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TO
Distribution

DATE
24 January, 2000

REFERENCES:
Vibration Test Plan (App. C)
ADF Task Order # 516
SDL T.O. # 99-1

SUBJECT

Technology Demonstrator Convertor (TDC) Stirling Engine. Prototype Unit. Vibration Test Report.

SUMMARY

On November 29 - December 2, 1999, vibration tests were conducted on the TDC Stirling Engine Prototype, at the NASA Glenn Research Center Structural Dynamics Lab (SDL). Testing was performed in accordance with the requirements of the "Vibration Test Plan to Characterize the TDC Stirling Engine for Future Technology Development".

The objective of the vibration tests was to evaluate structural integrity of the TDC Stirling Engine Prototype while being subjected to either Random or Sinusoidal Vibration Excitation. Based on visual inspections and vibration and process parameter measurements, the Prototype maintained structural integrity and functionality during and at the conclusion of the vibration exposures.

A tabular summary of the vibration tests performed is shown in Table 1, pages 3,4 of this report. A narrative summary of test events begins on page 2.

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On November 29 - December 2, 1999, vibration tests were conducted on the TDC Stirling Engine Prototype. Testing was performed in accordance with the requirements of the "Vibration Test Plan to Characterize the TDC Stirling Engine for Future Technology Development" (see appendix C).
The test article was classified as Prototype hardware.
The vibration tests were conducted at the NASA Glenn Research Center Structural Dynamics Laboratory (SDL). Figure 1 shows vibration test schematic.
Vibration test setups and sensor locations are shown in the photographs of Figures 2 through 4.
Vibration input and structural dynamic responses during the vibration exposures were measured with accelerometers and strain gauges.12 charge accelerometers were adhered on the exterior of the Stirling Engine prototype and its mounting fixture. The Stirling Engine prototype has been mounted in the vibration fixture with 8 Force Sensing Socket Head Cap Screws #10-24. The vibration fixture has been mounted on the SDL 72 x 60 inch slip table (3/8 socket head cap screws torqued to 240 in-lbs) driven by the C-210 vibration exciter.
A microphone, mounted near the Stirling Engine prototype, measured noise during the vibration exposures. Also during the test the Engine process parameters were monitored with the Project supplied sensors. These parameters were pressure inside the engine, heater voltage and current, alternator voltage and current. Their signals were not recorded by the Vibration Controller, (see report SDL-TR 99-37-DATA).
The vibration input was controlled using the arithmetic average of the output from the two control accelerometers located on the vibration fixture, as shown in the photographs.
The vibration requirements were specified in the project provided test plan, Vibration Test Plan to Characterize the TDC Stirling Engine for Future Technology Development. The vibration specifications for the test are shown in Figures 5,6,7.
Table 1 presents the sequence of the vibration tests. Testing began in the Lateral, X axis, was continued in the Axial, Y axis, and than concluded in the Lateral axis.
Visual inspections of the mounting fasteners and exterior of the Engine prototype were made after each test exposure. These inspections revealed no anomalies. The Engine maintained functionality during and after vibration exposures.
The specified vibration excitations were applied within the required tolerances. Vibration input and response measurements, in the form of Acceleration Spectral Density (g^2/Hz) vs. Frequency (Hz) plots for Random excitation, and in the form of Acceleration (g) vs. Frequency (Hz) plots for Sinusoidal excitation, are presented in Appendix A. Recorded data from the accelerometer measurements are stored at the SDL on DAT tape and will be archived for up to one year after the test completion.
Appendix B contains a list of the vibration test equipment and sensors used for these tests. All test equipment and sensors were verified to be within their current calibration period.
For additional information on the Technology Demonstrator Convertor (TDC) Stirling Engine, contact Jeff Schreiber/5490 [ph. (216) 433-6144]. Questions regarding the vibration tests or this report may be directed to Sergey Samorezov/ADF, [ph. [(216) 977-0354].

Table 1

Test Summary for the Technology Demonstrator Convertor (TDC) Stirling Engine Vibration Tests

NOTE: This table presents the sequence in which tests were conducted. **Test Run #'s** are designations by SDL personnel for test run identification on data plots. Test Run **Numbers** in **BOLD** are those conducted with the test article.

Test Date	Test Run #	Test Axis	Test Description	Comments
11/29/99	11	Y, axial	0.5 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	Empty Fixture Test
	12	Y, axial	12.3 Grms Random, 20-2000 Hz, FA+3dB, JPL D-15517, 1 min	Empty Fixture Test
	13	Y, axial	6.8 Grms Random, 20-2000 Hz, modified NASA-STD-7001, 1 min	Empty Fixture Test
	14	X, lateral	0.5 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	Empty Fixture Test
	15	X, lateral	12.3 Grms Random, 20-2000 Hz, FA+3dB, JPL D-15517, 1 min	Empty Fixture Test
	16	X, lateral	6.8 Grms Random, 20-2000 Hz, modified NASA-STD-7001, 1 min	Empty Fixture Test
11/30/99	**17**	**X, lateral**	**.25G 5Hz Sinusoidal Excitation 5 seconds duration**	**Calibration Run**
	18	**X, lateral**	**0.25 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 02 sec**	**PSD Abort @ 1420Hz**
	19	**X, lateral**	**0.25 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 05 sec**	**PSD Abort @ 1649Hz**
12/1/99	**20**	**X, lateral**	**0.25 G Sine Sweep, 2000-5 Hz, 4 Octaves per minute, 2 min 10 sec**	**No Anomalies**
	21	**X, lateral**	**6.8 Grms Random, 20-2000 Hz, modified NASA-STD-7001, 1 min**	**No Anomalies**
	22	**X, lateral**	**0.25 G Sine Sweep, 2000-5 Hz, 4 Octaves per minute, 2 min 10 sec**	**No Anomalies**
	23	**X, lateral**	**0.375 G Sine Sweep, 2000-5 Hz, 4 Octaves per minute, 2 min 10 sec**	**No Anomalies**
	24	**X, lateral**	**0.5 G Sine Sweep, 2000-5 Hz, 4 Octaves per minute, 2 min 10 sec**	**No Anomalies**

