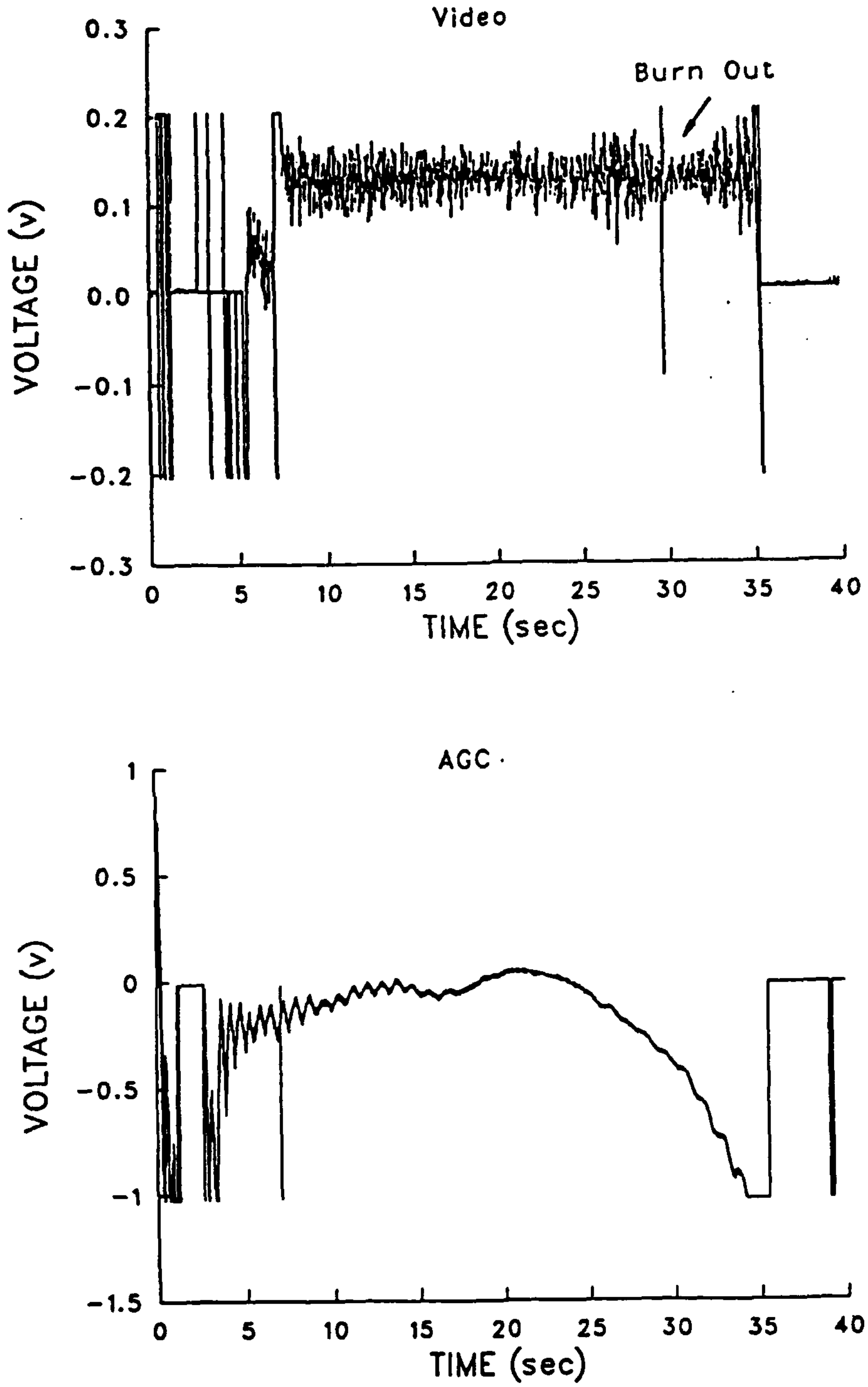


Figure 8. Video and AGC signals for Round 1, September 1988. (live)

