SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2238

REV. OCT2001

Issued 1994-06
Revised 2001-10

Superseding J2238 MAR1995

Airbag Inflator Ballistic Tank Test Procedure Gas Generators Used In Inflatable Restraint Systems

TABLE OF CONTENTS

TO PLACE A DOCUMENT ORDER: +1 (724) 776-4970 FAX: +1 (724) 776-0790
SAE WEB ADDRESS http://www.sae.org

Printed in U.S.A.

1. Scope—This SAE Recommended Practice establishes a ballistic tank test procedure for evaluating inflator assemblies used in inflatable restraint systems. It is intended to be a general procedure for repetitive testing and suggests only general guidelines for the safe conduct of tests and data correlation. Uniform test requirements, test procedures, and data recording requirements are specified. The intent of the document is to provide a procedure employing a ballistic tank test method for determining the ability of an inflator to meet requirements for deploying inflatable restraint systems. A ballistic tank test is described which will yield repeatable and comparable results for evaluating a given inflator configuration's pressure output versus time. Use of the ballistic tank test for comparison of various inflator configurations may be of limited value due to differences in gas temperature and mass flow effects on airbag performance as it relates to occupant protection.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J211-1—Instrumentation for Impact Test—Part 1: Electronic Instrumentation
SAE Paper 91080—Use and Selection of Thermocouples

2.1.2 ASME PUBLICATION—Available from ASME, 22 Law Drive, Fairfield, NJ 07007.

ASME Boiler and Pressure Vessel Code, Section VIII Rule for Construction of Pressure Vessels, Division 11, an American Standard 1983 Edition (please see current amendment)

2.1.3 OTHER PUBLICATION

Lange's Handbook of Chemistry, McGraw Hill, 1985

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this specification.

2.2.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1538—Glossary of Automotive Inflatable Restraint Systems

2.2.2 OTHER PUBLICATIONS

Abernethy, R. B. and Thompson, J. W., "Measurement Uncertainty Handbook," Instrument Society of America, 1980

Stein, P. K., "The Response of Transducers to Their Environment, the Problem of Signal and Noise," Shock and Vibration Bulletin, Vol. 40, No. 7, pp. 1-15,1970

Taylor, J. L., "Computer-Based Data Acquisition Systems, Design Techniques," Instrument Society of America, 1986

Megyesy, Eugene F., "Pressure Vessel Handbook," Publishing, Inc., 1989

3. General Test Requirements**—**The ballistic tank test equipment for acceptance testing of inflators used in inflatable restraints systems shall provide a reliable, accurate, and repeatable testing system, adaptable for mounting various configurations of inflators. The following sections will describe the general needs for the test facility equipment and safety requirements.

3.1 Test Facility—Airbag inflators are typically classified by the US Department of Transportation (DOT) as Explosive Class C, Flammable Solid or Argon comparison nonflammable. Therefore, the facility for conducting tests on pyrotechnic or pressure vessel devices must comply with all local and state building codes.

A proper floor plan and work area design is also very important for proper execution of tests. Features include a physical barrier between test personnel and the device under test. In addition, a temperature controlled environment is important for test result accuracy, and a room exhaust fan is recommended to vent smoke and particulates from the test bay.

3.2 Safety Requirements—In consideration of safety for test personnel working with experimental devices, appropriate facility and proper personal protective equipment must be provided. Examples of this equipment include remote firing capability, warning system (e.g., siren and/or light) shielding, flame-retardant lab coats, electrostatic ground straps, safety glasses, hearing protection, respirators, and gloves as required.

Proper written safety procedures and check lists should be followed in accordance with industry practice. All applicable OSHA safety standards must be followed.

3.3 Equipment List—The equipment will typically consist of the following basic components:

a. Pressure Tank—Contains the generated gas
b. Pressure Transducer—Measures the pressures inside the tank or inflator
c. Data Acquisition System—Records and displays the temperature and pressure versus time results of an inflator test
d. Temperature Conditioning Chamber—Conditions inflator to desired deployment temperature
e. Thermocouple—Measures the temperature of gas inside the tank (optional)
f. Firing Source—Provides the proper stimulus to actuate the inflator

Section 4 of this procedure will discuss the equipment specifications typically used.

4. Equipment Specification**—**The ballistics tank test facility shall consist of equipment meeting the following specifications.

4.1 Pressure Tank—A pressure tank shall be provided for containing the inflator's pressure output over the anticipated temperature range. The pressure tank should conform to the ASME Code for Pressure Vessels Section VIII Division 2. A tank shape with a hemispherical end is preferred to facilitate tank washing. The pressure tank shall be secured and of such design that no movement or distortion of the pressure tank results upon deployment of the inflator.

4.1.1 TANK VOLUME—The volume of the pressure tank to be used for a particular inflator is determined based on the inflator's design output as follows:

a. For inflators designed for driver side applications, the volume shall be 28.3 L ± 0.28 L or 60.0 L ± 0.60 L.
b. For inflators designed for passenger side applications, the volume shall be 60 L ± 0.60 L, 100 L ± 1.0 L, or 146 L ± 1.5 L.
c. For inflators designed for side impact, roll over, or active knee bolster applications, the volume shall be 28.3 L ± 0.28 L.
d. If different tank volumes do exist, a method of correlation of the tank to tank pressure data is required; i.e., test a statistically significant number of samples in each tank and compare values.
e. Tank volume is to be measured. A recommended procedure is outlined in Appendix A.
f. For other applications such as pretensioners, hypertensioners, headrest, foot, roof or pedestrian applications the volume selected should be near the specific application volume or new tank volumes should be developed.

4.1.2 INFLATOR ORIENTATION/SEALING—The inflator shall be oriented relative to the pressure tank such that the gases generated are distributed symmetrically (with respect to the centerline of the inflator) throughout the pressure tank. The pressure tank must provide adequate sealing such that pressure is contained within the tank during deployment of the inflator.

4.1.3 TANK SURFACE FINISH—The inside surfaces of the pressure tank shall be smooth to facilitate cleaning and tank washing. A finish of equal to or better than 32 µm finish is recommended. Coatings may be used to facilitate tank wash; however, caution should be used in coatings that may wear off or otherwise exhibit deterioration.

4.1.4 TANK CONFIGURATION—The pressure tank shall provide a means to rigidly mount the inflator to the tank without restricting the flow of gas into the tank. Figure 1 depicts a type of test tank used in the airbag industry. Other shapes are acceptable; however, a correlation between different shape tanks may be required.