Test Date	Test Run #	Test Axis	Test Description	Comments
	25	X, lateral	0.5 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
12/1/99	26	Y, axial	0.25 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
	27	Y, axial	6.8 Grms Random, 20-2000 Hz, modified NASA-STD-7001, 1 min	No Anomalies
	28	Y, axial	0.25 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
	29	Y, axial	0.375 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
	30	Y, axial	0.5 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
	31	Y, axial	0.5 G Sine Sweep, 2000-5 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
12/2/99	32	Y, axial	0.25 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
	33	Y, axial	Random, JPL D-15517, 20-2000 Hz, FA-3dB, 6.2 Grms, 1 min FA, 8.7 Grms, 1 min FA+3dB, 12.3 Grms, 3 min (FA=Flight Acceptance)	No Anomalies
	34	Y, axial	0.25 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
	35	X, lateral	0.25 G Sine Sweep, 5-2000 Hz, 4 Octaves per minute, 2 min 05 sec	PSD Abort @ 1638Hz
	36	X, lateral	0.25 G Sine Sweep, 2000-5 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies
	37	X, lateral	Random, JPL D-15517, 20-2000 Hz, FA-3dB, 6.2 Grms, 1 min FA, 8.7 Grms, 1 min FA+3dB, 12.3 Grms, 3 min (FA=Flight Acceptance)	No Anomalies
	38	X, lateral	0.25 G Sine Sweep, 2000-5 Hz, 4 Octaves per minute, 2 min 10 sec	No Anomalies

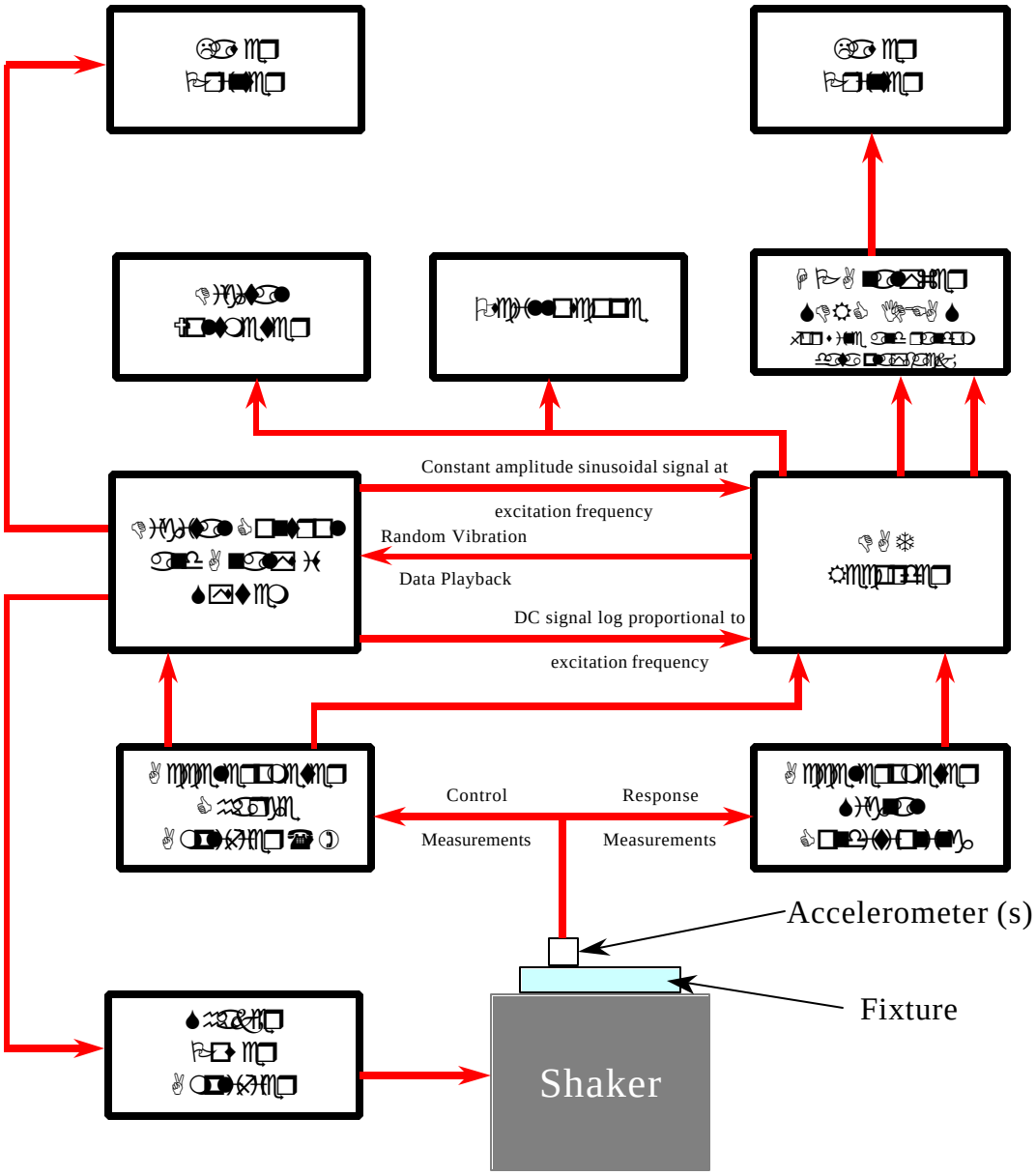

Constant amplitude sinusoidal signal at
excitation frequency
Random Vibration
Data Playback
DC signal log proportional to
excitation frequency
Control
Measurements
Response
Measurements
Accelerometer (s)
Fixture
Shaker