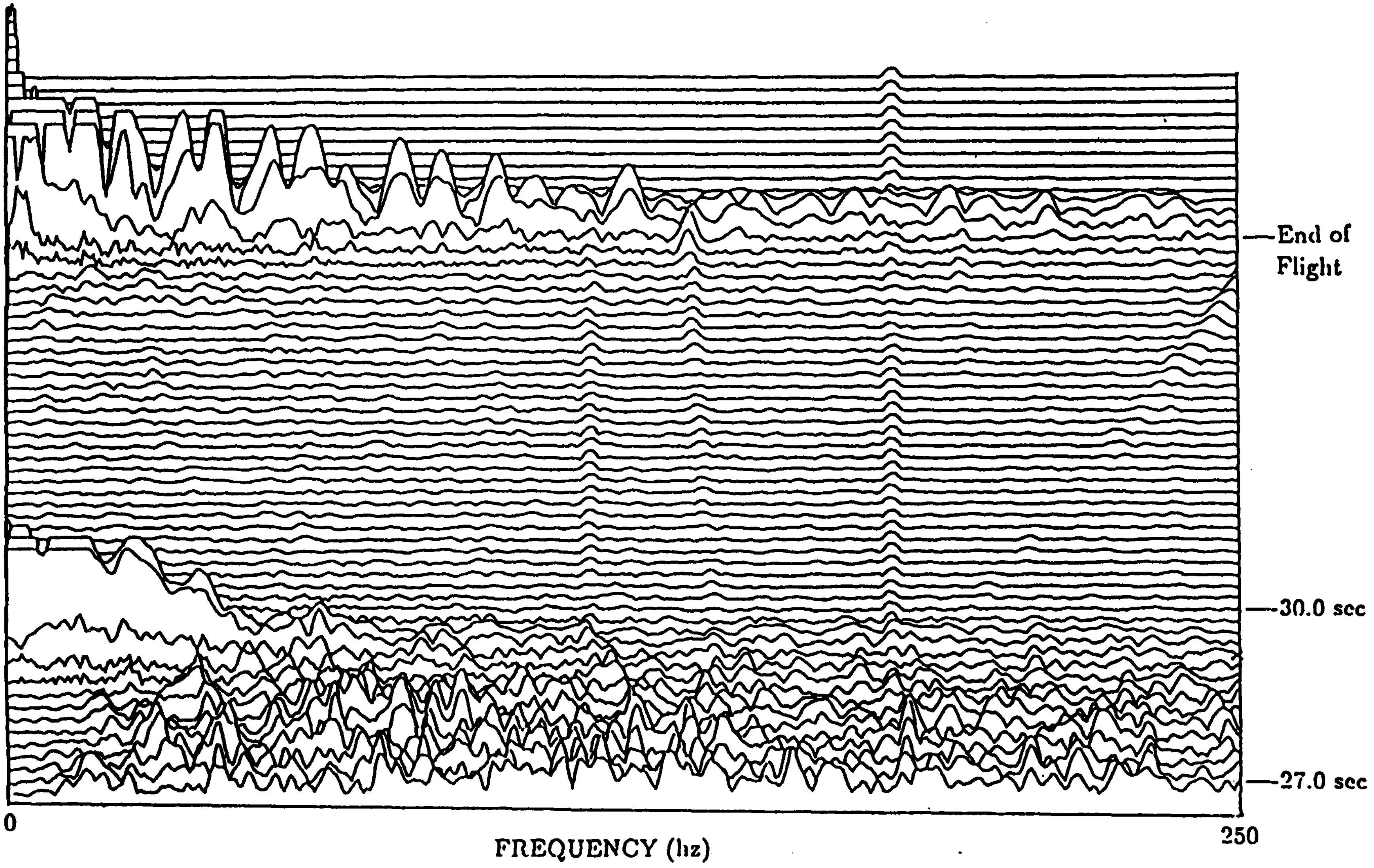


Figure 9. Waterfall Plot of Video Data for Round 1, September 1988

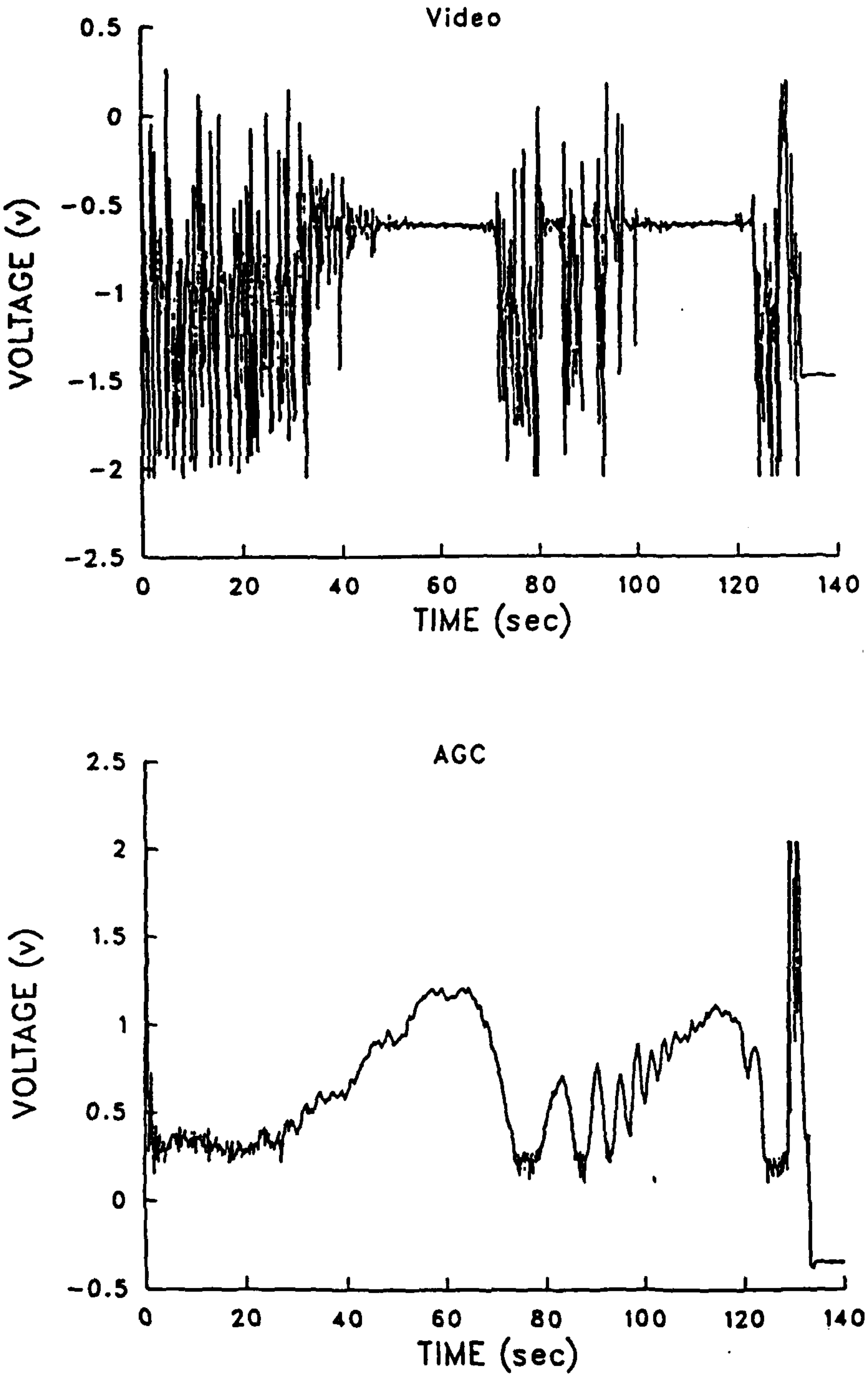


Figure 10. Video and AGC signals for Round 3, June 1989. (live)

