UTEC CORPORATION, / R&D LABORATORY
8500 SE JAYHAWK DR, RIVERTON, KANSAS 66770 · (620) 783-1361 · FAX (620) 783-1360
EMAIL: john@utec-corp.com

Project: **Test N2 2"x14" Steel Bodied Generators for Heat Transfer and Maximum Single-Nozzle Jet Pressure Generated to Evaluate Possible Stress on Nearby External Structural Components Using the Boeing Test Stand.**

Conducted For: **N_2 Towers Inc.**
175 Lahr Drive
Belleville, ON, Canada K8N 5S2

Requested By: **Mr. Adam Richardson**
Vice President of Business Development

Report No.: **N2T2013-0314-04**

Written By: **John Bowles**
Project Chemist

Date: **March 22, 2013**

UTEC CORPORATION, / R&D LABORATORY
8500 SE JAYHAWK DR, RIVERTON, KANSAS 66770 · (620) 783-1361 · FAX (620) 783-1360
EMAIL: john@utec-corp.com

Generator Pressure Screening Tests

Objective:

Test N2 2”x14” steel bodied generators for heat transfer and maximum single-nozzle jet pressure generated to evaluate possible stress on nearby external structural components using the Boeing test stand.

Conclusions:

Seven steel-bodied N2 Towers 2”x14” inch fire suppression gas generators were assembled at the UTEC test facility. There were several different test configurations. A test fixture was built as per drawings supplied by engineers from The Boeing Company seen in Figures 2 and 3. The test fixture consisted of a pair of steel brackets with which to mount the N2 generator and a transfer plate of aluminum backed by a wood support at a fixed distance from one of the nozzled faces of the generator. Twenty thermocouples were arranged on the generator surface, end caps, mounting bracket and transfer plate. A pressure transducer was also installed in the plate backer and located directly in line with one of the nozzles to obtain the jet pressure during activation. The transfer plate assembly was set at three different separation distances to obtain a distance based differential.

Six of the seven tests were conducted in the presence of two Environmental Control engineers from The Boeing Company. The tests were conducted inside a steel and Lexan test chamber (Figure 1, Photograph 1). Seven separate tests were conducted in the test series: one test with the transfer plate assembly set 3 inches from the generator, one at 2 inches, and five tests at a 1 inch separation.

The gasses released from an N2 Generator when activated passed through several layers of filter material before exiting the filter material into a plenum space between the filter and the generator body. The gasses then had to build enough pressure to rupture the 0.004 inch thick aluminum burst foil, located along the inner wall of the body. Not all of the nozzles would succeed in breaking the burst foil. An average of 70% of the burst foil was ruptured at the generator nozzles, ranging +/- 20%. The breakage pattern was extremely random, thus it was necessary to manually break the burst foil under the pressure transducer(s). This random breakage and differing breakage ratio would have had an effect on the jet pressure released by any chosen nozzle. Defining a maximum jet pressure to be found would require a number of repetitions, and most effectively utilizing multiple sensors. The minimum jet pressure would be zero for a nozzle where the burst foil remained intact. Tests have been scheduled to study the performance of 0.002 inch thick burst foil to increase the break percentage and reduce the variance of inter-hole pressures.

The jet pressure was recorded at approximately 2000 samples per second. Two different pressure transducers were used in the seven tests; a 100 psi transducer and a 15 psi transducer. The estimated maximum jet pressure was 50 psi; therefore the first tests utilized the 100 psi transducer. The aluminum “burst foil” was punctured in the nozzle directly under the transducer, to ensure a reading. The results recorded were far lower than expected, so an existing 15 psi transducer was threaded into place and the test was repeated. The following test exceeded the maximum capacity of the sensor, “clipping” the waveform.