Figure 1. Vibration Test Instrumentation Schematic

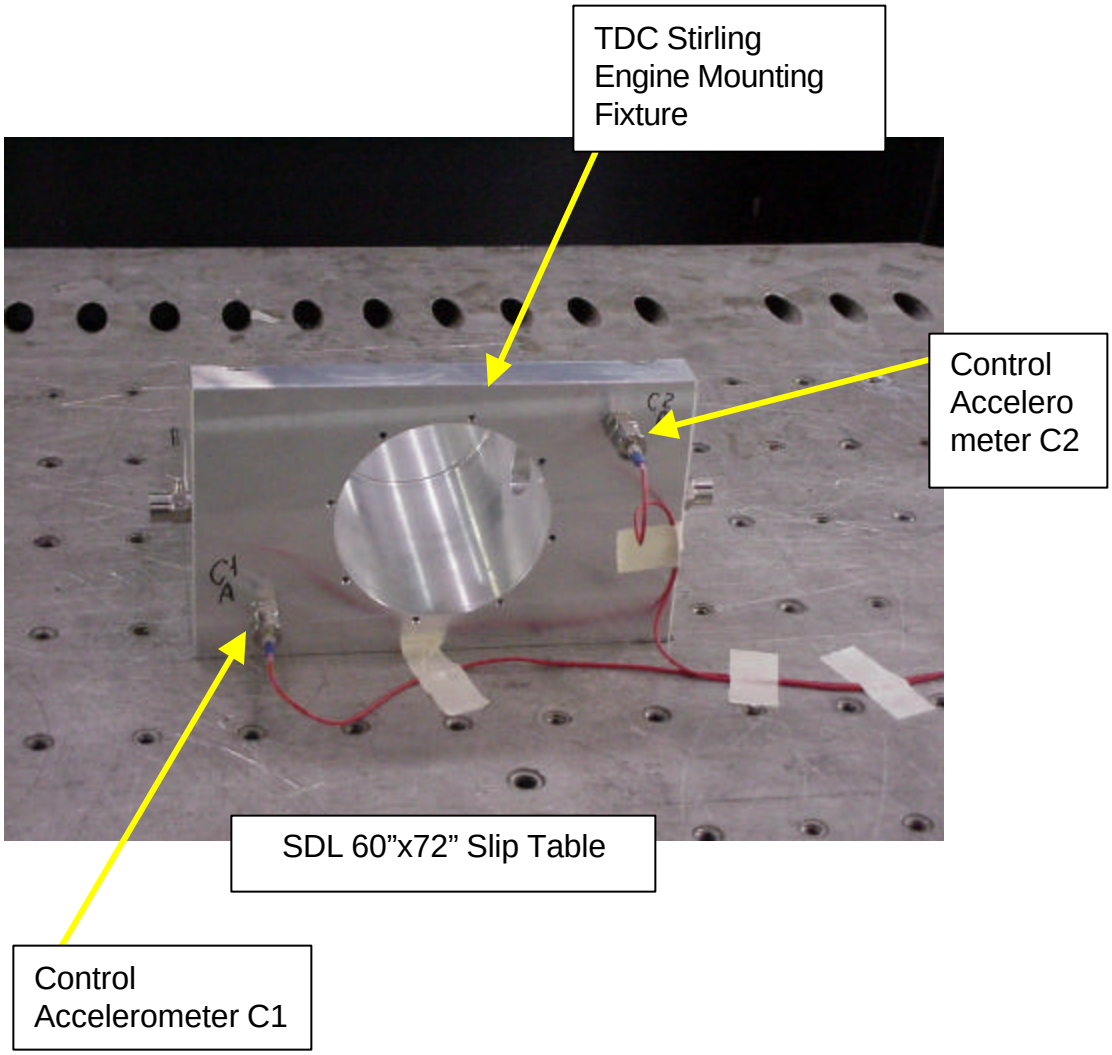
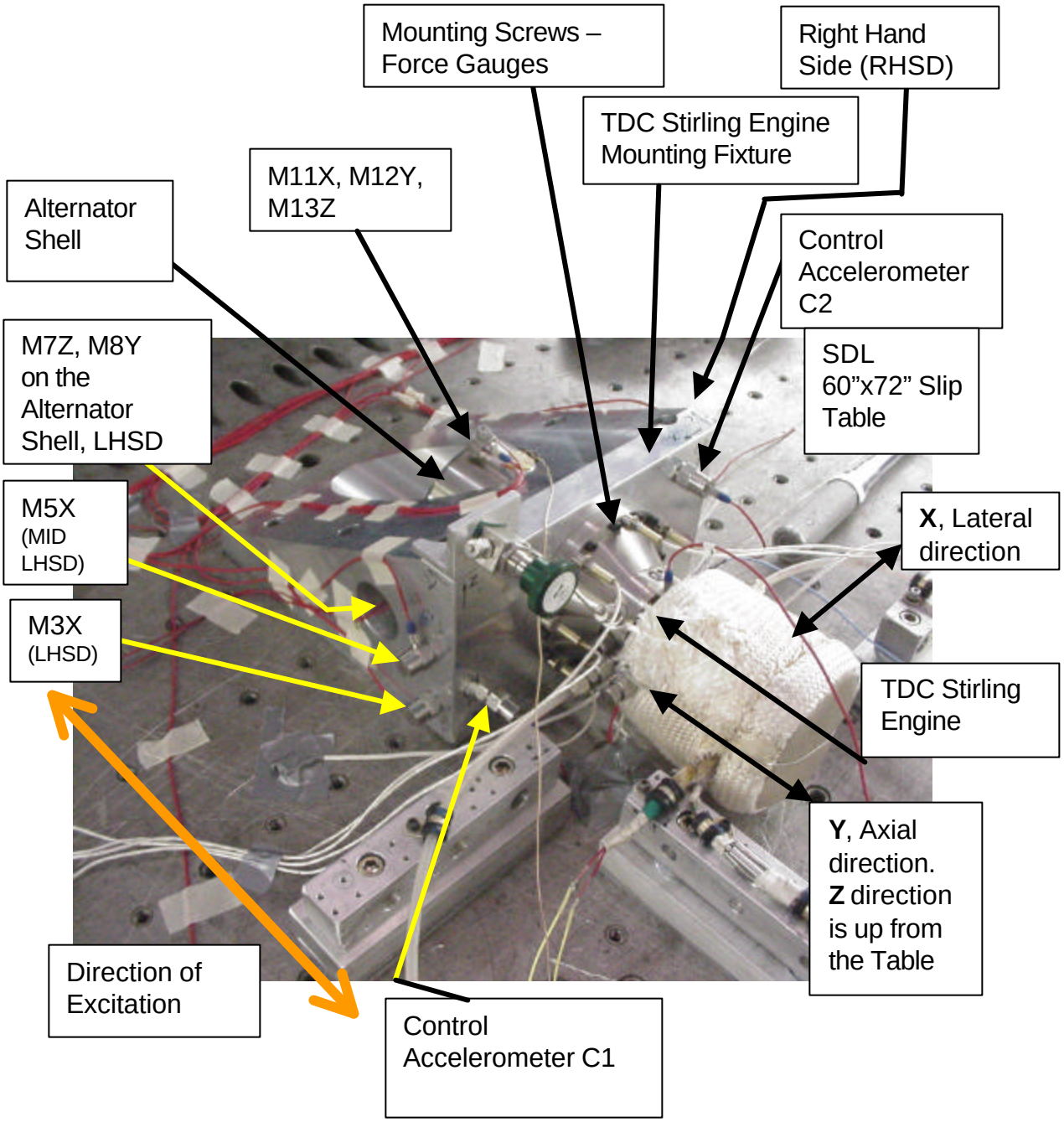