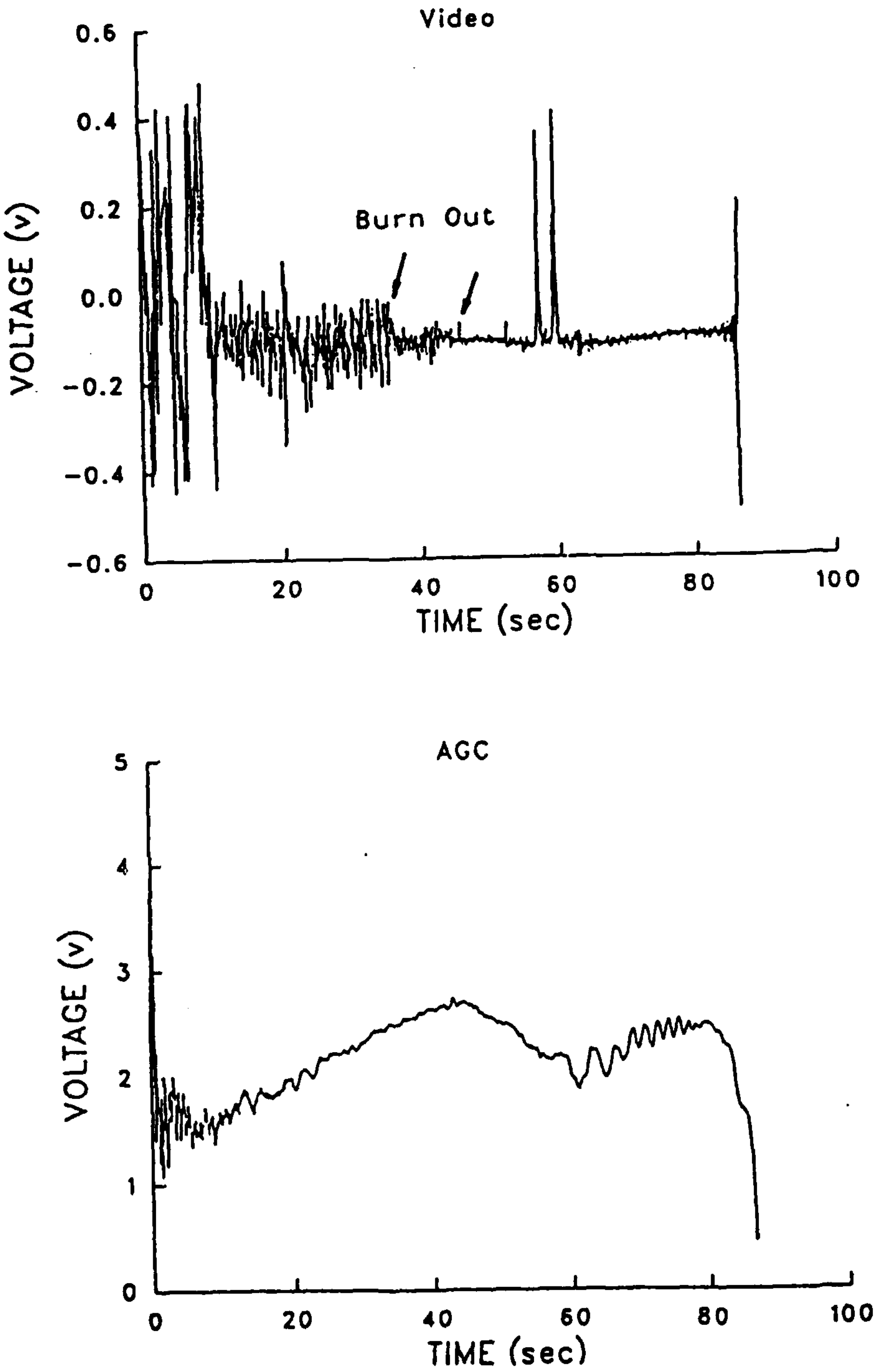


Figure 11. Video and AGC signals for Round 11, June 1989. (live)

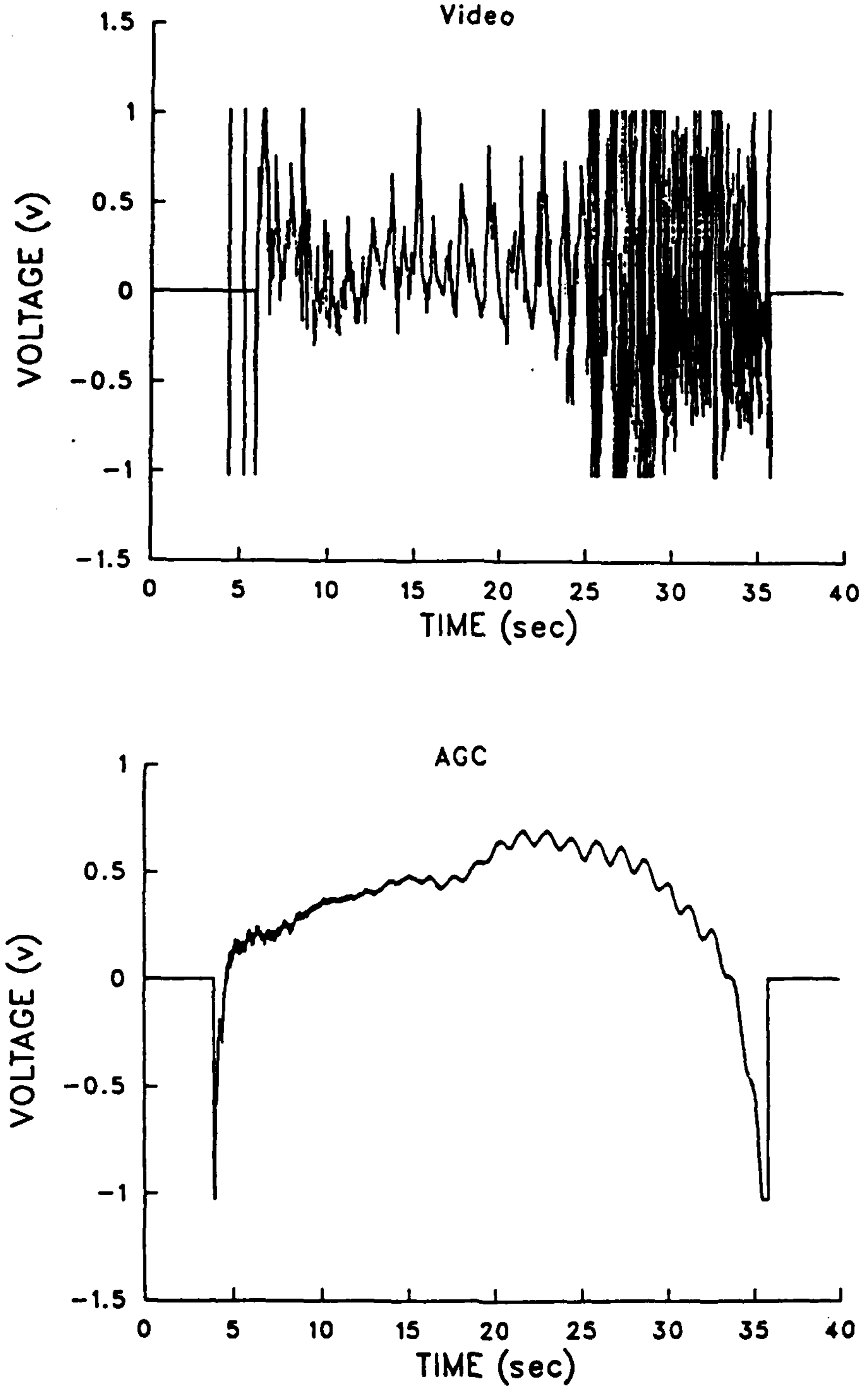


Figure 12. Video and AGC signals for Round 7. September 1988. (inert)

