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This TOP provides guidance and procedures for acquiring dynamic transient mechanical and thermal data (shock, vibration, displacement, strain, acoustics, pressure, and temperature) of launchers, associated ground equipment (i.e., missile loaders, control stations, and generators), and the launch area during stationary firings of ground launched rockets and missiles. Guidance is provided for the appropriate properties, installation, and use of transducers, wiring, signal conditioning, signal filtering, and digital data acquisition systems. Procedures for measurement system validation and "end-to-end" calibrations (mechanical and electrical) are also provided.

15. SUBJECT TERMS

Transducer	Accelerometer	Transient Data	Data Acquisition
Sensor	Microphone	Missile Launch	Instrumentation

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 05-2-544 — 31 July 2012
DTIC AD No.

LAUNCHER DYNAMIC DATA ACQUISITION

*Approved for public release; distribution is unlimited.

1. SCOPE.

This Test Operations Procedure (TOP) provides guidance and procedures for acquiring dynamic transient mechanical and thermal data (shock, vibration, displacement, strain, acoustics, pressure and temperature) of launchers, associated ground equipment (i.e., missile loaders, control stations, and generators) and the launch area during stationary firings of surface (ground) launched rockets and missiles. Guidance is provided for the appropriate properties, installation and use of transducers, wiring, signal conditioning, signal filtering and digital data acquisition systems. Procedures for measurement system validation and "end-to-end" calibrations (mechanical and electrical) are provided. Required documentation and records of the measurement system and data acquisition process are defined. This TOP is limited to tests associated with stationary (during the launch event) ground mobile launchers.

This TOP will supplement and/or complement Military Standard (MIL-STD)-1474D[1]* and International Test Operations Procedure (ITOP) 04-2-822[2] for impulse noise measurements as applicable to the firing of ground launched rocket and missile systems.

This TOP will discuss potential data processing techniques, as part of the data acquisition process, however, the specific procedures for post-acquisition data processing and data validation are not addressed. The processes and procedures described in this TOP will not require telemetry systems and therefore will not be discussed. Also, this TOP does not address the other measurements of environments associated with rocket and missile launches that may be required such as electromagnetic phenomena (visible, infrared (IR), radio frequency (RF), etc), chemical releases (toxic gasses), and debris effects.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Launch site/test range	Launch site and test range as required to accomplish the missile or rocket launch and flight test. These can vary in complexity. The level of infrastructure at the site may be minimal or highly developed.

*Superscript numbers correspond to Appendix C, References.

Item	Requirement
Instrumentation shelter	To provide shelter for the instrumentation systems from the natural environment and the adverse mechanical and thermal effects when in close proximity to a missile launch. In some cases RF shielding may be necessary. Depending on the level of infrastructure development at the launch site, the instrumentation shelter may be a room in a permanent building or a temporarily emplaced trailer, portable building or van. The shelter requires adequate electrical power (firm or generated) with an uninterruptable power supply (UPS). The shelter must include a heating ventilation and cooling (HVAC) system to provide controlled ambient temperature conditions within the operating specifications of the instrumentation systems.
Data acquisition system	The data acquisition system consists of the transducers (sensors), signal conditioning, filters, analog-to-digital converters, interconnecting electrical signal cables and data storage device suitable for high speed, multi channel data acquisition.

2.2 Instrumentation.

Devices for Measuring	Requirements
Motion (accelerometers, velocity pickups, displacement transducers, rate gyroscopes, tilt sensors, etc.)	Transducers are selected as required to achieve the specific measurement objectives. The following requirements shall be met over the amplitude and frequency range of interest for each measurement channel: Accuracy: Acceleration: ± 5% Velocity: ± 3% Displacement: ± 1% Phase linearity: within 5 degrees Off-axis sensitivity: less than 5 percent

Devices for Measuring	Requirements
Pressure (gages and microphones)	Microphones and pressure gages for impulse noise and blast overpressure measurements shall meet the requirements of ITOP 04-2-822 Pressure transducers for other launcher dynamics applications shall meet the following requirements over the amplitude and frequency range of interest: Accuracy: ± 0.5 dB
Force and strain	Transducers and gages are selected as required to achieve the specific measurement objectives. The following requirements shall be met over the amplitude and frequency range of interest for each measurement channel: Accuracy: ± 1.0 percent
Temperature	Temperature measurement sensors shall have time constants as required to measure the expected phenomena with the following accuracy: Thermocouple (TC): ± 0.7 Celsius (C) Resistance temperature device (RTD): ± 0.1 C
Signal conditioning	As required. Signal conditioning, filters, analog-to-digital converters and storage devices - the complete data acquisition system - shall be calibrated using end-to-end electrical (excluding transducers) or mechanical calibrations (including transducers).
Time	Dynamic data acquisition requires unambiguous time data recorded on all data acquisition systems. Some data acquisition systems provide time stamped data that is correlated to an external source such as one of the standard Inter Range Instrumentation Group (IRIG) time codes. However, it is usually worthwhile to dedicate one channel on each system to recording properly formatted time code (usually IRIG B). This recorded channel with defined characteristics can be used to detect acquisition sampling errors, verify system integrity as well as time-correlate data across various systems and locations. Accuracy: ± 0.1 millisecond (ms)

Devices for Measuring	Requirements
Calibration	As required. Any piece of equipment (calibrators) that is used to generate electrical or mechanical calibration signals for the purpose of end-to-end system or component calibrations.
Launch platform motion (video)	As required.
Meteorological conditions	As required.

NOTE 1: The permissible measurement uncertainty is the two-standard deviation value for normally distributed instrumentation calibration data. Thus 95% of all instrumentation calibration data readings will fall within two standard deviations from the calibration value.

2.3 Instrumentation Calibration.

a. Transducers and Calibration Sources: All transducers and sources (electrical signal or mechanical sources used for end-to-end calibrations) shall be calibrated to laboratory standards whose calibration is traceable to each nation's national standards within 1-year prior to use or in accordance with the manufacturer recommended interval whichever is shorter. Post-test calibrations are recommended for those transducers that are exposed to environments outside the manufacturer specified ranges or if suspected of having incurred damage during the data acquisition event.

b. Other Instrumentation: All other instrumentation, signal conditioning and data recording equipment shall receive routine maintenance and calibration in accordance with the manufacturer's recommended procedures and intervals. End-to-End calibrations using calibrated mechanical or electrical sources (see paragraph 2.3.a) will include all signal conditioning, filters, amplifiers and recording instrumentation.

c. The test laboratory shall maintain the calibration records.

3. REQUIRED TEST CONDITIONS.

3.1 Safety.

All test operations shall be conducted in accordance with the applicable Safety Regulations and Standing Operating Procedures of the test range or facility. If US Soldiers are desired, ensure a Test Schedule and Review Committee (TSARC) request is submitted within one year from the start of testing or as early as possible. A Safety Release, issued by the US Army Evaluation Center, should also be obtained prior to the test event and provided to the US Soldiers Unit Commander.

3.2 Test Objectives.

Launcher Dynamic Data Acquisition tasks are performed to measure the dynamic mechanical and thermal environments (shock, vibration, displacement, strain, acoustics, pressure and temperature) of launchers, the associated ground equipment (i.e., missile loaders, control stations, and generators) and the launch area during stationary firings of surface launched rockets and missiles.

a. Requests, requirements and specifications for measurements come from many and often disparate sources. Sources of data requests may be the Materiel Developer, Program Management Office, the System Contractor or Sub-contractors, regulatory agencies, safety organizations and/or the Test and Evaluation organization. Successfully achieving measurement objectives requires that the data acquisition and instrumentation engineers have an understanding of the purpose for which each channel of dynamic data is to be acquired. The overall and detailed (channel-by-channel) objectives of the launcher dynamic data acquisition task must be well defined prior to the detailed planning of the data acquisition process. Although, each task will have system specific objectives and requirements, some typical launcher dynamic data requirements are listed below.