Figure 2. TDC Stirling Engine Mounting Fixture vibration test setup.

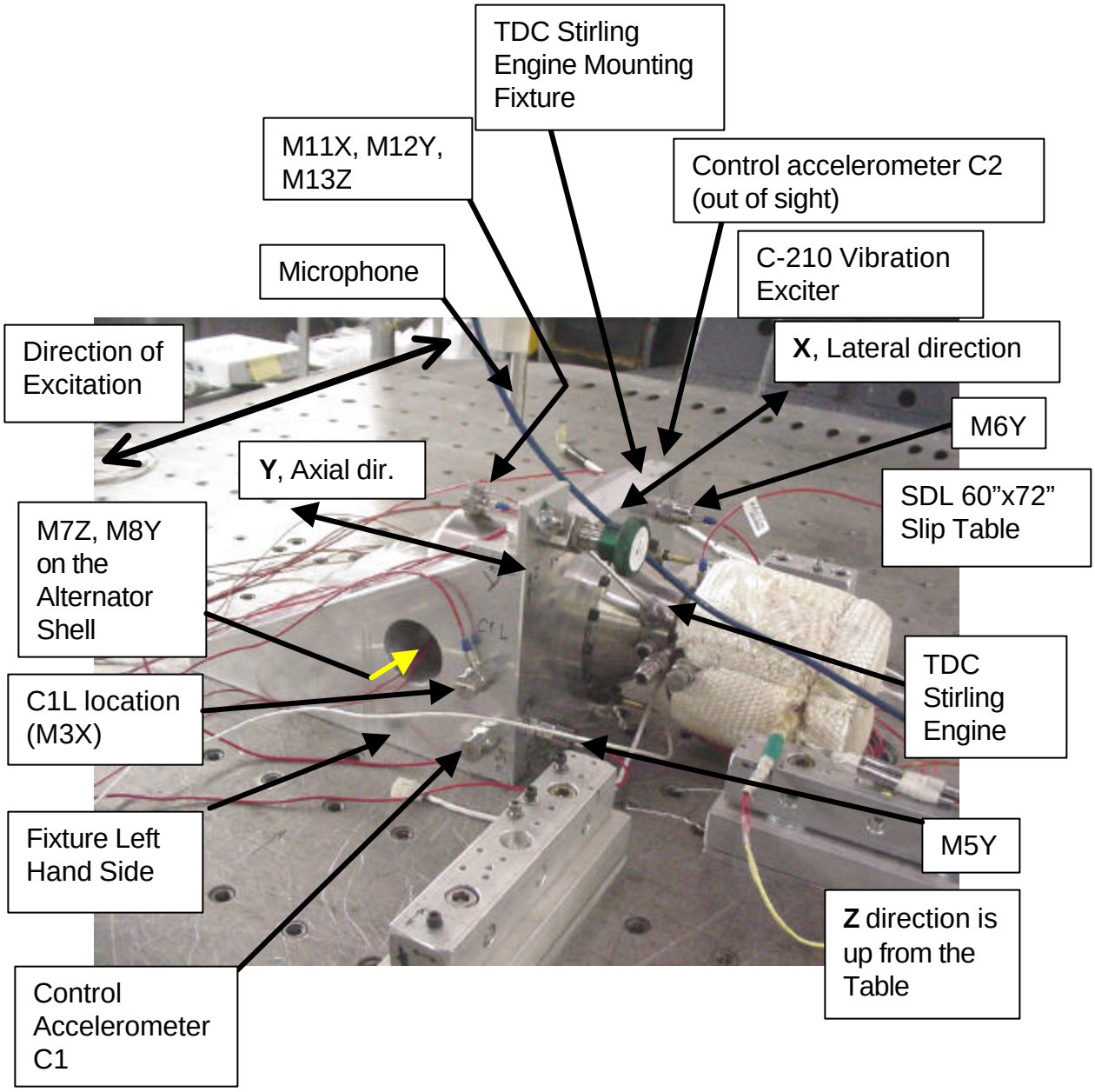


M4X and M6X accelerometers are located on the fixture Right Hand Side, M4X-top, M6X-middle.

M9Z and M10Y accelerometers are located on the Alternator Shell, Right Hand Side, opposite to the M7Z, M8Y.

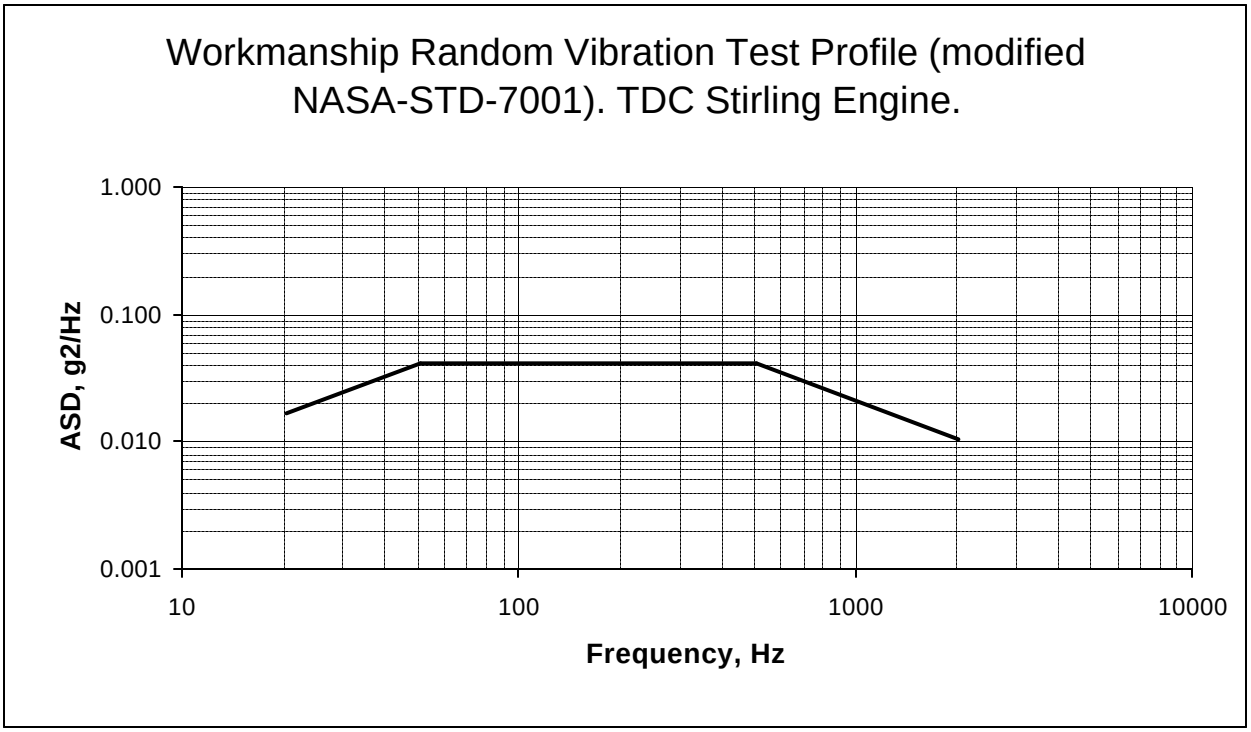
Acceleration data from the M13Z location, Force Gauges data and Process Parameters were not recorded by the vibration controller. See supplemental report SDL-TR 99-37-DATA for more info.

Figure 3. TDC Stirling Engine Axial Excitation test setup.



C2L location accelerometer is on the Right Hand Side of the Fixture, opposite to C1L location. M9Z and M10Y accelerometers are located on the Alternator Shell, Right Hand Side, opposite to the M7Z, M8Y.
Acceleration data from the M13Z location, Force Gauges data and Process Parameters were not recorded by the vibration controller. See supplemental report SDL-TR 99-37-DATA for more info.