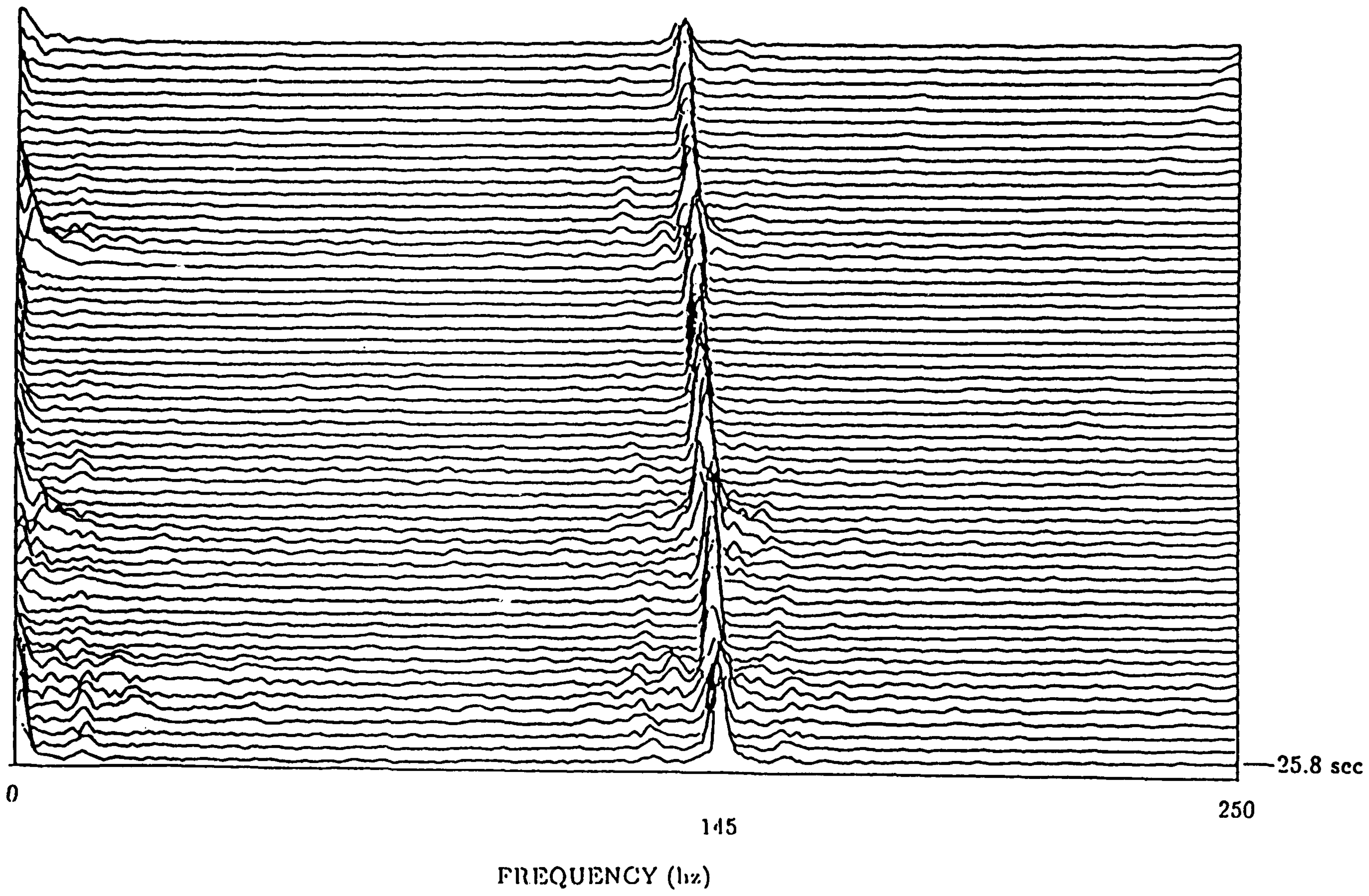


Figure 13. Waterfall Plot of Video Data for Round 7, September 1988. (inert)