(1) Measurements of structural forces and motions using low frequency strain gages, displacement transducers, angular rate gyroscopes and accelerometers to characterize overall system dynamics may be specified.

(2) Measurement of localized shock and vibration using high frequency accelerometers to determine design and test parameters for specific areas or items/components of the launcher is usually required.

(3) Thermocouples or RTDs to measure the transient surface, air, or exhaust plume temperatures may be required.

(4) Acoustic and/or blast overpressure measurements using microphones and/or pressure gages may be required to determine safety of personnel (reference MIL-STD-1474D and ITOP 04-2-822) or other acoustic pressure effects on the launcher or surrounding equipment.

(5) Pressure measurements to determine timing and amplitude of gas or air pressure waves within launch tubes or other enclosed or partially enclosed elements of the launcher system are commonly required.

b. Data Processing: The types of data processing that the recorded data will eventually undergo may have a direct effect on the data acquisition process. Channels that require simultaneous sampling or otherwise time/phase aligned for multi-channel processing shall be identified. This can be a significant issue if channel counts are high and multiple data acquisition systems are required. If it is identified early in the planning process, those channels designated for multi-channel processing, can be acquired on the same data acquisition system and the required sampling/phase alignment can be easily achieved.

c. Data Priority: The relative priority of each measurement channel should be defined. It has often been the case that critical data channels have been compromised (or lost) based on a "lowest common denominator" or system limitation unnecessarily reached in order to capture relatively low priority data channels. If there is no relative priority assigned to data channels then all channels will be assumed to have equal importance which may have negative impacts on the overall data acquisition task in terms of cost, schedule, risk and quality.

3.3 Launch Site.

The launch site shall be selected as required to meet the objectives of the flight test mission. The procedures for dynamic data acquisition described in this TOP are, to the maximum extent possible, independent of the configuration, location, and in some cases, the infrastructure of the launch site.

3.4 Instrumentation Shelter.

An instrumentation room, van or shelter that houses the data acquisition, signal conditioning and recording equipment and provides protection from the natural environment and limits the adverse mechanical, thermal and sometimes chemical and/or electromagnetic environments of the launch event is required.

a. The equipment shelter shall be located at an appropriate distance from the launcher to provide protection from the missile launch effects (blast overpressure, acoustic and thermal). The distance will vary as a function of the predicted intensity of the launch environment and physical constraints of the launch site. The instrumentation shelter may also need a separation distance such that it does not interfere with dynamic data such as acoustic and blast overpressure measurements. The equipment shelter must also be located away from the launcher to avoid interference with radar, telemetry, and optical coverage of the launch event. The effects of long cable runs must be assessed during the planning process.

b. The instrumentation shelter may be too close to the launcher to be occupied by personnel during the launch. A means of remote control or a monitoring system is often desired to provide control and feedback that the instrumentation systems are operating properly from the evacuation time (usually the system arming time) up through the missile launch.

c. The instrumentation shelter shall also provide environmental conditioning such that all instrumentation systems are maintained and operated within the specified temperature and humidity conditions. All electronic systems have specified operating limits that are required for stable, accurate and calibrated (traceable) measurements. In the case of thermocouple systems, the reference junction may only accurately compensate over a very narrow temperature range centered on "Standard Ambient Temperature" (23 °C). Significant fluctuations in temperature within the instrumentation shelter will have adverse effects on the measurement accuracy and must be avoided.

d. The shelter requires adequate electrical power (firm or generated) with an UPS.

3.5 Data Acquisition Planning.

Planning for data acquisition should be initiated as soon as possible, preferably during the proposal stage of a new program. There are several issues to be addressed, particularly the ultimate use of the data; the selection, number, and type of transducers and their frequency ranges; and the instrumentation hardware required to collect the data. The following paragraphs describe the selection and documentation process. See Table 1 for an example of a short instrumentation listing. Keep in mind that the instrumentation planning table is a living document and requirements may change.

3.5.1 Defining the Channel Table.

Channel-by-channel planning and documentation shall include the following as a minimum:

a. Channel identification or sequence number.

b. Measurement location and axis (transducer orientation).

c. Channel measurand and Engineering Units (EU).

d. Measurement duration.

e. Amplitude range, maximum and minimum expected measurand.

f. Frequency range.

(1) Maximum frequency response (f_{max}) required.

(2) Minimum frequency response (f_{min}) required.

3.5.2 Channel Identification or Sequence Number.

Each data channel shall be assigned a unique alpha numeric identification or sequence number. A logical and consistent method should be used throughout the planning, execution, data processing and reporting phases of the overall data acquisition task.

3.5.3 Channel Measurand and Engineering Units (EU).

The physical phenomenon that is to be measured (i.e., acceleration, velocity, displacement, pressure, strain, etc.) and the engineering units (i.e., G, meters/second, meters, Pascal, micro-strain, etc.) of the recorded data shall be clearly identified. Modern digital data acquisition systems often provide convenient mechanisms to scale recorded data in the specified EU; however, there may be situations where it is required or advantageous to record un-scaled data. In those situations it must be clearly identified that the data is un-scaled or is in voltage units that must be converted to meaningful EU during data processing. The required conversion parameters (scale factors, offsets, etc.) shall be documented and conveyed to the data processing organization/personnel.