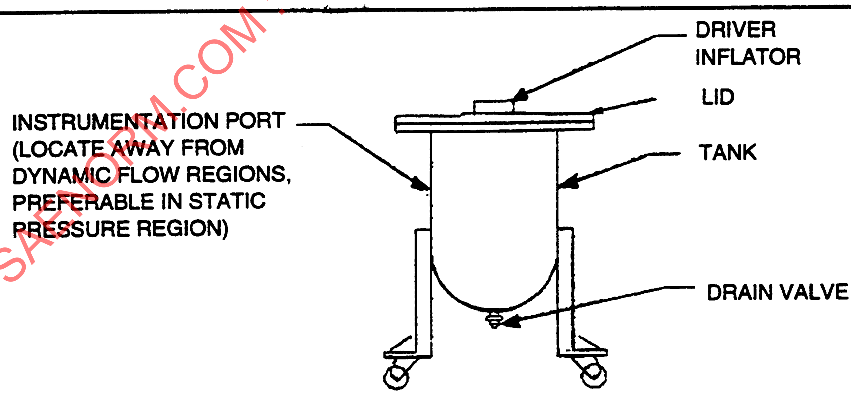

FIGURE 1—PRESSURE TANK

4.2 Pressure Transducer—A pressure transducer shall be provided and mounted to the pressure tank to measure the inflators pressure output. Two pressure transducers may be used (as an option) to avoid data loss in the event of pressure transducer malfunction. A pressure transducer may also be provided to measure the inflator's internal pressure.

Pressure transducers are selected based upon how they are to be used, the speed and range of expected pressures, and where they are to be mounted. Where practicable, pressure transducers used for comparison testing should be standardized. Results from different transducer types or models may vary significantly—especially when measuring short duration pressure pulses. All transducers, instrumentation, and data filters (analog and digital) should be selected per SAE J211. See Appendix B for an example of typical requirements and selection guidelines.

The dynamic range of the device must be compatible with the temperature and pressure expected from the test. A means to calibrate the pressure transducers prior to testing shall be provided. Pressure transducer calibrations shall be conducted regularly and calibration results recorded. Refer to the transducer manufacturer's recommended procedure for calibrations.

4.3 Data Acquisition System—A data acquisition system (per SAE J211) shall be provided to measure and record the pressure output versus time of the inflator. Filter requirements, data sampling rate of test system, transducer frequency response, and amplifier frequency response should be such that there is minimal effect on accuracy of the data. Overall accuracy of the data acquisition system should be within 3% or better. The data acquisition system must have clearly defined capabilities such as sample rate, resolution, and digital filtering as supported by SAE J211.

4.4 Temperature Conditioning Chamber—Temperature conditioning chambers shall be provided to temperature condition inflators prior to testing. For safety considerations, explosion-proof chambers are recommended. For inflator development, consideration for conditioning the entire pressure tank can be made. Chamber capabilities typically extend from –55 to 120 °C but, as a minimum, should extend from –40 to 90 °C. The temperature conditioning chamber should be capable of providing a uniformity of the temperature extremes with control level variations not to exceed 3 °C throughout the chamber.

4.5 Tank Thermocouple—For proper selection and use of thermocouple refer to SAE Paper 910808.

5. Test Procedure—Ambient test lab conditions (e.g., temperature, % relative humidity, and barometric pressure) should be recorded. Pressure tank wall temperature may be recorded and should be within the range of 22 °C ± 3 °C if the tank is not conditioned. The inflator conditioning temperature and time shall be recorded for each test. The tank should normally be cleaned and dried prior to each test. In some circumstances it may be more practical to clean the tank after a number of tests, e.g., high-volume production lot acceptance testing.

5.1 Temperature Conditioning—Test samples may be temperature conditioned prior to testing. The typical lower and upper temperature ranges for conditioning the inflators are –35 °C ± 3 °C and +85 °C ± 3 °C. Ambient test temperature is 22 °C ± 3 °C. The inflator shall be conditioned for a sufficient period of time to ensure the entire inflator assembly is at the required temperature. Typical conditioning times are 1 to 4 h. Inflators are placed in the conditioning chamber in a manner that allows free air movement around assemblies and no direct contact with chamber walls.

5.2 Installation to Tank—The inflator shall be rigidly mounted to the pressure tank such that no movement of the inflator or gas pressure leaks occur during testing.

5.3 Time to Deployment—The test sample should be deployed in the pressure tank typically within 3 min of removing the sample from the temperature conditioning chamber, if conditioned separately from the tank. If the 3 min period is exceeded, recondition the sample 10 min for every minute beyond the 3 min period. However, the acceptable deployment time limit and reconditioning schedule are a function of the inflator design, which can affect the internal warm up or cool down rate. Thus, consideration should be made to measure the internal thermal change rate of a particular inflator design to determine the proper time limit to deployment after removal from the conditioning chamber.

5.4 Deployment Pulse/Stimulus—An appropriate level and duration of deployment pulse or stimulus as specified by the manufacturer or customer should be used to deploy the inflator (e.g., all-fire current for electric initiators or mechanical shock for mechanical sensors). The deployment pulse or stimulus and equipment specification (e.g., hardware, calibration) shall be recorded (including magnitude and duration to establish time 0 for the event).

5.5 Typical Test Sequence—The following list is a typical sequence of events to tank test an inflator and provides an overview of the testing process. See Appendix C for a typical tank test set-up.

Before entering the test area ensure all required personal protective equipment is being used as follows:

a. Verify presence and location of all equipment and tools to be used to conduct the test.
b. Check test tank to ensure it is clean, dry, and that all instrumentation is attached properly.
c. If O-rings are used to seal the lid to the tank and inflator to lid, examine them to ensure they are not damaged.
d. Perform all system calibrations required including the transducers and system amplifiers.
e. Log-on to the test computer, storage oscilloscope, or other data collection device to enter test serial number, etc. Record lab ambient conditions and tank wall temperature.
f. Obtain the inflator for testing, weigh and record pre-fire weight if required.
Note that a time limit to deploy the inflator after removal from the temperature conditioning chamber exists.
g. Mount the inflator to the test tank making sure all seals and fastening systems are tightened securely. Verify that deployment leads are grounded and shorted prior to connecting to the initiator leads of the inflator to avoid unwanted electrical potential which could inadvertently deploy the device.
h. Close door to test bay and turn warning light on before arming the deployment circuit.
i. Connect cable for supplying inflator deployment current to the inflator deployment circuit.
j. Review check list to ensure all prior listed actions are complete before actuating the inflator.
k. Warn personnel in the vicinity that a test is being conducted.
l. Actuate inflator and note the response of the data acquisition system to verify successful deployment.
m. Turn on test bay exhaust fan to remove any fumes and smoke that may exist.
n. Enter test bay and remove inflator from tank. Ensure appropriate protective equipment is used when handling the inflator since it is likely to be hot.

5.6 Tank Cleaning—After deployment of the inflator, the tank may need to be cleaned in preparation for the next test. Depending upon the nature of the by-products of combustion and whether they are soluble in water or not will determine the specific procedure.

Typically a water rinse will be sufficient, followed by wiping the inside tank surfaces with a clean cloth or paper towel. The tank can be dried with nitrogen from a nitrogen pressure bottle to facilitate the process in preparation for the next test.