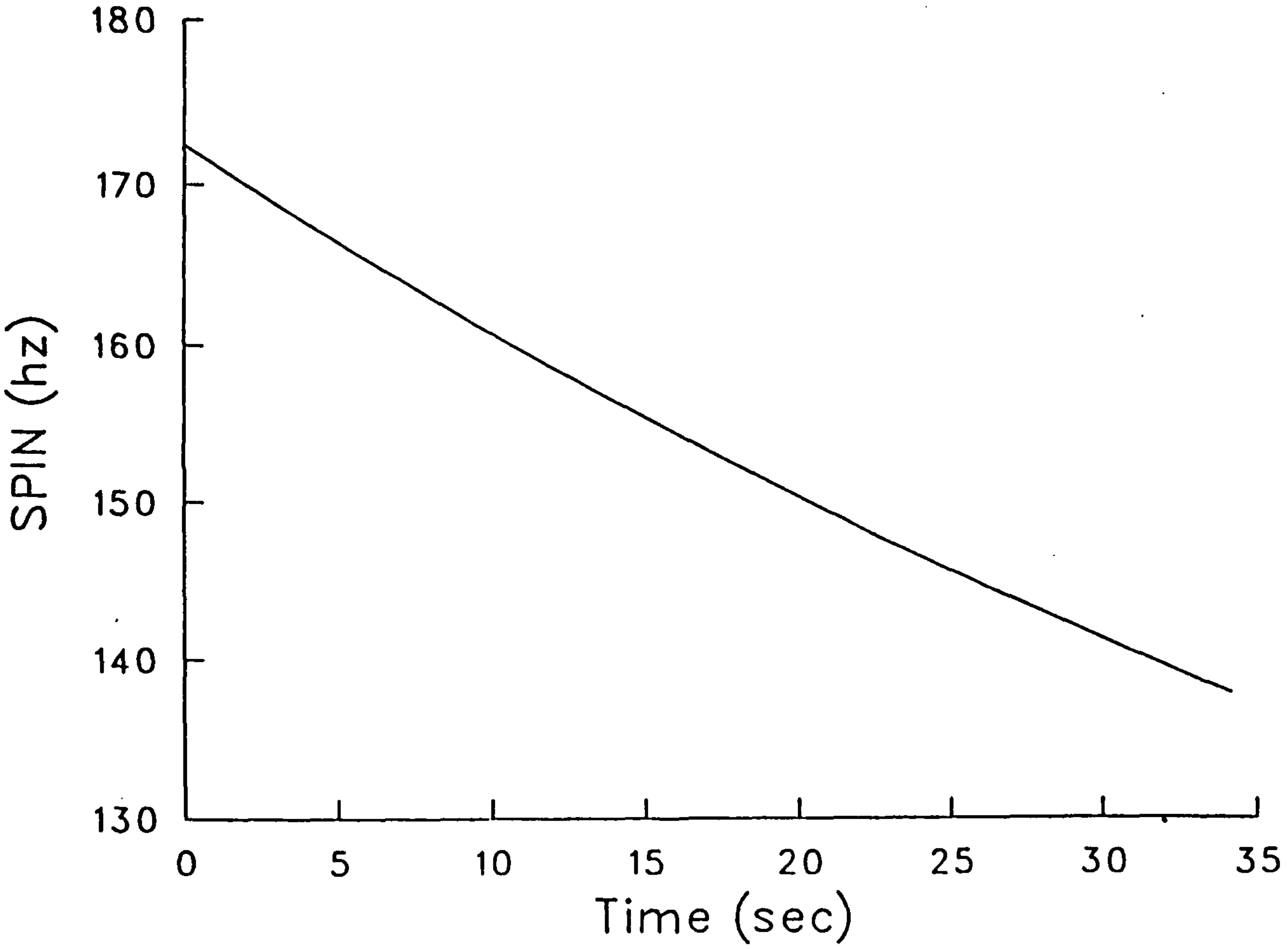


Figure 14. Spin Data (from AGC) for Round 7, September 1988. (inert)