TABLE 1. EXAMPLE INSTRUMENTATION LIST

CHANNEL REQUIREMENTS																
Channel Type	Temperature		Pressure		Acceleration			Blast Pressure		Acoustic Pressure		Angular Velocity			First Motion	Timing
Channel Identification	T01	T02	P01	P02	A01	A02	A03	B01	B02	M01	M02	R01	R02	R03	BW01	IRIG-B
Location/Orientation	Outside Launch Tube	Outside Launch Tube	Launch Tube #2	Launch Tube #1	X Axis	Y Axis	Z Axis	0° at 15 m	90° at 15 m	0° at 150 m	45° at 250 m	Crossbar Roll	Crossbar Pitch	Crossbar Yaw	Missile Launch Tube	N/A
Engineering Units (EU)	°C	°C	psia	psia	g	g	g	psig	psig	Pa	Pa	°/sec	°/sec	°/sec	V	V
Required Amplitude Range	0-800	0-800	0-100	0-100	+/- 200	+/- 200	+/- 200	+/-8	+/-8	+/- 2000	+/- 2000	+/- 50	+/- 50	+/- 50	0-5	+/- 2
Required Min Frequency (Hz)	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC
Required Max Frequency (Hz)	3	3	10000	10000	1500	1500	1500	10000	10000	40000	40000	60	60	60	10000	10000
TRANSDUCERS																
TYPE	TC Type K	TC Type K	PR Pressure	PR Pressure	PR Accelerometer	PR Accelerometer	PR Accelerometer	PR Pressure	PR Pressure	IEPE Microphone	IEPE Microphone	Rate Gyro	Rate Gyro	Rate Gyro	Breakwire	IRIG-B
Manufacturer	Omega	Omega	Endevco	Endevco	Endevco	Endevco	Endevco	Kulite	Kulite	PCB	PCB	Systron Donner	Systron Donner	Systron Donner	N/A	Symmetricom
Model	SA1XL-K-120-SRTC	SA1XL-K-120-SRTC	8520A-100	8530C-100	2262A-200	2262A-200	2262A-200	XLT-190-10A	XLT-190-10A	377B10 / 426B03	377B10 / 426B03	160260-121	160260-121	160260-121	N/A	820-501-000
Serial Number	N/A	N/A	10174	10402	AJHN2	AJHR9	11096	B90-47	B90-48	111012 / 011075	111013 / 011076	0797X	0797Z	0797Y	N/A	73756503
Sensitivity	N/A	N/A	2.63	1.7	2.751	2.927	2.901	10.03	10.01	0.733	0.77	25.981	24.982	25.007	1000	1000
Calibration Date	N/A	N/A	12-May-12	16-May-12	1-May-12	1-May-12	1-May-12	22-May-12	22-May-12	30-May-12	30-May-12	N/A	N/A	N/A	N/A	N/A
Transducer Cable ID	T01	T02	P01	P02	A01	A02	A03	B01	B02	M01	M02	R01	R02	R03	BW01	IRIG
SIGNAL CONDITIONERS																
Manufacturer	Dataforth	Dataforth	Pacific	Pacific	Ectron	Ectron	Ectron	Pacific	Pacific	Endevco	Endevco	N/A	N/A	N/A	N/A	N/A
Model	N/A	N/A	6060HF	6060HF	428LO	428LO	428LO	6060HF	6060HF	2775B	2775B	N/A	N/A	N/A	N/A	N/A
Serial Number	N/A	N/A	3218139-0	3218139-1	65049	65050	65051	3218146-0	3218146-1	AF06	AF07	N/A	N/A	N/A	N/A	N/A
Pre-Filter (kHz)	0.003	0.003	10	10	1	1	1	N/A	N/A	30	30	0.06	0.06	0.06	N/A	N/A
Gain	N/A	N/A	20	50	10	10	10	100	100	4.5475	4.329	1	1	1	1	N/A
Max Volts Out	5	5	10	10	10	10	10	10	10	10	10	2.5	2.5	2.5	5	N/A
Max EU Out	1000	1000	190.1	117.6	363.5	341.6	344.7	10.0	10.0	10.0	10.0	96.2	100.1	100.0	5.0	N/A
Excitation	N/A	N/A	10 V_{DC}	10 V_{DC}	10 V_{DC}	10 V_{DC}	10 V_{DC}	10 V_{DC}	10 V_{DC}	4mA	4mA	+5,- 5 V_{DC}	+5,- 5 V_{DC}	+5,- 5 V_{DC}	5.0	N/A
Calibration Date	10-May-12	10-May-12	N/A	N/A	12-May-12	12-May-12	12-May-12	N/A	N/A	22-May-12	22-May-12	N/A	N/A	N/A	N/A	N/A
Output Cable ID	A01	A02	A04	A05	A07	A08	A09	S01	S02	B01	B02	B04	B05	B06	S04	IRIG
DATA RECORDERS																
Manufacturer	Dewetron	Dewetron	Dewetron	Dewetron	Dewetron	Dewetron	Dewetron	Sony	Sony	Dewetron	Dewetron	Dewetron	Dewetron	Dewetron	Sony	Dewetron
Model	DEWE5008	DEWE5008	DEWE5008	DEWE5008	DEWE5008	DEWE5008	DEWE5008	SIR-3400H	SIR-3400H	DEWE5000	DEWE5000	DEWE5000	DEWE5000	DEWE5000	SIR-3400H	DEWE5000
Serial Number	08080069	8080069	8080069	8080069	8080069	8080069	8080069	U15056	U15056	07090358	07090358	07090358	07090358	07090358	U15056	07090358
DAS Channel	A01	A02	A04	A05	A07	A08	A09	S01	S02	B01	B02	B04	B05	B06	S04	B08
DAS Sensitivity (mV/EU)	N/A	N/A	52.6	85	27.51	29.27	29.01	1003	1001	3.333	3.333	25.981	24.982	25.007	1000	1000
DAS Offset (EU)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amplitude Range Maximum (EU)	1000	1000	190.1	117.6	363.5	341.6	344.7	10.0	10.0	3000.0	3000.0	96.2	100.1	100.0	5.0	2.5
Amplitude Range Minimum(EU)	0	0	-190.1	-117.6	-363.5	-341.6	-344.7	-10.0	-10.0	-3000.0	-3000.0	-96.2	-100.1	-100.0	-5.0	-2.5
DAS Range (V)	5	5	10	10	10	10	10	10	10	10	10	2.5	2.5	2.5	5	2.5
Measurement Duration (hh:mm:ss)	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00	1:45:00
DAS Sample Rate (kSPS)	50	50	50	50	50	50	50	96	96	160	160	160	160	160	96	50
CALIBRATORS																
Manufacturer	Omega	Omega	MTI	MTI	MTI	MTI	MTI	MTI	MTI	Endevco	Endevco	MTI	MTI	MTI	MTI	MTI
Model	CL27	CL27	1510A	1510A	1510A	1510A	1510A	1510A	1510A	4830A	4830A	1510A	1510A	1510A	1510A	1510A
Serial Number	T-282353	T-282353	209809	209809	209809	209809	209809	209809	209809	AB90	AB90	209809	209809	209809	209809	209809
Insertion Value (V, pC, Ω)	N/A	N/A	0.263	0.170	0.550	0.585	0.580	0.080	0.080	1.466	1.540	1.299	1.249	1.250	5.000	2.000
Insertion Value (EU)	800	800	100	100	200	200	200	8	8	2000	2000	50	50	50	5	2
Measured Value (V)	5.000	5.000	5.260	8.500	5.502	5.854	5.802	8.024	8.008	6.667	6.667	1.299	1.249	1.250	5.000	2.000
Measured Value (EU)	1000	1000	100	100	200	200	200	8	8	2000	2000	50	50	50	5	2
Calibration Date	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12	30-May-12

3.5.4 Measurement Coordinate System.

The required measurement coordinate system, location and orientation of each data channel shall be defined. The required accuracy of the measurement location will depend on the specific measurement type and requirements. For any Launcher Dynamic Data Acquisition task there may be multiple coordinate systems that apply to different data channels. For example, accelerometers mounted on the missile launch tube may be referenced with X-axis along the missile thrust axis (or direction of flight), and accelerometers to measure the launch vehicle motion may use an X, Y and Z-Axis coordinate system referenced to the longitudinal, transverse and vertical Axes (respectively) of the vehicle. There could be a third global coordinate system used for geodetic purposes.

3.5.5 Measurement Duration.

The required measurement duration is typically specified to be the same for all data channels and is usually greater than required for the longest duration event. The data of interest for each channel is then edited to a shorter data segment during data processing. However, there may be situations where the measurement durations may be specified or determined on a channel-by-channel or channel group basis. The measurement duration shall be defined in order to optimize the selection and programming of data acquisition system, start times, stop times, and data storage requirements.

3.5.6 Amplitude Range.

The required amplitude range to be recorded, A_{min} (EU) to A_{max} (EU), shall be defined based on the predicted low and high values of the phenomenon to be measured based on analysis and/or modeling of the system, or previous measurements and experience with the same or similar systems. During the planning process it is important to know if a specified value (provided by a data requestor or other outside source) incorporates a margin or “headroom” above (and below) the predicted values. To reduce the possibility of clipping the data or otherwise overloading the instrumentation systems, headroom shall always be included in the definition of amplitude range to be recorded (A_{min} to A_{max}).

3.5.7 Frequency Range.

The minimum and maximum frequencies of interest, f_{min} (hertz (Hz)) to f_{max} (Hz), to be recorded for each channel must be specified or determined based on the measurement objectives, characteristics of the measurand, and in some cases, the type of data processing that will be eventually performed on the measured data. Specific recommendations for determining the required minimum and maximum frequency response parameters are provided in Appendix A.