6. ***Data Reduction—***Although only the low frequency data is of interest, to prevent data aliasing and phase shifting during digitization, the analog data should be digitized at a sample rate at least five times greater than the highest frequency that has any visually significant amplitude. Generally, the pressure trace will not contain any significant signal content above 1000 Hz; so that a digital sample rate in the range of 5000 to 10 000 samples per second will usually be adequate. If there is any uncertainty above the signal content, then an anti-alias analog filter set at 1000 Hz is recommended prior to digital sampling.

(Note that the highest significant frequency present in the data is also limited by the transducer response time capability. However, using a slow transducer to effectively filter the data will produce the same data aliasing and phase shifting as would a slow digital sample rate.)

The transducer selection, data sample rate, and filter class should be matched to the expected magnitude and signal frequency per SAE J211.

After acquisition, the digital data trace should be inspected for any anomalies, and for clarity.

If the data has an initial vertical offset, it should be run through an amplitude offset removal routine (e.g., average the first ms of unfiltered data after ignition time zero, and vertically shift the data by this average offset).

If the data is noisy, it should be digitally filtered to obtain the underlying smooth pressure curve for data presentation and analysis. The recommended filter cutoff frequency is 100 Hz (Class 60), and the filter should meet the requirements of SAE J21 1.

(If there were any anomalies in the raw data, these must be noted on the filtered data, since filtering will obscure them.)

It should be noted that the time of first pressure, the initial rise rate, and the time to peak pressure will all be a function of the specific type of filter and the filter initialization technique that is used.

There is no single filter and initialization technique that will meet all objectives. However, a combination of different filtering techniques can be employed to obtain greatest fidelity for different aspects of the pressure curve.

A discussion of some of the currently available filtering techniques, and the objectives they will meet, is presented in Appendix D.

7. Acceptance Records

7.1 Pressure Versus Time Plot—The pressure versus time history shall be recorded during each test by the appropriate and properly calibrated instrumentation. Pressure shall be plotted along the vertical axis and time along the horizontal axis. Maintain appropriate calibration records. See Figure 2 for example of typical plot.

7.2 Typical Data Measurements—Typical data measurements for characterizing performance are as follows:

a. Time to initial pressure (e.g., 1 kPa)
b. Pressure at 20 ms, 40 ms, and maximum pressure
c. Maximum or average slope of pressure rise in either 5 or 10 ms time increments
d. Inflator internal operating pressure (if measured)
e. Deployment pulse

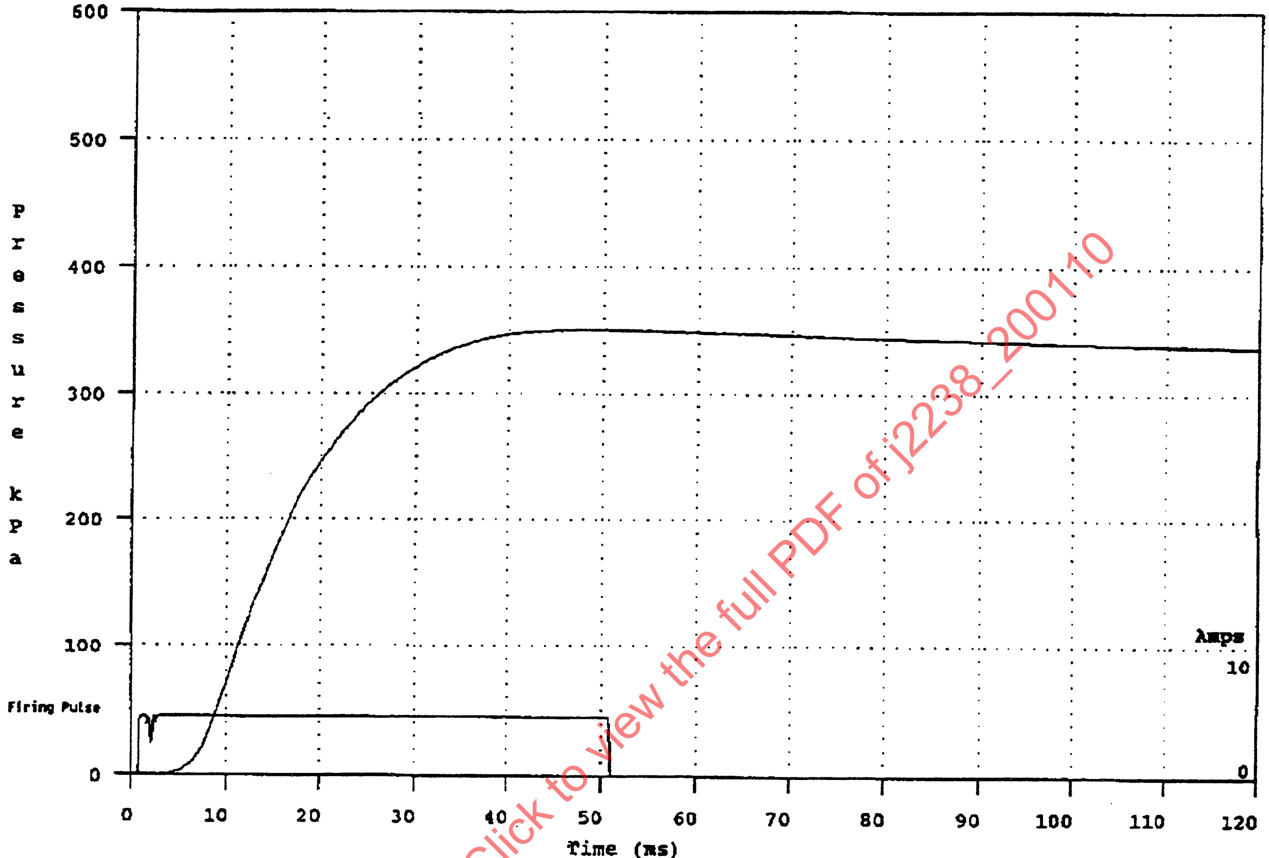

FIGURE 2—PRESSURE TIME CURVE

7.2.1 SLOPE—A measurement of the rate of rise of the pressure time curve. Generally calculated over a 5 ms or 10 ms window. The preferred calculation is to take the desired time window and calculate the associated pressure change and divide by the length of time of the window to obtain an average kPa (psi)/ ms (slope). (For example, pressure @ time (5 ms) – pressure @ time (0 ms)/5 ms, for a 5 ms window.) Continue the calculation interatively by shifing the calculation window one time step (typically, 1 ms) across the data to obtain a slope curve. The maximum number obtained is the peak slope. Graph the average kPa (psi)/ms (slope) resultant on the y-axis against the time period end-point (preferred) on the x-axis. Alternatively, the starting-point or mid-point of the time window can be used on the x-axis. The initial time period will be a smaller window and still divided by the full time period, thus creating a gradual rise in the slope curve. The slope calculation should be done following filtering process of the closed tank pressure data with an SAE class 60 filter.

8. Notes

8.1 Marginal Indicia—The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE INFLATABLE RESTRAINTS STANDARDS COMMITTEE

APPENDIX A

TANK VOLUME MEASUREMENT METHOD

A.1 Background—The tank volume will drastically affect pressure readings. To be able to correlate test results between customers and vendor it is necessary to measure the volume.