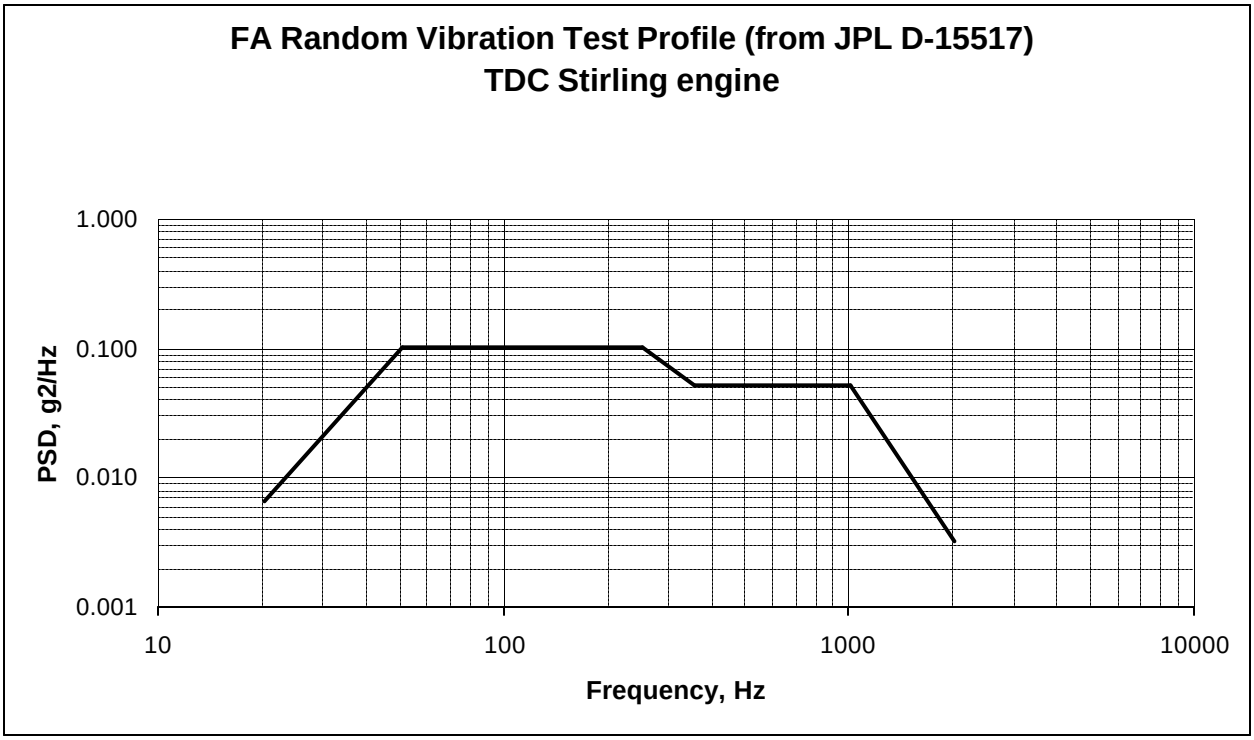
Figure 4. TDC Stirling Engine Lateral Excitation test setup.



Frequency, Hz			Test Level		Slope	
	20		0.016	g2/Hz		
20	to	50			3.01	dB/Octave
	50		0.04	g2/Hz		
50	to	500	0.04	g2/Hz		
	500		0.04	g2/Hz		
500	to	2000			-3.01	dB/Octave
	2000		0.01	g2/Hz		
	Duration		Overall level			
	60	seconds	6.82	Grms		

TOLERANCE AND ABORT CONDITIONS	
Overall Grms Alarm	+/- 1 dB
Overall Grms Abort	+/- 2 dB
Spectral Density Alarm	+/- 2 dB
Spectral Density Abort	+/- 3 dB
Spectral Bandwidth to Abort	25 Hz

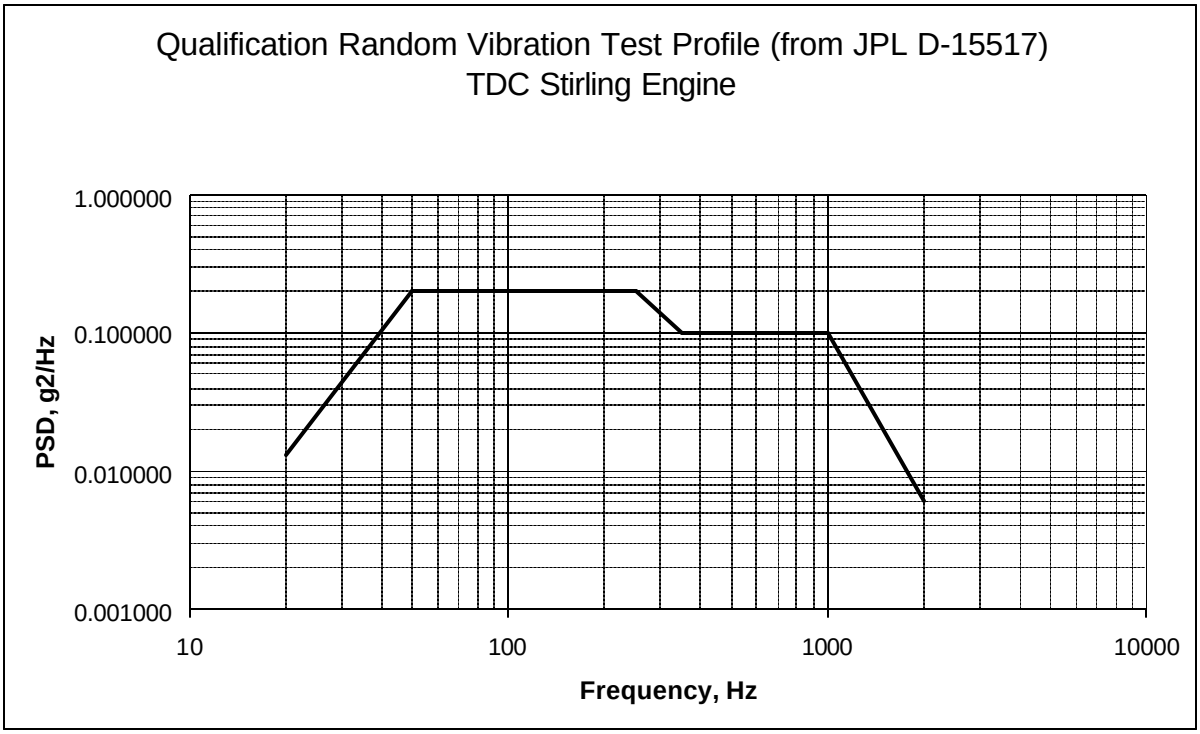
Figure 5. Workmanship Random Test Profile