3.6 Data Acquisition System.

The data acquisition system consists of the transducers (sensors), signal conditioning, filters, analog-to-digital converters, interconnecting electrical signal cables, and data storage device.

3.6.1 Transducer Selection.

The transducers for each channel are selected based on the dynamic response characteristics, environmental response characteristics, and physical characteristics necessary to achieve the measurement objective.

a. Dynamic Characteristics: For each channel select a transducer that has the appropriate dynamic characteristics (sensitivity, signal-to-noise ratio, linearity, natural frequency, etc.) to measure the required phenomenon over the required amplitude range (A_{min} to A_{max}) and frequency range (f_{min} to f_{max}) in accordance with the requirements specified for the transducer types in paragraph 2.2.

b. Environmental Characteristics: Transducer and sensor responses to the launch environments other than the intended parameter to be measured need to be addressed during the selection of the transducer. For example; an accelerometer will provide an undesirable electrical output to thermal transients, base strain, acoustic excitation, electromagnetic fields, and electrical grounding anomalies. In most cases the manufacturer will incorporate design elements to reduce the unintended responses and will publish the transducer output to standardized environmental inputs. Often, it is necessary during the installation of the transducer to further protect the transducer from the unintended environmental response. For all measurement channels, ensure that the environmental responses of the selected transducers are minimized by the design of the transducer, or can be reduced to an acceptable level by installation techniques that shield or isolate them from the unintended environments.

c. Physical Characteristics: Select transducers with physical characteristics (mass, dimensions, mounting method, cabling etc.) that are compatible with the physical constraints of measurement structure and do not significantly alter the dynamic response of the structure that is the target of the measurement.

d. Further guidance for selecting commonly used transducer types for various measurements is provided in Appendix A. For each transducer selected, document the type, manufacturer, model, serial number, sensitivity, and calibration information.

3.6.2 Signal Conditioning.

Signal conditioning includes the amplifiers, attenuators, filters, power supplies, cables, and any other electronics in the overall data system between the transducers (sensors) and the digital data acquisition system. This document addresses only traditional analog signal conditioning systems. There are many specialty transducers available that have specific digital or hybrid signal conditioning that is uniquely applicable to those transducers and is therefore outside the scope of this document. Select signal conditioning for each measurement channel as appropriate for each type of transducer and with the characteristics described below.

a. Dynamic Characteristics: For each channel, select signal conditioning that has the required gain, amplitude range (A_{min} to A_{max}), and sensitivity with the amplitude accuracy, signal-to-noise ratio, and amplitude linearity specified in paragraph 2.2. The selected signal conditioning shall have a flat amplitude frequency response within ± 0.05 dB from 2 f_{min} to

0.5 f_{max} and with less than 0.5 dB attenuation at f_{min} and f_{max}. The selected signal conditioning shall provide linear phase frequency response within ± 5° over the required frequency range from f_{min} to f_{max}. Ensure that cable and instrument current limitations, resistances, and capacitances do not result in slew rate limiting of signals within the required frequency range. Slew rate limiting results in signal distortions including zero shifts and direct current (DC) offsets.

b. Environmental Protection: Generally the signal conditioning system will be installed in the temperature controlled instrumentation shelter which provides protection from the natural environment and limits the adverse mechanical, thermal, and sometimes chemical and/or electromagnetic environments of the launch event. All signal conditioning systems that are located in close proximity to the launcher shall be ruggedized or protected in such a manner that unintended response of the signal conditioning to the launch environment does not result in erroneous signal or contaminated data.

c. Power Supplies: Signal conditioning power supplies provide constant voltage or constant current to power transducers such as strain gages, load cells, piezoresistive accelerometers and pressure transducers, displacement potentiometers, or Integrated Electronics Piezoelectric (IEPE) microphones and accelerometers. The characteristics of these power supplies can have a significant effect on the quality of the dynamic data measurement. Therefore, the signal conditioning power supplies shall meet the following requirements as a minimum:

(1) Each channel should have an individual independent power supply to preclude a failure in any one channel from disrupting or contaminating the data for another channel.

(2) Power supplies shall provide regulated, filtered, stable, ripple free voltages, and currents such that the required voltage or current is maintained within 0.05% over the required operating time, temperature changes, or transducer load fluctuations.

(3) If the cable runs are long (greater than 10 meters) from the power supply to the transducer, remote voltage sensing should be used for the regulation of constant voltage transducer excitation.

d. Pre-filtering. In some instances it is required or desirable to filter the analog data signal in conjunction with, or immediately following the signal conditioning, but independent of the data acquisition system anti-alias filters. This may be performed to give the data a specific spectral weighting (such as for acoustic data) or to provide for easy comparison to other data. For the purpose of this document this is referred to as pre-filtering (prior to recording) and is considered separately from the anti-alias filters regardless of the contribution to the attenuation of aliasing terms. No specific guidance is provided here for selection of filter settings; however, any filter in the data acquisition system shall be characterized and documented.

e. Cables. Cables and connecters that transmit signals and excitation voltages are selected based on the specific transducers and applications.

(1) Piezoelectric transducers and charge amplifiers systems are particularly sensitive to triboelectric noise (see Institute of Environmental Sciences and Technology (IEST)-RD-DTE012.2[3]). Triboelectric noise shall be minimized for piezoelectric transducer/charge amplifier channels by using low noise cables and proper restraint/installation of the cables.

(2) For piezoelectric transducer/charge amplifier systems, the length of the cable and the associated cable capacitance (typically 100 picofarad (pF) per meter) significantly affects the input noise and limits the frequency response of both the input and output of the charge amplifier. Verify that the selected cables (input and output) do not reduce the maximum frequency response of the channel below the maximum frequency to be recorded (f_{max}).

(3) For bridge transducers, voltage amplifiers and constant current systems individually shielded twisted pair cables should be used.

f. Grounding and Shielding: Grounding and shielding of the cables and systems will vary depending on the specific requirements, location, configuration, instruments and components in the total data acquisition system. Specific guidance for grounding and shielding for instrumentation can be found in Morrison, Grounding and Shielding Techniques in Instrumentation[4].

3.6.3 Analog-to-Digital (A/D) Conversion, Anti-Alias Filters and Data Storage.

a. Sample Rate. The sample rate, f_s (Hz), for each channel shall be at least 10 times the specified or required high frequency response, f_{max} (Hz), as determined in paragraph 3.3.7. The sample rate may be reduced to an appropriate value between 2.2 and 10 times f_{max} if the measurement channel objective and data processing methods can be adequately accomplished with a lower sample rate (up-sampling or frequency domain processing).

b. Anti-Alias Filter.

(1) Low pass anti-alias filtering shall be provided for each data channel. This may be accomplished with traditional analog filters or through combinations of analog filters with over-sampling A/D converters followed by digital filtering and data decimation.

(2) The anti-alias filter shall have an attenuation slope of at least 60 dB per octave. The -3 dB (half power point) cut-off frequency of the anti-alias filter, f_{AA} (Hz), shall be sufficiently above (depending on the type of filter) the required high frequency response, f_{max}, such that the amplitude attenuation at f_{max} is less than 0.5 dB. The cut-off frequency shall be sufficiently below the Nyquist frequency, $f_{Nyquist}$ (Hz), such that the signal amplitude attenuation at $f_{Nyquist}$ is at least -60 dB. Regardless of the attenuation slope f_{AA} shall never be set above 0.8 times $f_{Nyquist}$. The Nyquist frequency is the highest frequency that can be represented in a digital signal of a specified sampling frequency. It is equal to one-half of the sampling rate.