It is recommended to control the volume within 1% of the target volume.

To be able to accomplish this control, the tank volume measurement shall be done three times and the repeatability of the measurement should be within 0.25% of each other.

A.2 Tank Volume Measurement Procedure—Seal the tank with no hardware inside to measure actual tank volume. Completely fill tank with water making sure that no air is trapped inside. The volume occupied by the inflator should be taken into consideration through use of a mass which simulates the inflator dimensions.

Remove water and weigh it by using an accurate scale.[1]

Convert the weight of water to volume based on conversion tables that account for temperature. Repeat measurement three times to ensure accurate readings.

Each time the resulting volume should be within 0.25% of each other.

A conversion table for density of water may be found in Lange's Handbook of Chemistry, McGraw Hill, 1985.

A.3 Equipment—The following equipment or equivalent is recommended as follows:

a. Scale Md Gt 8000 oHAus
b. Bottle, 2 L (plastic or glass)
c. Flexible plastic hose to facilitate connection to a water source
d. Hose clamps
e. Digital thermometer
f. TC probe

1. An optional method may be to weigh the entire tank both empty and full to determine the tare weight of the water. However, accuracy of scales in higher weight ranges may not be sufficient, therefore caution should be used in this method.

APPENDIX B

TRANSDUCER SELECTION

B.1 The following is provided to highlight some typical requirements of pressure transducers:

a. Accuracy: 0.5% F.S.O.
b. Temperature Range: –55 to 120 °C
c. Compensated Temperature Range: –30 to 80 °C
d. Resonant Frequency: >5 kHz
e. Response Time: <1/3 ms

The values for the criteria listed previously will depend upon the actual test requirements, transducer type and manufacturer selected, and are listed only to provide an insight to the typical values used in the airbag industry. Specific transducer selection should be consistant with the guidelines described in SAE J211.

B.2 A definition of the terms used previously is provided as follows:

B.2.1 **Accuracy—**The degree of conformity of an indicated value to a recognized/accepted standard value, or ideal value.

B.2.2 **Temperature Range—**The range of temperature within which the transducer will operate without nonreversible changes in the performance specifications.

B.2.3 **Compensated Temperature Range—**The range of temperature within which the transducer will conform to the stated performance specifications.

B.2.4 **Resonant Frequency—**The mechanical resonant frequency of the pressure sensing assembly; the frequency of pressure application at which the transducer responds with maximum output amplitude.

B.2.5 **Response Time—**The time required for the output to increase from zero to some specified percentage of its final value, when excited by a step change in pressure.

APPENDIX C

TYPICAL TEST SET-UP DIAGRAM

C.1 See Figure C1.

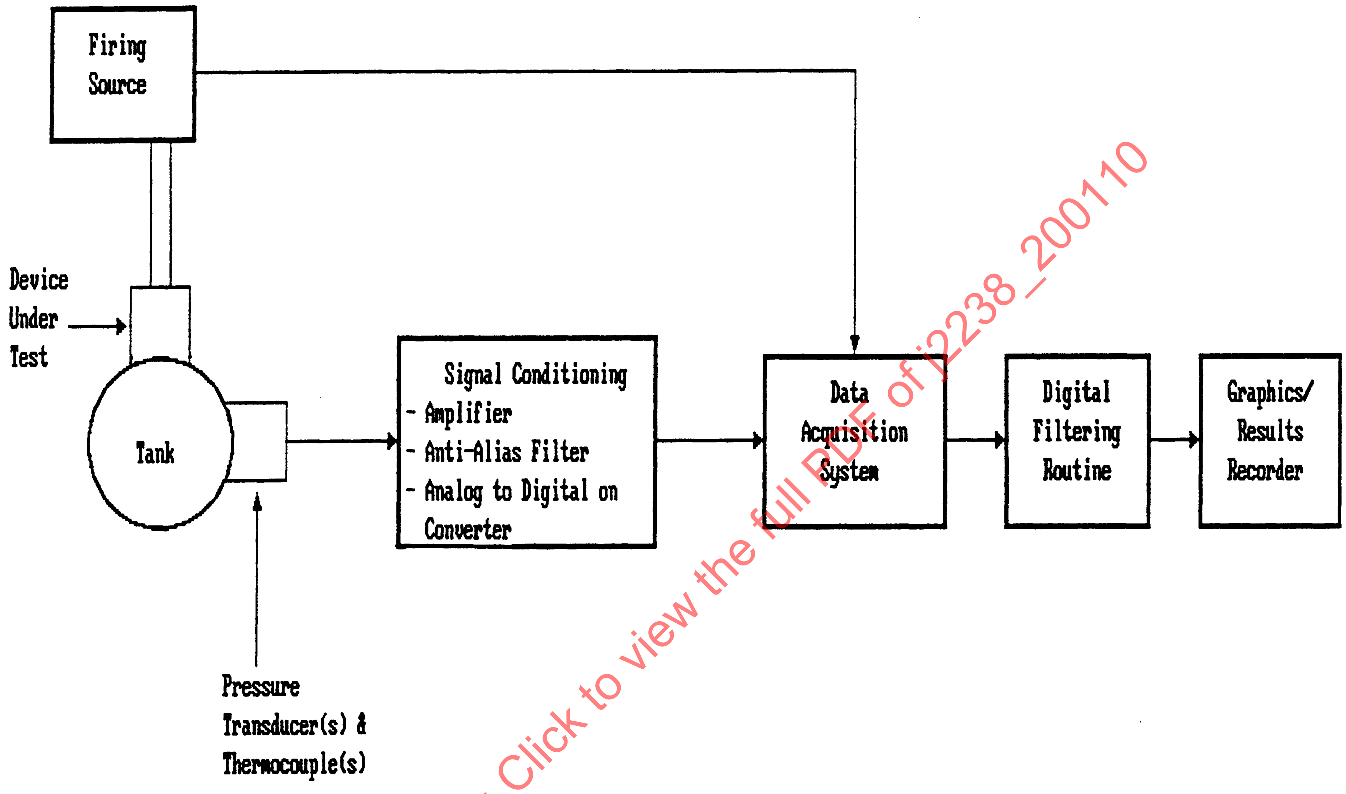

FIGURE C1—TYPICAL TEST SET-UP

APPENDIX D

DATA FILTERING TECHNIQUES

D.1 Presented herein is a discussion of some of the currently available filtering techniques that are most suitable for specific objectives. Prior to using these techniques, it is important that any initial vertical offset of the data has been removed (e.g., average the first ms of unfiltered data after ignition time zero, and vertically shift the data by this average offset).

Also, for displaying the main body of the pressure curve, the recommended filter cutoff frequency is 100 Hz (Class 60), and the filter should meet the requirements of SAE J211.

D.1.1 Time of First Pressure—If the actual pressure data consistently has low noise at the onset of first pressure, then determination of the time of first pressure can most accurately be obtained by using the unfiltered data.