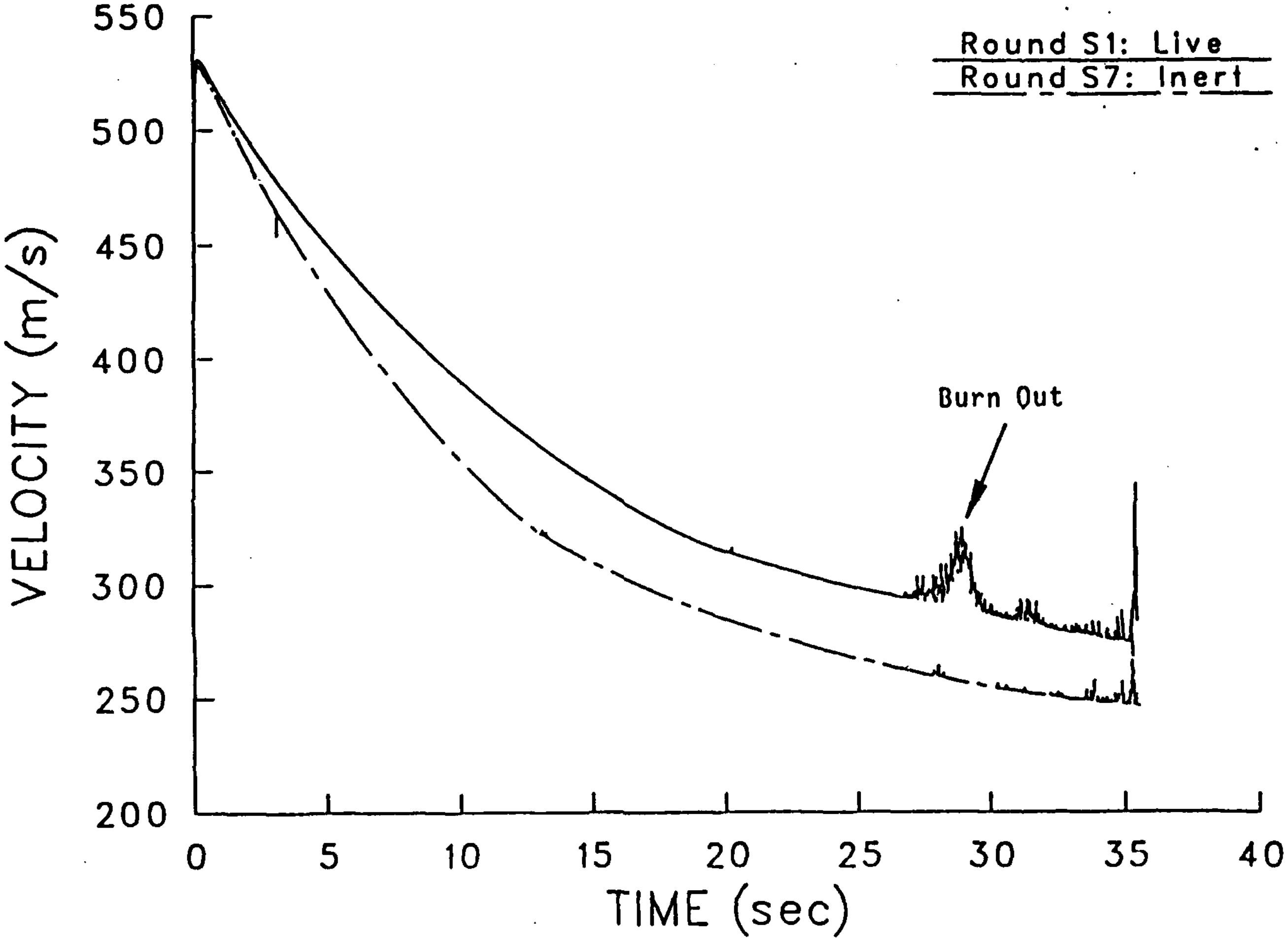


Figure 15. Discriminated Doppler data for Rounds 1 and 7 September 1988.