Frequency, Hz			Test Level		Slope	
	20		0.0064	g2/Hz		
20	to	50			9.03	dB/Octave
	50		0.1	g2/Hz		
50	to	250	0.1	g2/Hz		
	250		0.1	g2/Hz		
250	to	350			-6.20	dB/Octave
	350		0.05	g2/Hz		
350	to	1000	0.05	g2/Hz		
	1000		0.05	g2/Hz		
1000	to	2000			-12.08	dB/Octave
	2000		0.0031	g2/Hz		
	Duration		Overall level			
	60 seconds		8.68 Grms			
Test level FA-3dB		60 seconds	6.2 Grms			

TOLERANCE AND ABORT CONDITIONS	
Overall Grms Alarm	+/- 1 dB
Overall Grms Abort	+/- 2 dB
Spectral Density Alarm	+/- 2 dB
Spectral Density Abort	+/- 3 dB
Spectral Bandwidth to Abort	25 Hz

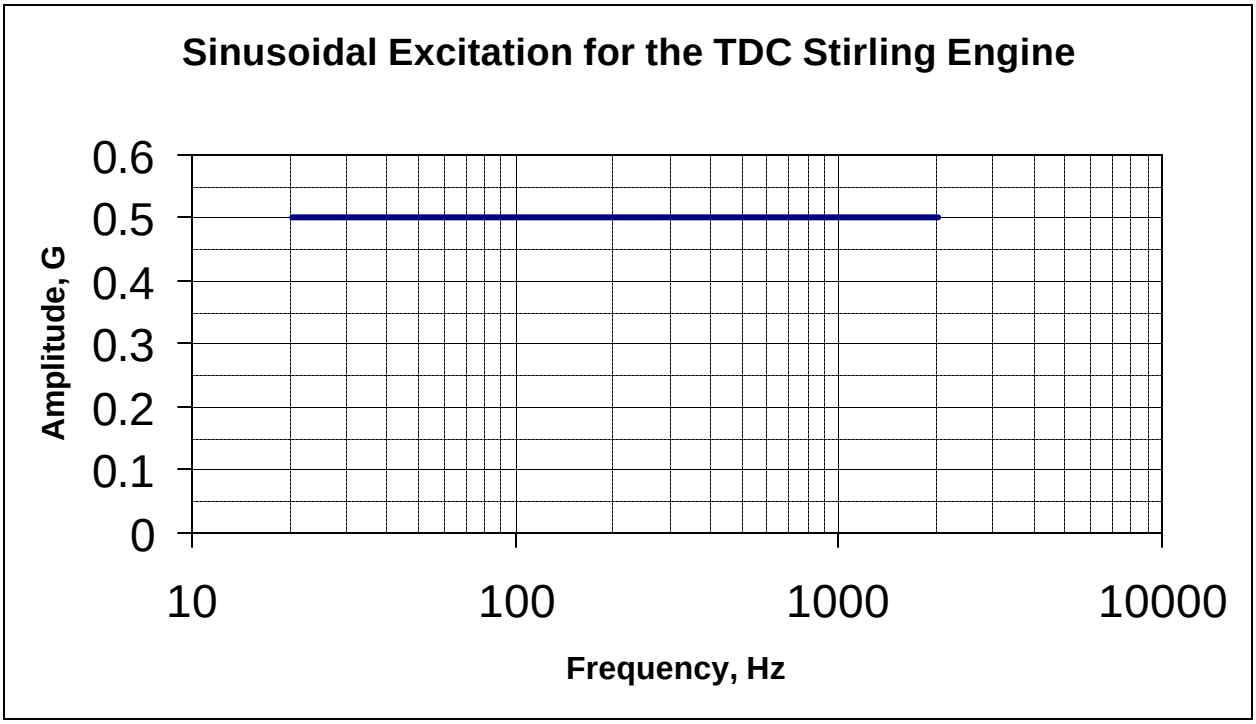
Figure 6. Flight Acceptance (FA) Random Test Profile.



Frequency, Hz			Test Level		Slope	
	20		0.0128	g2/Hz		
20	to	50			9.03	dB/Octave
	50		0.2	g2/Hz		
50	to	250	0.2	g2/Hz		
	250		0.2	g2/Hz		
250	to	350			-6.20	dB/Octave
	350		0.1	g2/Hz		
350	to	1000	0.1	g2/Hz		
	1000		0.1	g2/Hz		
1000	to	2000			-12.08	dB/Octave
	2000		0.0062	g2/Hz		
	Duration		Overall level			
	180	seconds	12.27	Grms		

TOLERANCE AND ABORT CONDITIONS	
Overall Grms Alarm	+/- 1 dB
Overall Grms Abort	+/- 2 dB
Spectral Density Alarm	+/- 2 dB
Spectral Density Abort	+/- 3 dB
Spectral Bandwidth to Abort	25 Hz

Figure 7. Qualification Random Test Profile.