The recommended procedure is to first move forward on the curve to some specified pressure value that is definitely above the initial noise level. Then, start back down the curve until you reach some small epsilon pressure value that can be considered the start of first pressure.

A typically used epsilon pressure value that can be considered the start of first pressure is 1 kPa (0.15 psi).

However, if there is substantial signal oscillation at the onset of first pressure, then determination of the time of first pressure is best obtained by filtering the data using a forward pass filter only, with a lead-in of zeros for the filter initialization. This causes the filter to initially follow the X-axis, and to start rising when the actual data starts its rise.

The time of first pressure would then be determined using the same procedure described previously, but on this forward pass filtered curve.

Although this type of filter technique will generally result in a rise rate that lags behind the true data, it is the best filter for capturing the occurrence of the initial rise.

As such, this filter is best used as part of a computational routine to determine the time of first pressure. It is not generally a good filter for representing the main body of the curve, since it will lag in rise rate and cause phase shift of the data.

This response lag of a forward pass only filter is shown in Figure D1.

However, Figure D2 (which is a zoom of the initial portion of Figure D1) shows the initial rise of the filter for 100 and 200 Hz cutoff frequencies. As expected, both filtered curves start to rise almost immediately after the initial rise of the actual data. However, the time delay to achieve the 1 kPa (0.15 psi) pressure line is directly dependent on the filter cutoff frequency.

Although higher cutoff frequencies will produce less time delay, they also start to follow the oscillation dip of the actual data, which in this case falls below the 1 kPa (0.15 psi) pressure line, thereby leading to an erroneous late determination for the time of first pressure when you back down the filtered curve.

Thus, in using a filtered curve for determination of the time of first pressure, it is desirable to use the highest filter cutoff frequency that does not follow the oscillation dip of the data.

For data exhibiting the type of onset oscillation shown in Figures D1 and D2, the recommended filter cutoff frequency for determination of the time of first pressure is 200 Hz (Class 120).

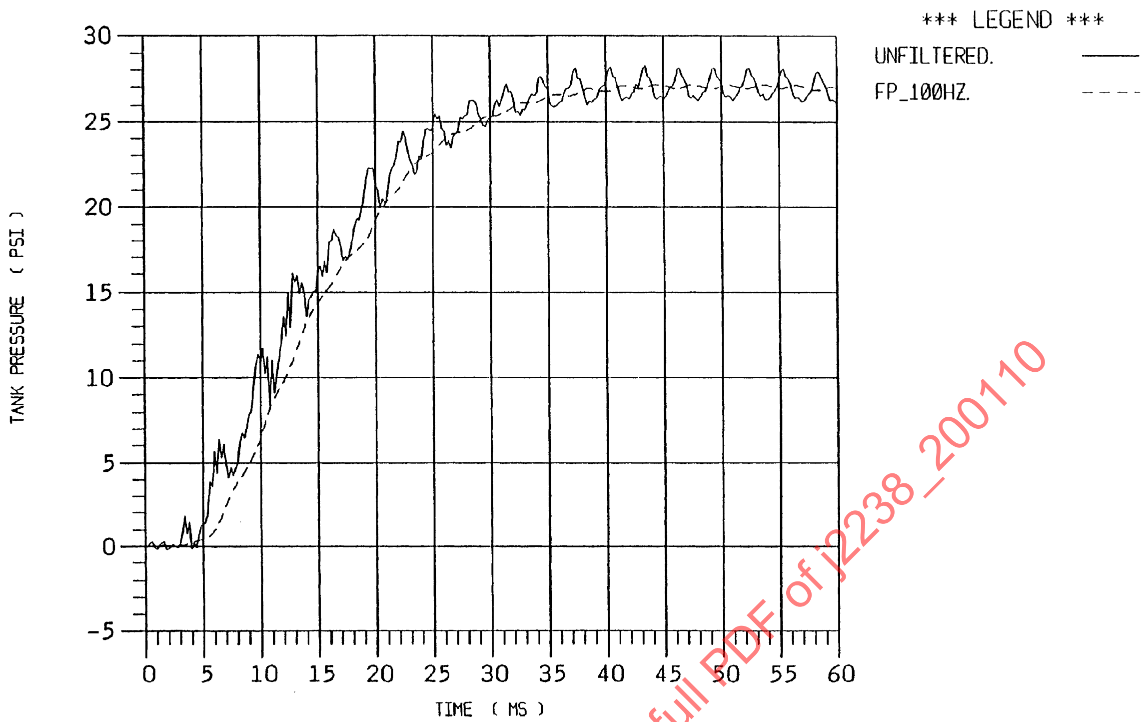

FIGURE D1—ACTUAL TANK TEST DATA VERSUS 100 Hz FORWARD PASS FILTERED CURVE (SHOWING LAG IN RISE RATE AND DATA PHASE SHIFT FOR FORWARD PASS ONLY FILTER)

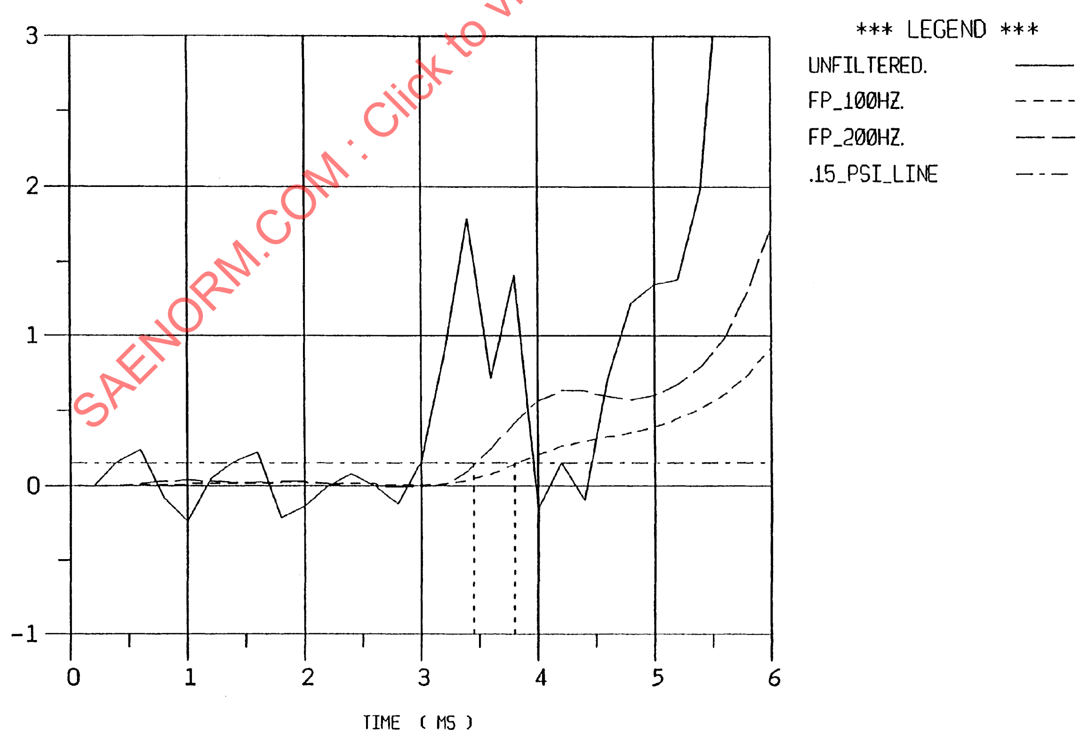

FIGURE D2—ZOOM OF FIGURE D1 WITH 100 AND 200 Hz FORWARD PASS FILTERED CURVES (COMPARING DETERMINATION OF TIME OF FIRST PRESSURE: 3.0, 3.45, 3.0 ms)