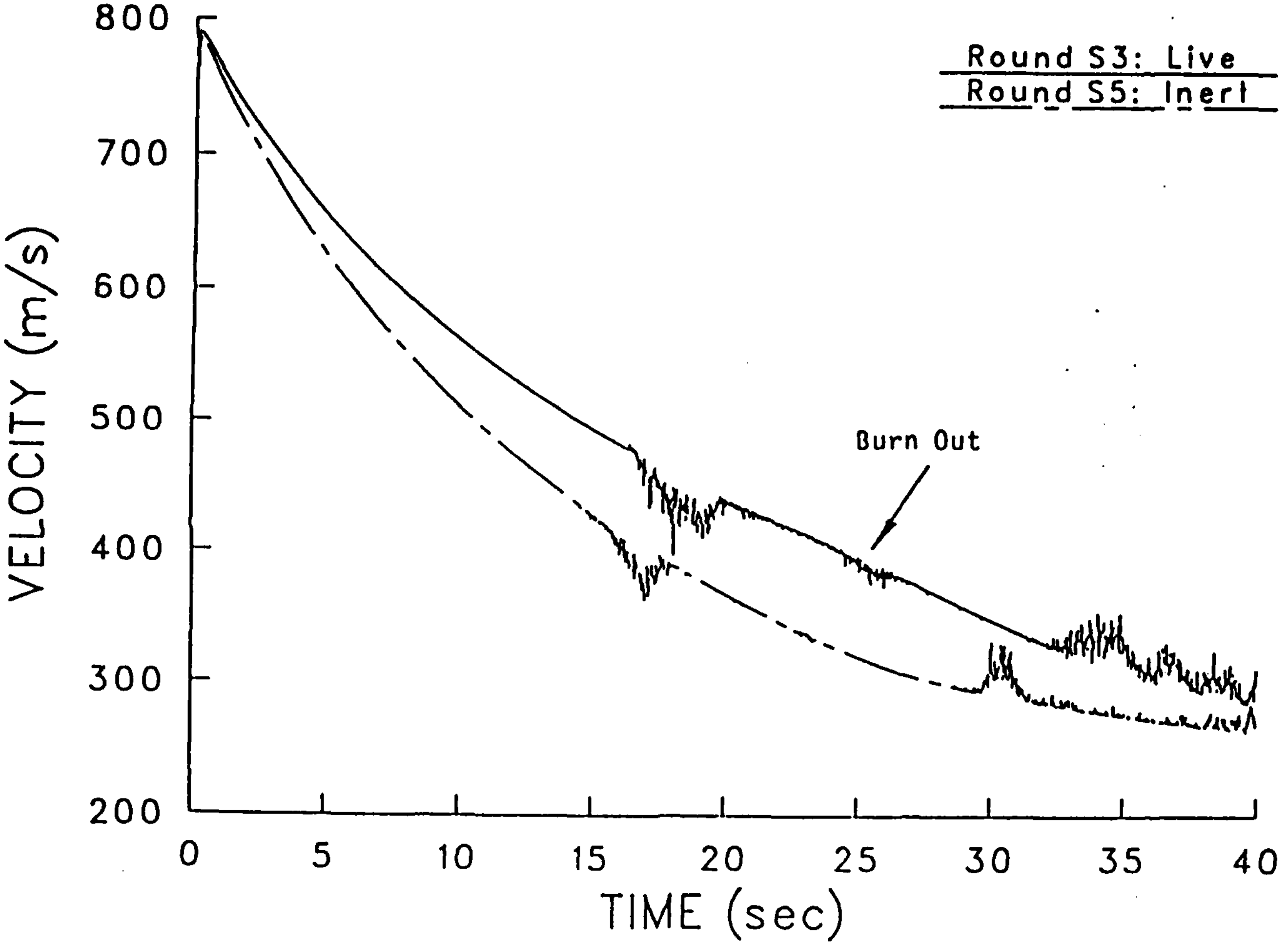


Figure 16. Discriminated Doppler data for Rounds 3 and 5 September 1988.