(3) The anti-alias filter shall provide linear phase, ± 5 degrees, over the total frequency range of interest (f_{min} to f_{max}).

(4) Where the acquired data will undergo multi-channel data processing it is necessary for the anti-alias filters for the individual acquisition channels to be precisely matched in both amplitude and phase response.

3.7 Meteorological Conditions.

The local ambient environment or changes that occur during the set-up, calibration, and measurement process may have a significant effect on the data. Meteorological conditions at a launch site are typically monitored to support launch mission and recorded by organizations that specialize in those measurements.

4. TEST PROCEDURES.

The following generalized procedures are provided as guidance; the sequence of the steps in some cases is not critical and may not be appropriate for the specific mission or launch facility.

4.1 Transducer Installation.

The transducers shall be installed at the locations and orientations as determined/defined in paragraph 3.5. Transducers for mobile launchers are often installed at a maintenance or pre-test preparation facility prior to transport and emplacement at the launch site. In general, the transducers and electrical cables shall be installed in accordance with the manufacturers' recommendations; however, the following specific guidance is provided for some types of transducers.

a. Motion transducers (shock, vibration, displacement, etc.): The transducers shall be rigidly fixed to the launcher structure using mechanical fasteners or adhesives. The method of mounting shall be such that the required frequency response is not compromised and the transducer remains secure through the entire launch event. Covers or shielding are usually required to reduce exposure to thermal transients and harmful airborne exhaust products (hydrogen chloride (HCl)) in and around the launcher. In some cases thermal and electrical isolation from the launcher structure is required. All electrical cables will be securely restrained and routed to minimize exposure to the rocket motor blast.

b. Pressure transducers and microphones: Each pressure transducer or microphone, for the purpose of measuring blast overpressure and impulse noise, shall be installed and oriented in accordance with the guidance of ITOP 04-2-822; however, locations (distances from the launcher) must be tailored to the missile system under test. Any pressure transducer diaphragm or sensing element that is directly exposed to the flash, heat, and chemical exhaust products of the rocket motor must be protected by a suitable coating such as a silicone grease (black) or room temperature vulcanize (RTV) silicone. Any coatings applied by the user must be evaluated to assure the proper level of protection while not compromising the frequency response of the specific transducer.

4.2 Shelter Installation.

Configure/emplace the instrumentation shelter at a location that is a sufficient distance from the launcher to provide shelter for the instrumentation systems from the adverse mechanical and thermal effects of the missile launch. Ensure that there is adequate, high quality, electrical power with an uninterruptable power system. Ensure that the electrical grounding system at the instrumentation shelter is adequate. Ensure that the heating and cooling systems are operational and will provide the necessary environment for the signal conditioning and data acquisition systems to perform in accordance with the manufacturers' specifications.

4.3 Data Acquisition System Installation.

Configure (set-up and program) and verify operation of all of the signal conditioning, data recorders, time code systems, power supplies, remote controls, patch cables, and any other systems and components to be located in the instrumentation shelter. Verify the operation of the system on a channel-by-channel basis to ensure that each channel of the data acquisition system (signal conditioner to recorder) is functioning and configured properly. Verify the operation of any remote control or trigger system that will be used to start and/or control the data recording function. Document the configuration of the complete data acquisition system and settings.

4.4 Cable Installation.

Emplace/route the signal conditioning input cables from the instrumentation shelter to the locations where they will be connected to the transducer output cables. All cables in the immediate area of the launcher will generally need to be protected from the rocket motor blast. This may be previously installed or fixed conduits (above or below ground), sand bags, or some other system specific to the test facility.

4.5 End-to-End Calibration.

Prior to making the final connections of the signal conditioning input cables to the transducer output cables, perform the end-to-end insertion/substitution calibration for each channel. End-to-end calibration techniques are discussed in detail in IEST-RD-DTE012.2. Verify that all required excitation voltages and currents are present and correct with the transducer load applied (usually with a break-out connector). If mechanical calibrations are to be performed, make the final connection of the transducer to the signal conditioner and apply the required stimulus to the transducer. To the maximum extent possible, channel-by-channel mechanical checks (tap checks, sound checks, temperature changes, etc.) should be performed to verify that all transducers are responding to appropriate stimuli. Document all of the calibration input and output values, excitation voltage, and current measurements.

4.6 Start/Arm the Data Recording System(s).

In most cases all personnel will be evacuated from the launch area at some pre-determined time prior to the missile launch (usually at final arming of the missile launch circuits). At this time, perform all final operations and "Arm" (awaiting trigger or remote start command) the data recorder. If the recorder is to be manually started, ensure that there sufficient recording time available and start the data recorder immediately prior to leaving the launch area. Whether manually or automatically started, it is important to have a period of recorded noise and offset data immediately prior to the launch event.

4.7 Post-Test Inspection.

After the launch mission, stop the data recording as required. Carefully inspect the condition of all of the transducers, cables and any instrumentation that may have sustained damage as a result of the launch environment. Document any findings. Whether manually or automatically stopped, it is important to have a period of recorded noise and off-set data that immediately follows the launch event.

4.8 Data Review.

Perform a thorough review of the recorded data. Assess the quality of each channel and document any anomalies. If anomalies were noted, determine the probable causes.

4.9 Data Delivery.

Deliver the data to the customer/analysts in the previously determined formats. Ensure that all required information (scaling, sample rates, time stamps, etc.) as necessary to process the data is provided.

5. DATA REQUIRED.

Data requirements will be coordinated and agreed upon between the test agency and the test sponsor. Typical data requirements include, but are not limited to, the following:

a. Channel identification or sequence number.

b. Measurement transducer location and axis (transducer orientation).

c. Channel measurand and engineering units.

d. Measurement duration.

e. Amplitude range to include maximum and minimum expected measurand.

f. Frequency range (maximum frequency response (f_{max}) required and minimum frequency response (f_{min}) required).

g. Transducer selection to include type, manufacturer, model, serial number, sensitivity, and calibration date.

h. Signal conditioning used to include type, manufacturer, model, serial number, gain or full scale output, and calibration date.

i. Anti-alias filter characteristics to include type, phase, manufacturer, model , and serial number, cut-off frequency, attenuation at cut-off frequency, attenuation slope (dB/octave), and attenuation of aliasing components.

j. Data acquisition system type, manufacturer, model, and serial number.

k. Data sampling rate (samples per second).

l. Meteorological conditions.

6. PRESENTATION OF DATA.

a. All instrumentation and data acquisition equipment nomenclature shall be tabularized and provided in the test report. Table 1 illustrates a shortened instrumentation list example.

b. The test report shall contain drawings or photographs depicting instrumentation locations with respect to the launcher/missile as shown in Figures 1 and 2.

c. The test data shall be processed into data plots for inclusion in the test report. Two typical time history plots are provided in Figures 3 and 4. Data records may also be provided in digital format, such as comma separated variable listings, for additional processing.