D.1.2 Main Body of Curve—To best capture the mean smooth curve through the main body of the data, a forward and backward dual pass filter is the optimal choice. The dual pass filter minimizes phase shift, and tends to line up major peaks and troughs in the data very accurately.

Figure D3 shows the accurate mean performance of the dual pass filter.

The dual pass filter will generally follow the underlying mean smooth curve through the main body of the data, providing the mean curve does not go through an abrupt or very rapid change.

However, where the mean data does change rapidly, such as at the initial pressure rise, the dual pass filter will radius the starting knee in the curve, and then will shift it backwards to start at an earlier time, in order for the main body of the data to be aligned.

The result is that, for the initial pressure rise, the dual pass filtered curve will start its rise earlier than the real data, and with a slower rise rate, until it catches up and merges with the main body of the data.

Figure D4 (which is a zoom of the initial portion of Figure D3) shows how the dual pass filter radiuses the knee of the initial pressure rise and shifts it backwards in time.

D.1.3 Main Body of Curve and Initial Rise Rate—To accurately capture both the initial rise rate and the main body of the curve, a modification to the standard dual pass filter technique can be implemented.

The modification consists of two parts. First, the start of the dual pass filter is delayed until a specified pressure value is reached. This pressure value should be selected to ensure that the filter is starting on the main initial rise, and that it is above any initial noise in the data.

Second, the filter initialization should have a lead-in that corresponds to the projected rise of the data, so that the filter is initially set up to follow that rise. This can be accomplished by creating a lead-in that is the reflection (both in magnitude and time) of the data rise about the specified starting pressure value.

Using this technique, the resulting output curve will consist of the actual unfiltered data up to the specified starting pressure value, and will then smoothly join with the filtered curve that passes through the mean of the subsequent rise. This output curve thus accurately captures both the initial pressure rise rate and the mean smooth curve through the main body of the data.

Figures D5 and D6 (which zooms the initial portion of Figure D5) show the accurate mean main body curve and the preserved initial rise rate performance of the dual pass filter with a delayed pressure start of 20 kPa (3psi).

Figure D7 is the Fortran Code for implementing this delayed start, dual pass filter technique, based upon a modification of the standard forward and backward pass Butterworth Filter used by NHTSA.

In order to ensure that the filter starts on the main initial pressure rise, and is above any initial noise in the data, the following delayed start pressure values are typically recommended:

a. 20 kPa (3 psi) for Tank Pressure up to about 340 kPa (50 psi)
b. 40 kPa (6 psi) for Tank Pressure greater than the previous level
c. 2000 kPa (300 psi) for Combustor Pressure (if filtering needed)

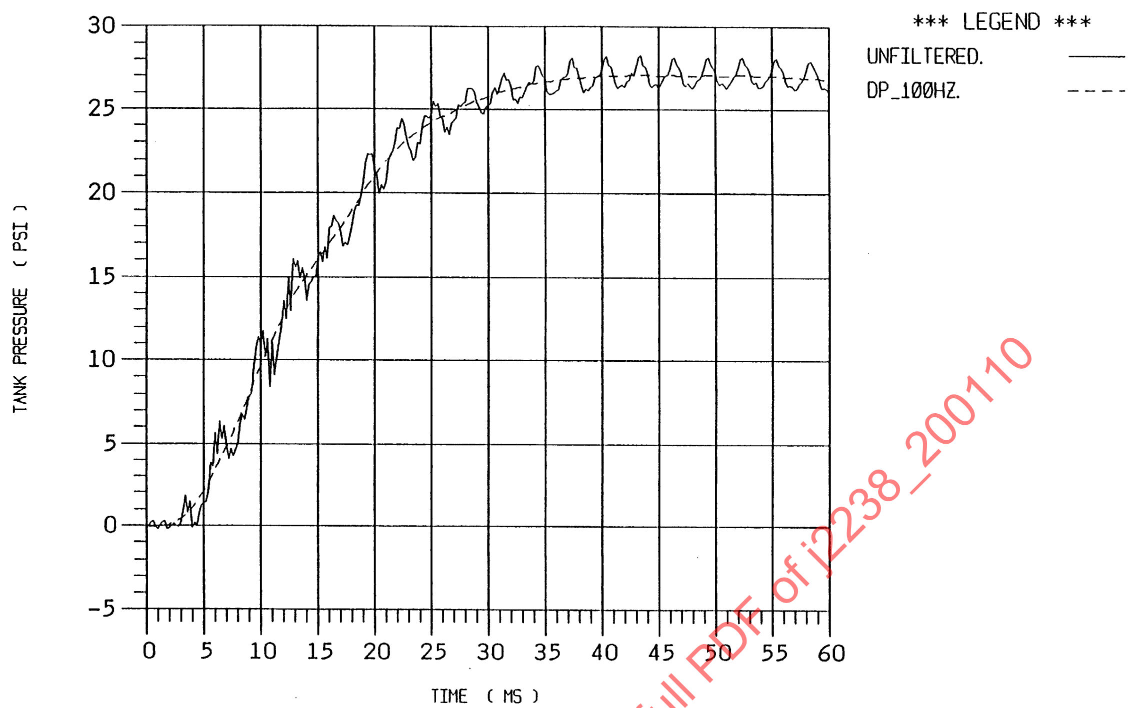

FIGURE D3—ACTUAL TANK TEST DATA VERSUS 100 Hz DUAL PASS FILTERED CURVE (SHOWING ACCURATE MEAN MAIN BODY CURVE FOR THE DUAL PASS FILTER)