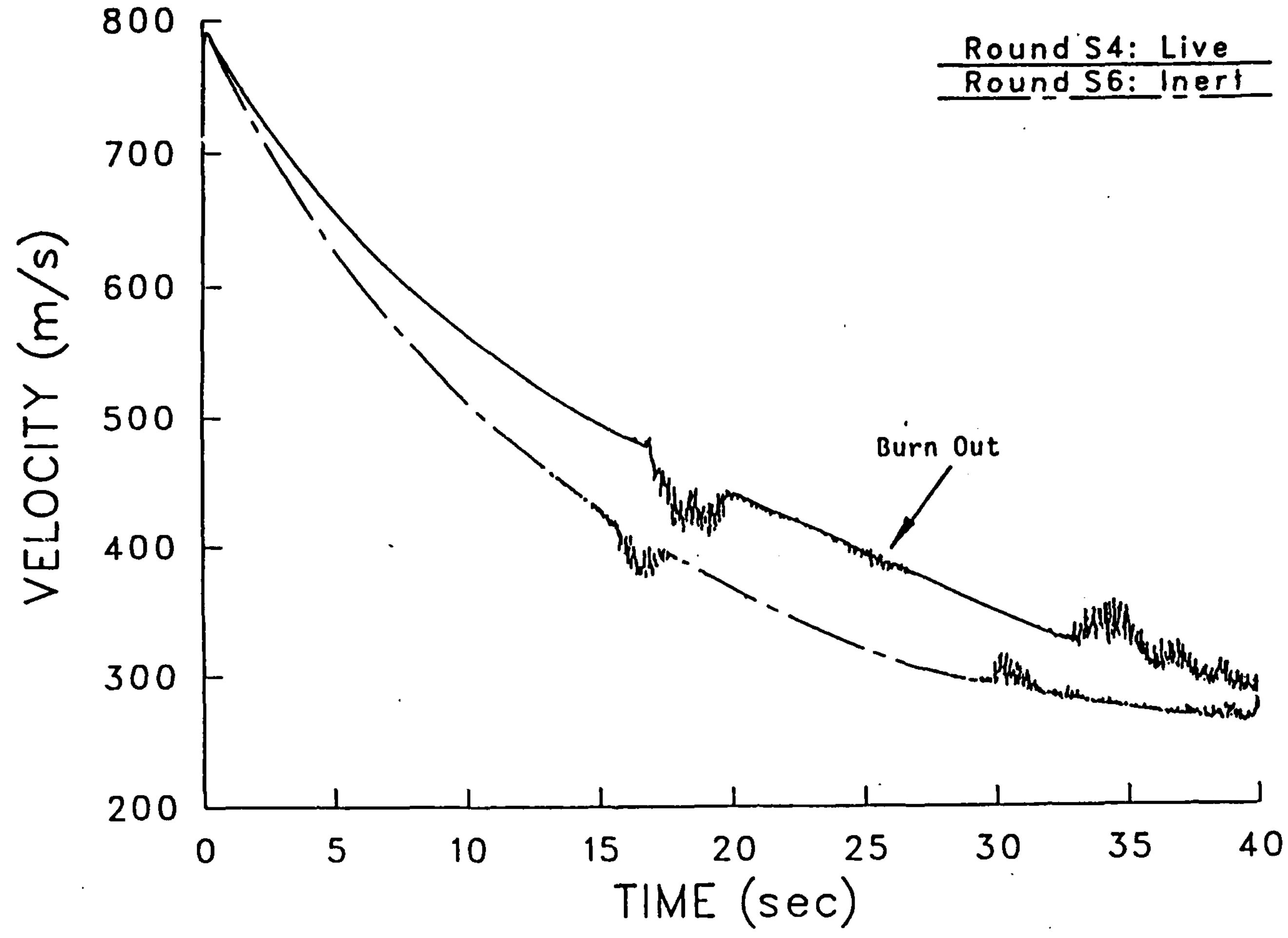


Figure 17. Discriminated Doppler data for Rounds 4 and 6 September 1988.

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3. Kayser, L., Kuzan, J., "Flight Testing for a 155 MM Base Burn Projectile," AIAA Paper AIAA-89-2208, Proceedings of AIAA 7th Annual Applied Aerodynamics Conference, Seattle, Washington 31 July-2 August, 1989.

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