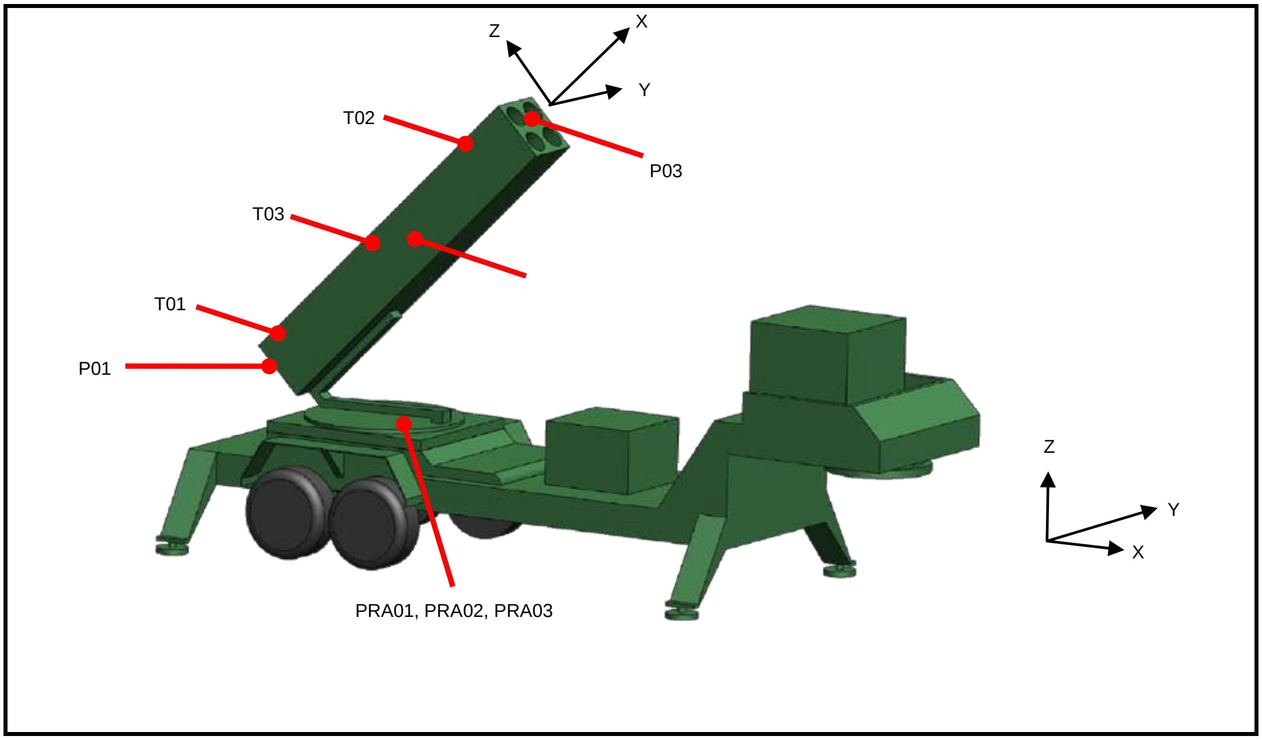

Figure 1. Launcher with example piezoresistive accelerometer (PRA), thermocouple (T) and pressure transducer (P) instrumentation locations. Note: there are two coordinate systems, one for the launcher and one for the missile.

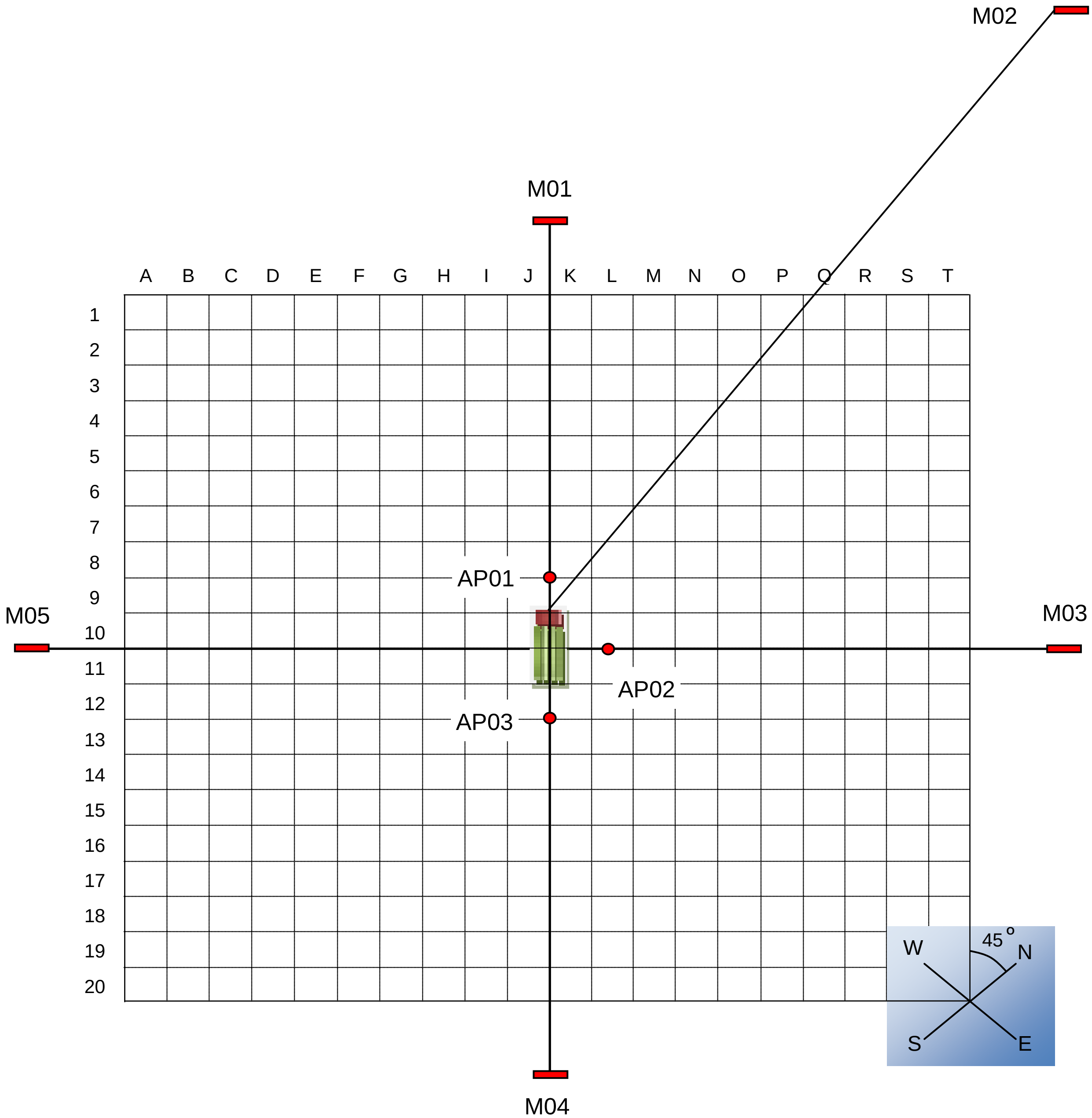

Figure 2. Launcher with example microphone (M) and acoustic pressure (AP) instrumentation locations.