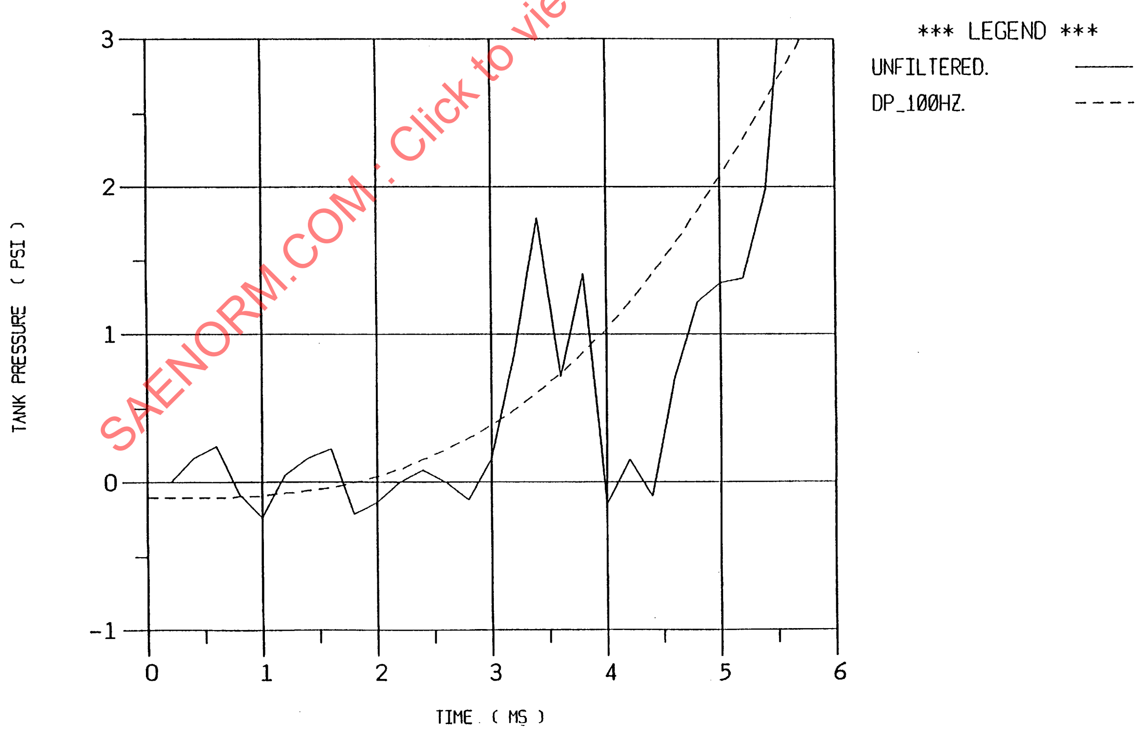

FIGURE D4—ZOOM OF FIGURE D3 WITH 100 Hz DUAL PASS FILTERED CURVE (SHOWING EARLIER PRESSURE START AND SLOWER RISE RATE THAN ACTUAL DATA)

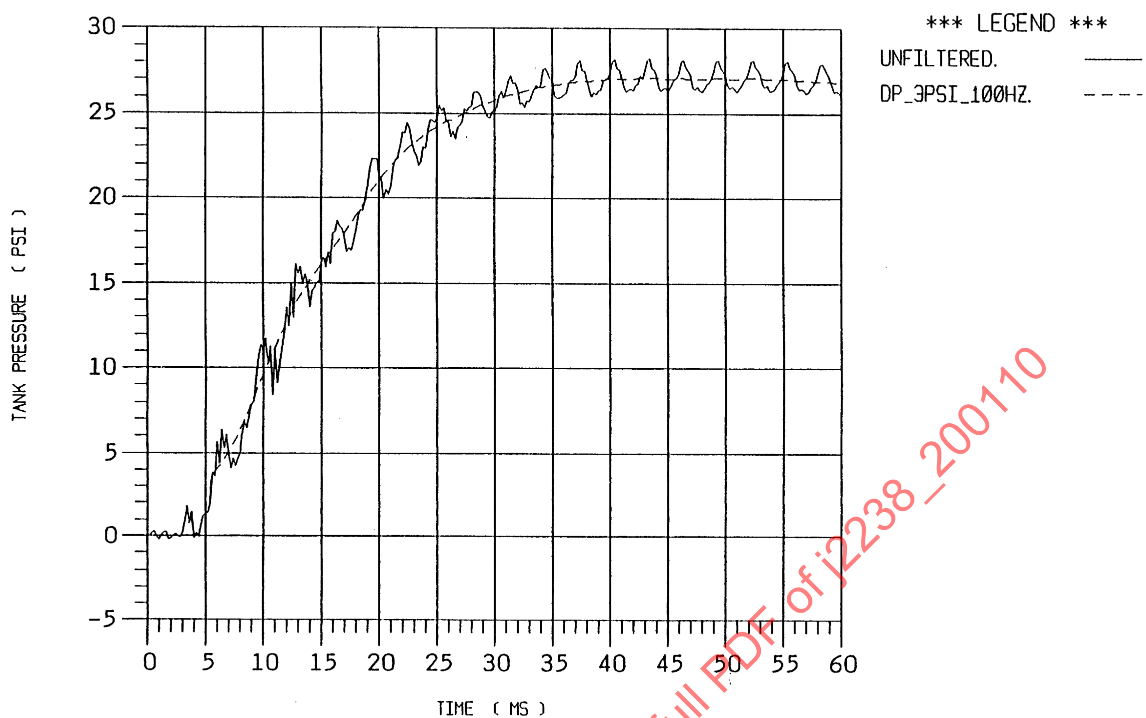

FIGURE D5—ACTUAL TANK TEST DATA VERSUS 100 HZ DUAL PASS FILTERED CURVE WITH 3 PSI DELAY (SHOWING ACCURATE MEAN MAIN BODY CURVE FOR THE DUAL PASS FILTER WITH DELAY)