Amplitude	Frequency Range	Sweep Rate	Duration
.5G	5-2000 Hz	4 Oct/min	2 min 10 sec
.375G	5-2000 Hz	4 Oct/min	2 min 10 sec
.25G	5-2000 Hz	4 Oct/min	2 min 10 sec

TOLERANCE AND ABORT CONDITIONS	
Spectral Density Tolerance	+/- 2 dB
Spectral Density Abort	+/- 4 dB

50G limit used during the tests.

Figure 8. Sinusoidal Excitation Test Profile

List of Appendices

Appendix A TDC Stirling Engine Vibration Input and Response Data.

Appendix B Test Equipment and Sensor List.

Appendix C Vibration Test Plan to Characterize the TDC Stirling Engine for Future Technology Development.

APPENDIX A

TDC Stirling Engine Vibration Input and Response Data

Random Vibration Excitation

Axial		Lateral	
Test Run #	Measurement	Test Run #	Measurement
12, 13, 27	Control signals: measured C1, C2, computed (C1+C2)/2	15, 16, 21	Control signals: measured C1, C2, computed (C1+C2)/2
	Response signals: M3X through M11X, accelerometers as shown on Figures 2-4.		Response signals: M3X through M11X, accelerometers as shown on Figures 2-4.
33	Control signals: measured C1, C2, computed (C1+C2)/2	37	Control signals: measured C1, C2, computed (C1+C2)/2
	Response signals: M3X through M12Y, accelerometers as shown on Figures 2-4.		Response signals: M3X through M12Y, accelerometers as shown on Figures 2-4.

APPENDIX A (cont.)

TDC Stirling Engine Vibration Input and Response Data

Sinusoidal Vibration Excitation

Axial		Lateral	
Test Run #	Measurement	Test Run #	Measurement
11, 26, 28, 29, 30, 31, 32	Control signals: measured C1, C2, computed (C1+C2)/2	14, 20, 22, 23, 24, 25	Control signals: measured C1, C2, computed (C1+C2)/2
	Response signals: M3X through M11X, accelerometers as shown on Figures 2-4.		Response signals: M3X through M11X, accelerometers as shown on Figures 2-4.
34	Control signals: measured C1, C2, computed (C1+C2)/2	35, 36, 38	Control signals: measured C1, C2, computed (C1+C2)/2
	Response signals: M3X through M12Y, accelerometers as shown on Figures 2-4.		Response signals: M3X through M12Y, accelerometers as shown on Figures 2-4.

APPENDIX B

Test Equipment and Sensor List.

Vibration Test Equipment

Equipment/Instrumentation	Manufacturer	Model
1. Excitation in Z, X axes - Vibration Shaker	MB Dynamics	C210
2. Power Amplifier	Ling Electronics	DMA-48BDR/C60,C210/48
3. Control & Analysis System Control Processor	 GEN RAD Sun	 2552B SPARC5
4. Signal Conditioning Charge Amplifiers	 Unholtz-Dickie	 D22 Series
5. Data Record & Output DAT Tape Recorder Printer	 Sony Hewlett Packard	 PC216Ax LaserJet 6MP

APPENDIX B (cont.)

Accelerometer List

Measurement	Type	Serial Number	Calibration Date	Location
C1	2271AM20	CQ24	23 Mar 99	Control 1 (see Fig. 2-4)
C2	2271AM20	CU05	10 Oct 99	Control 2 (see Fig. 2-4)
M3x	2271AM20	CD79	10 Oct 99	See Figures 2-4
M4x	2271AM20	CP96	10 Oct 99	See Figures 2-4
M5y	2271AM20	AM4M3	17 Jun 99	See Figures 2-4
M6y	2271AM20	AK1F3	17 Jun 99	See Figures 2-4
M7z	2222C	22156	24 Jun 99	See Figures 2-4
M8y	2222C	22005	24 Jun 99	See Figures 2-4
M9z	2222C	KD30	22 Jan 99	See Figures 2-4
M10y	2222C	HU55	22 Jan 99	See Figures 2-4
M11x	2220D	DA86	14 Jan 99	See Figures 2-4
M12y	2226	MK57	14 Jan 99	See Figures 2-4
M13z	2220D	DA84	14 Jan 99	See Figures 2-4

All accelerometers are manufactured by Endevco.
Calibration is valid for one year after Calibration Date.

APPENDIX B (cont.)

Charge Amplifier List

All Charge Amplifiers are Unholtz-Dikie 22 Series

Measurement	Serial Number	Calibration Date
C1	810208	24 Feb 99
C2	810210	24 Feb 99
M3x	810213	23 Feb 99
M4x	810209	19 Feb 99
M5y	809973	19 Feb 99
M6y	810218	23 Feb 99
M7z	809974	22 Feb 99
M8y	810216	23 Feb 99
M9z	809971	13 Apr 99
M10y	809970	22 Feb 99
M11x	810212	22 Feb 99
M12y	809953	13 Apr 99
M13z	796149	13 Jul 99

APPENDIX C

Vibration Test Plan
To Characterize the Technology Demonstrator Convertor (TDC) Stirling Engine
For Future Technology Development