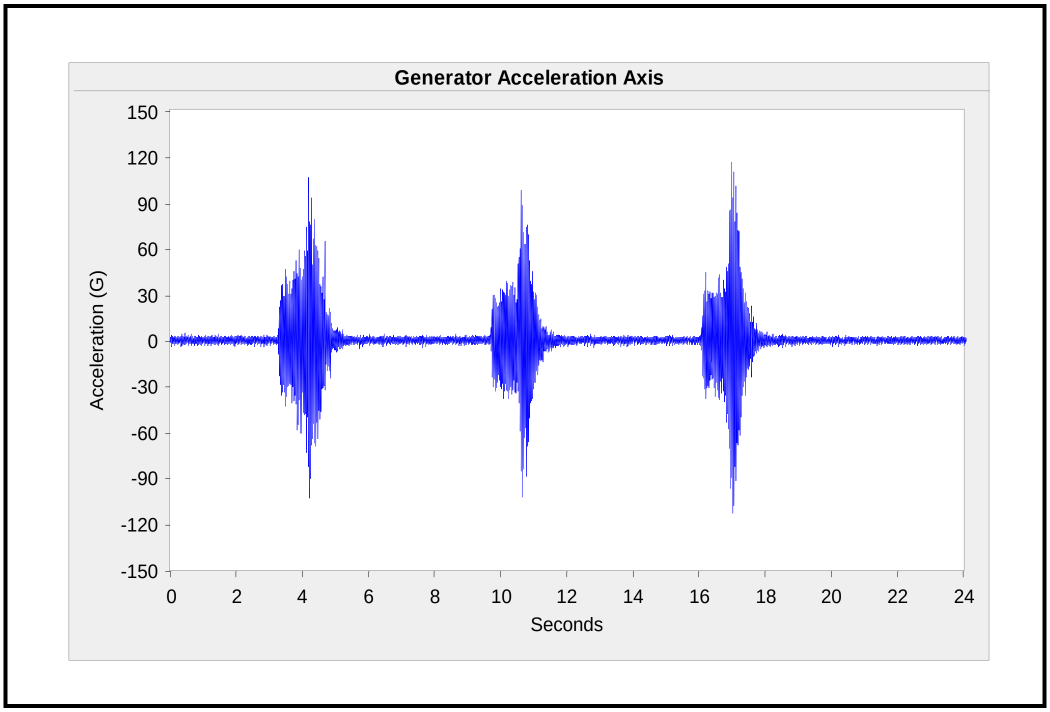

Figure 3. Example acceleration time history plot.

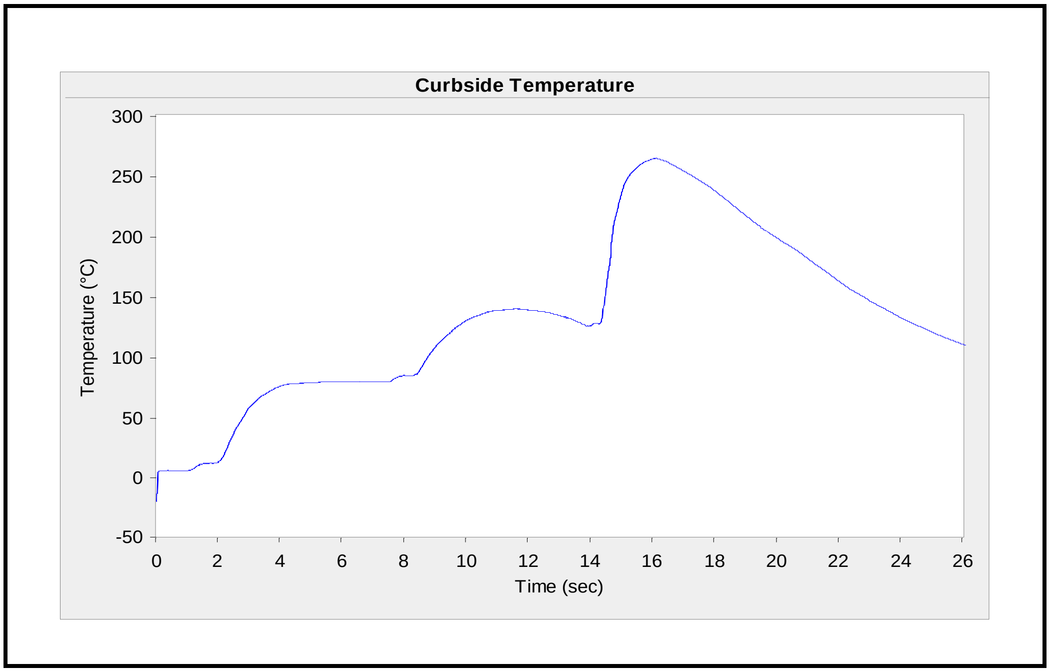

Figure 4. Example temperature history plot.

APPENDIX A. BACKGROUND.

A1. Transient Dynamic Data.

a. The dynamic environments of the missile/rocket launcher and surrounding area resulting from a launch are best described as a transient dynamic environment. Instrumentation selection and data acquisition parameters shall be based on the best practices for transient data. Traditional practices of determining required instrumentation frequency response, filtering, sample rates, etc. for steady state or stationary data are not in most cases applicable to Launcher Dynamic Data Acquisition.

b. When planning and selecting the instrumentation and data acquisition parameters, it should be considered that unexpected, sometimes catastrophic, events may occur during missile launches. Whenever practical and if the measurement objectives are not significantly compromised, the frequency and amplitude ranges should be set to allow for potentially anomalous launch environments.

A2. Noise Sources.

The launch site may have significant sources of data noise. Some of the noise sources are not present during the set-up, system check and calibration, but may appear during the launch. Noise sources should be evaluated and mitigated during the planning and set-up of the data acquisition and instrumentation system.

a. Electromagnetic effects. The electromagnetic environment at a launch site during a missile launch requires careful consideration. Most test ranges use powerful radars aimed directly at the launch site to track the missile from launch through flight. The missile and launch systems may also use radar guidance, microwave, and/or RF communication and telemetry systems. All of these sources of electromagnetic radiation may induce noise on measurement and data acquisition systems. Proper grounding, shielding, and filtering shall be employed to reduce noise contamination of the data.

b. Thermal and flash. The thermal and flash environment of the rocket motor ignition can be very intense and result in erroneous responses from most transducers. Transducers and wiring that may be exposed to the thermal and flash shall be protected or sheltered to reduce data contamination.

c. Smoke and dust. The missile launch typically generates a substantial dust cloud as well as a generous amount of toxic smoke. Both the smoke and dust will interfere with optical measurement systems. In addition, the smoke usually contains acids (e.g., hydrogen chloride) that can damage sensitive instruments and/or induce unwanted responses.

d. Cable whip. Motion of the launcher and rocket blast can induce significant whip in the instrumentation cables. The effects of cable whip for each channel type (transducer, cable, connectors, and signal conditioning combination) shall be evaluated.

APPENDIX A. BACKGROUND.

A3. High Frequency Response (f_{max}).

The high frequency response for each channel must be carefully considered and selected because it has the most significant influence on the design and selection of the overall measurement and data acquisition system. Whenever possible the determination should be based on the maximum expected frequency content of the physical phenomenon to be measured; however, the real-world limitations of total system bandwidth generally require that the high frequency response must be limited or tailored to the an acceptable value. It is also important to not over state the maximum frequency required for any specific channel. It is often erroneously assumed that selection of higher frequency response will improve data quality. However, an erroneously specified high frequency response requirement may force the selection of a less-than-optimal transducer that sacrifices low frequency data in order to accurately capture the high frequency energy that may be irrelevant to the measurement objective. In all cases where the data signal may contain frequency content above the determined or specified maximum frequency to be recorded, special attention must be given to eliminate or reduce the contamination of the data from energy that is outside the frequency range of interest (see anti-alias filters).

a. A key parameter in determination of the high frequency response is the expected “rise time” or leading edge of the event to be accurately measured and recorded. The rise time has traditionally been defined as the time from 10% above the baseline to 10% below the peak value of the initial slope of a dynamic event. For large structural motions of the launcher the rise time may be tens or even hundreds of milliseconds in duration. When planning for acoustic and blast overpressure measurements, rise times in the range of 10 to 20 microseconds are generally required. For pyroshock measurements, rise times of less than 10 microseconds should be expected (see reference Wright, Charles, Effective Data Validation Methodology for Pyrotechnic Shock Testing[5]). As a generally accepted rule (source unknown) the maximum frequency response (f_{max}) required for a given rise time is:

$$f_{max}\,(\text{Hz}) = 0.35 \,/\, \text{Rise Time (seconds)}$$

b. If the objective is the measurement of the localized shock environment of specific items or components, the acquired data will most likely be used to compute Shock Response Spectra (SRS) for each of the measurement locations. It is critical for the instrumentation engineer to know the maximum frequency of the SRS that will be computed. To compute an accurate SRS for any transient waveform the recorded data must contain accurate (amplitude and phase) data to a maximum frequency (f_{max}) well above the SRS maximum frequency (SRS_{fmax}). Reference 4 specifies that the valid acquisition bandwidth must extend to at least three times the SRS maximum frequency.