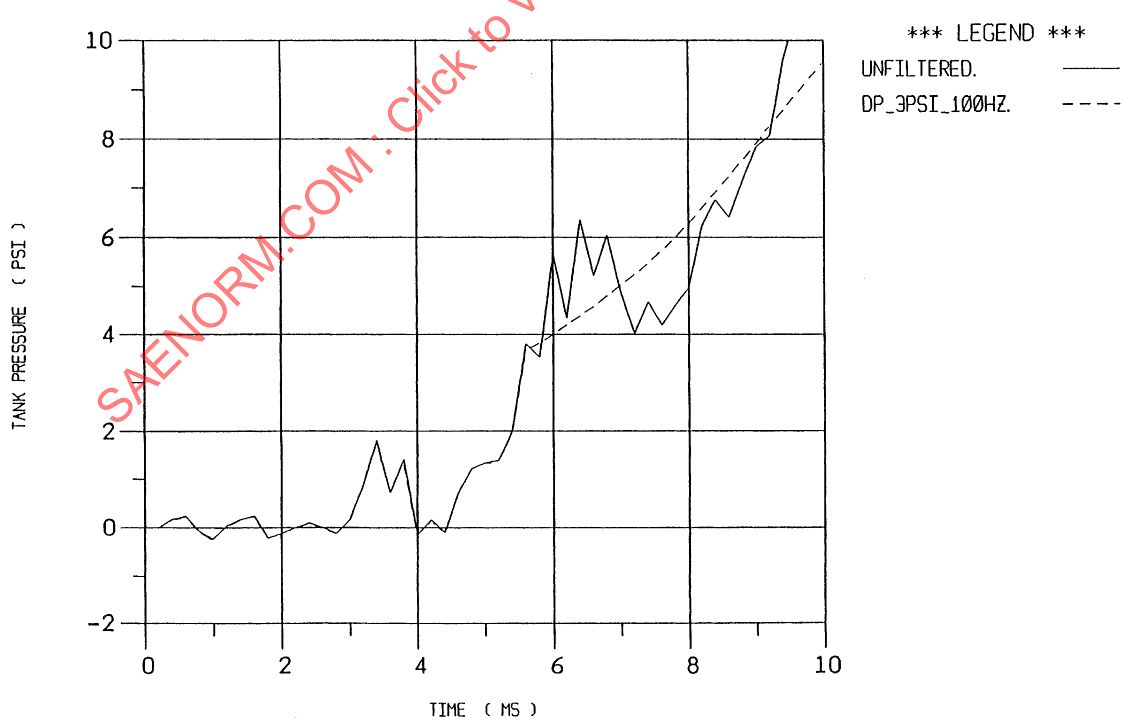

FIGURE D6—ZOOM OF FIGURE D5 WITH 100 Hz DUAL PASS FILTERED CURVE WITH 3 psi DELAY (SHOWING PRESERVED INITIAL RISE RATE FOR THE DUAL PASS FILTER WITH DELAY)

```
PROGRAM BWFILT                                    !(With Optional Delayed Start)

C------------------------------------------------------------------------------
C
C       Objective:
C
C               Apply a second order Butterworth Digital Filter to a
C           (Time,Y-value) data file or time-transducer response.
C
C           Forward & Backward passes are made to avoid Phase Shift.
C
CMC             Filtering may be delayed, if desired, until a specified
CMC             Y-axis value is exceeded.  The output will then be the
CMC             joined unfiltered and filtered segments.
CMC
CMC             The filter initialization uses a lead-in that is the
CMC             reflection (both in Y and T) of the initial data,
CMC             or of the data rise above the delayed Y-axis start,
CMC             if such is specified.
CMC
CMC             If desired, the output data can be specified with a
CMC             larger delta-T, to reduce the number of data points.
CMC
CMC             The form of the Input and Output files is (T,Y).
CMC
CMC             T in the data can be in either seconds or milliseconds.
CMC             For user input ease, however, the pgm asks for delta-T
CMC             in milliseconds.
CC
CC
CC      APPENDED TO THIS MAIN PROGRAM IS THE SUBROUTINE:  FILTER
CC
CC      (which does the actual forward & backward pass filtering)
C
C
C       Programmers:
C
C           ASGI - S. Mentzer, E. Cheung                  3/84
C           (under contract from NHTSA)
C
CMC     Modified: Michael McCarthy (Breed Automotive)     7/91
CMC                Russel Brantman
C
C------------------------------------------------------------------------------
```

FIGURE D7—FORTRAN CODE FOR IMPLEMENTING DELAYED START

```
          IMPLICIT NONE

          INTEGER NPTS,I,J,NSTEP,NYSTART

          REAL Y(-10:40000),T(0:40000),Z(-10:40000),FCUT,DEL,RATIO,YSTART

            CHARACTER*80 INFILE,OUTFILE

          CHARACTER*1 DELAY


            WRITE(*,'(//10X,A,///)')
     &    '*** BWFILT - BUTTERWORTH FILTERING PROGRAM ***'

C         ENTER INPUT/OUTPUT FILENAMES AND OPEN FILES

          WRITE(*,'(1X,A,$)') 'ENTER INPUT FILENAME > '
          READ(*,'(A)') INFILE
            WRITE(*,'(//1X,A,$)') 'ENTER OUTPUT FILENAME > '
          READ(*,'(A)') OUTFILE

            OPEN(UNIT=1,FILE=INFILE,STATUS='OLD')
          OPEN(UNIT=2,FILE=OUTFILE,STATUS='NEW')

CMC         Store T and Y values in locations 0 to (NPTS - 1)

          NPTS = 0

          WRITE(*,'(//1X,2A)') 'READING FROM:   ',INFILE

          DO WHILE(.TRUE.)
            READ(1,*,END=10) T(NPTS),Y(NPTS)
              NPTS = NPTS + 1
          ENDDO

10          CONTINUE

CMC         Echo # of points read; check whether filtering is to be delayed;
CMC         read cutoff frequency and time step.

            WRITE(*,'(/5X,I5,A)') NPTS,'  DATA POINTS WERE READ '

15        WRITE(*,'(//1X,A,/1X,A,$)')
     &    'DO YOU WISH TO DELAY THE START OF FILTERING UNTIL',
     &    'A SPECIFIED Y-AXIS VALUE IS EXCEEDED ?  (Y/N) > '
```

FIGURE D7—FORTRAN CODE FOR IMPLEMENTING DELAYED START (CONTINUED)

```
      READ(*,'(A1)') DELAY

      IF (DELAY .EQ. 'Y' .OR. DELAY .EQ. 'y') THEN
          WRITE(*,'(//1X,A,$)') 'ENTER ABOVE Y-AXIS VALUE > '
          READ(*,*) YSTART
      ELSEIF (DELAY .EQ. 'N' .OR. DELAY .EQ. 'n') THEN
          GOTO 20
        ELSE
          GOTO 15
      ENDIF

20    WRITE(*,'(//1X,2A,$)') 'ENTER FILTER CUTOFF FREQUENCY, ',
     &       '0 FOR NO FILTERING > '
      READ(*,*) FCUT

      IF (FCUT .LE. 1.E-6) THEN
        WRITE(*,'(//1X,A)')'FCUT = 0;  DATA WILL NOT BE FILTERED'
      ENDIF

30    CONTINUE

      WRITE(*,'(//1X,A,$)')
     &          'ENTER DATA TIME STEP INCREMENT IN MILLISECONDS > '
      READ(*,*) DEL

CMC      Check that time step DEL matches data.
CMC      Since data could be in seconds or milliseconds, RATIO should
CMC      equal 1000 or 1 (within floating point accuracy).

      RATIO = DEL / (T(1) - T(0))

      IF ((RATIO .LT. .999) .OR.
     &     (RATIO .GT. 1.001 .AND. RATIO .LT. 999) .OR.
     &     (RATIO .GT. 1001)) THEN
        WRITE(*,'(//1X,A)')
     &     '!!! TIME STEP ENTERED DOES NOT MATCH DATA !!!'
        GOTO 30
      ENDIF

      WRITE(*,'(//1X,2A,/1X,2A,//1X,A,$)')
     &          'FILTERED DATA MAY NOT NEED TO BE OUTPUT AT SUCH',
     &          ' A FINE TIME STEP.',
     &          'THEREFORE, TIME STEP FOR THE OUTPUT DATA WILL BE ',
     &          'N * (INPUT DATA TIME STEP)',
     &          'PLEASE ENTER N > '
      READ(*,*) NSTEP
```

FIGURE D7—FORTRAN CODE FOR IMPLEMENTING DELAYED START (CONTINUED)