$$f_{max}\,(\text{Hz}) = 3 \text{ x } SRS_{fmax}\,(\text{Hz})$$

c. When determining the maximum frequency required for temperature measurement channels, the Time Constant (τ) of available measuring devices will probably limit the maximum achievable frequency response. For a given Time Constant the required maximum frequency

APPENDIX A. BACKGROUND.

response (f_{max}) of the data channel is approximately:

$$f_{max}\,(\text{Hz}) = 0.16 / \tau\,(\text{seconds})$$

d. Slew Rate: This is a critical parameter in the selection of signal conditioning amplifiers. The slew rate of a signal conditioning amplifier is the rate of change of output voltage per unit time usually expressed in volts per microsecond. The maximum slew rate of an amplifier can be adversely affected or reduced below the specified value due to capacitance of the attached output cables and instruments. This may result in distortion of the output signal typically referred to as slew rate limiting. In order to avoid slew rate limiting, select a signal conditioning amplifier that provides a maximum slew rate (with output cables and attached instruments) that exceeds the value determined from the equation below, based on the previously determined required maximum frequency response (f_{max}) and the full scale output voltage (V_{max}).

$$\text{Slew Rate (volts/}\mu\text{-second)} = (1 \times 10^{-6})\,(2\pi)\,(f_{max})\,(V_{max})$$

A4. Low Frequency Response.

The low frequency response for each channel does not usually have a significant effect on the entire data acquisition system; however, it is a key parameter in the selection of transducers and signal conditioning components and must be specified or determined during the planning process.

a. It is recommended that transducers and signal conditioning with true DC (0 Hz) low frequency response be used whenever practical. True DC response measurement systems can accurately characterize static phenomena and the low frequency content of long duration transients. This also provides the ability to validate the dynamic data by comparing the measured initial and terminal conditions against the known or measured reality of the physical phenomenon. For example, if measuring acceleration with accelerometers, the beginning and ending zero conditions of acceleration and velocity can be easily checked as an indicator of data validity.

b. When using transducers and signal conditioning, such as piezoelectric accelerometers and pressure transducers, that do not provide DC response, the low frequency response of the measurement system (transducer, cable and signal conditioner) needs to be evaluated to ensure that it can accurately measure the phenomenon of interest. As a generally accepted “rule of thumb” (unknown source), to accurately measure (within 5%) a classical shaped transient pulse (such as a half-sine) of duration T (seconds), the required low frequency response f_{min} (Hz) of the measurement system is given by the following:

$$f_{min}\,(\text{Hz}) \leq 0.01 / T(\text{seconds})$$

For example, to accurately measure an acceleration half-sine pulse of 500 milliseconds duration the system low frequency response must be less than or equal to 0.02 Hz.

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APPENDIX B. ABBREVIATIONS.

A/D	analog to digital
ANSI	American National Standards Institute
AP	acoustic pressure transducer
ASA	Acoustical Society of America
dB	decibel
DC	direct current
EU	Engineering Units
HCl	hydrogen chloride
HVAC	heating ventilation and cooling
Hz	hertz
IEC	International Electrotechnical Commission
IEPE	Integrated Electronics Piezoelectric
IEST	Institute of Environmental Sciences and Technology
IR	infrared
IRIG	Inter Range Instrumentation Group
ISA	International Society of Automation
ISO	International Organization for Standardization
ITOP	International Test Operations Procedure
M	microphone
MIL-STD	Military Standard
PRA	piezoresistive accelerometer
RCC	Range Commanders Council
RF	radio frequency
RTD	resistance temperature device
RTV	room temperature vulcanized
SRS	Shock Response Spectra
τ	Time Constant
T	Time (duration) or thermocouple
TC	thermocouple
TOP	Test Operations Procedure
TSARC	Test Schedule and Review Committee
UPS	uninterruptable power supply

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APPENDIX C. REFERENCES.

1. MIL-STD 1474D, Design Criteria Standard, Noise Limits, 12 February 1997.

2. ITOP 04-2-822 Electronic Measurement of Airblast Overpressure and Impulse Noise, 25 September 2000.

3. IEST-RD-DTE012.2: Handbook for Dynamic Data Acquisition and Analysis, 1 September 2006.

4. Morrison, Ralph, Grounding and Shielding Techniques in Instrumentation, 2nd Edition, Wiley-Interscience, John Wiley and Sons, Inc 1977.

5. Wright, Charles, Effective Data Validation Methodology for Pyrotechnic Shock Testing, 25th Aerospace Testing Seminar, October 2009.

For information only (related publications).

a. Range Commanders Council (RCC) Document 121-07, Instrumentation Engineers Handbook, December 2007.

b. American National Standards Institute (ANSI) S2.11 - 1969, American National Standard for the Selection of Calibrations and Tests for Electrical Transducers Used for Measuring Shock and Vibration.

c. International Organization for Standardization (ISO) 16063-1:1998, Methods for the Calibration of Vibration and Shock Transducers - Part 1: Basic Concepts, 01 October 1998.

d. ISO 16063-21:2003(E), Methods for the Calibrations of Vibration and Shock Transducers - Part 21: Vibration Calibration by Comparison to a Reference Transducer.

e. ISO, 16063-22:2005, Methods for the Calibration of Vibration and Shock Transducers - Part 22: Shock Calibration by Comparison to a Reference Transducer.

f. American National Standards Institute/ Acoustical Society of America (ANSI/ASA) S1.15-2005/Part 2 (R2010), American National Standard Measurement Microphones - Part 2: Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique, 09-March 2005.

g. International Electrotechnical Commission (IEC) 61094-2 Ed. 2.0 b:2009, Electroacoustics - Measurement Microphones - Part 2: Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique, 20 February 2009.

APPENDIX C. REFERENCES.

h. International Society of Automation (ISA) 37.16.01-2002, A Guide for the Dynamic Calibration of Pressure Transducers, 01 November 2002.

i. ANSI Z540.3 Edition 06, Requirements for the Calibration of Measuring and Test Equipment, 03 August 2006.

j. ISO 10012:2003 Measurement Management Systems - Requirements for Measurement Processes and Measuring Equipment.

APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 20 August 2012

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, US Army Evaluation Center
US Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 05-2-544 Launcher Dynamic Data Acquisition, Approved for Publication

1. TOP 05-2-544 Launcher Dynamic Data Acquisition, has been reviewed by the US Army Test and Evaluation Command (ATEC) Test Centers, the US Army Operational Test Command, and the US Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The abstract of the document is as follows:

This TOP provides guidance and procedures for acquiring dynamic transient mechanical and thermal data (shock, vibration, displacement, strain, acoustics, pressure, and temperature) of launchers, associated ground equipment (i.e., missile loaders, control stations, and generators), and the launch area during stationary firings of ground launched rockets and missiles. Guidance is provided for the appropriate properties, installation, and use of transducers, wiring, signal conditioning, signal filtering, and digital data acquisition systems. Procedures for measurement system validation and "end-to-end" calibrations (mechanical and electrical) are also provided.

2. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to US Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, MD 21005-5001. Technical information may be obtained from the preparing activity: US Army White Sands Missile Range, TEDT-WSV, White Sands Missile Range, NM 88002-5178. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.