The pressure transducer was exchanged again for the 100 psi transducer. Unfortunately, immediately after the test, an incorrect empty 5 psi channel from the data acquisition device was reviewed and the pressure was incorrectly reported as 2.8 psi. (Chart 5) The “crosstalk” showing on open channels allowed this mistake to happen. Later that evening, when importing the pressure test data into a spreadsheet, this problem was discovered. Resistor shunt caps were constructed and placed on any unused channels in subsequent tests, squelching any crosstalk signals for those channels. The actual recorded pressure was 52 psi. As a result of the inconsistent data, it was decided to use both sensors simultaneously on all of the subsequent tests.

Both the 100 psi transducer and the 15 psi transducer were threaded directly into the test fixture. The pressures recorded were not equal, as to be expected based on the varied foil breakage. The 100 psi transducer continued to show a zero shift of 7-10 psi after the pressure subsided. It was considered that this might have been caused by elevated temperatures of the diaphragm inside the pressure transducer. A tee fitting was introduced in between the backing board and the sensor to help alleviate this phenomenon. The zero shift was reduced slightly with this arrangement on the last two tests.

The temperature recorders sampled the data 8 times per second for all 20 channels. It was found that the gas jet temperature and heat transfer plate temperature changed more rapidly than was being recorded. The thermocouples on the generator body, however, could have been read once per second without losing significant resolution of the waveform.

The heat transfer to the transfer plate was rapid during activation and the temperature fell rapidly as well. Only one thermocouple from one test showed a temperature in excess of 200°C. The temperature recorded at the transfer plate generally ranged from 100-150°C. Within two seconds, the temperatures recorded dropped to 50-75°C in each test, most reaching 40° within 4 seconds.

The generator body, however, required several minutes to reach maximum temperature. After the first four tests had been conducted, it was found that the temperature recorders were recording a maximum of 200°C. The programming was changed, allowing a maximum of 400°C, which was not reached in any of the subsequent tests. The maximum temperature recorded was 317°C for the thermocouple attached to the center of the generator body in the center of the rows of nozzles. The highest temperature attained on the end caps was 185°C, and the highest temperature recorded on the mounting bracket was 74°C.

The test setup as seen in the photographs was not the most efficient in terms of the oxygen level reached, as opposed to the amount of nitrogen that exited the pressure vent. As can be seen in Photograph 7, the two sets of nozzles were pointed at the lower front corner of the test chamber and the other at the plywood backing. The gas jets striking the plywood backing would have been diverted roughly towards the top front corner and the lower rear corner: where the vent was located. Thus, some of the nitrogen would have been expelled directly out the vent instead of pushing the chamber air out, having been replaced by nitrogen. The thermal transfer and jet pressures took precedent in this test series. For efficiency tests in the future, the fixture will be rotated 90° counter clockwise (as seen from an igniter end view) to place the backing plate directly between the generator and the opening of the door. This should generate the optimum results, displacing more of the chamber air, with a higher portion of nitrogen gas inside the test chamber.

Discussion:

Mr. Adam Richardson of N2 Towers, Inc. requested the UTEC Laboratory to conduct a series of tests designed by engineers at The Boeing Company to determine the viability of using the 2”x14” N2 Generator for fire suppression in certain spaces of aircraft. The two areas of most interest were the heat transferred from the gas jets during activation on surrounding materials and the gas jet pressure at various close separation distances. The separation distances of interest ranged from 1 to 3 inches between the generator body and the material.

All of the tests were conducted inside a ~14 cubic foot test chamber (Figure 1). The test chamber was constructed of a 1.5” angle iron frame and ¼” thick Lexan panels. The inside dimensions of the test chamber were 29”x 28.5”x 29” with one end (away from the camera) hinged at the top to open. During testing, the door is not latched tight; it is allowed to open to relieve the pressure from gasses generated during activation. Chains were used to limit the size of the vent opening to in turn limit the exchange of external atmospheric air. Foam weather stripping was placed on the face of the frame to seal the door when closed. The bottom of the door was allowed to open 5”, this gave a vent area of just over 285 square inches. Bungee cords were used to allow the door to open, venting the pressure during the pressure pulse, and then close again as the pressure subsided, to minimize the exchange of external atmospheric air. This permitted the nitrogen released from the generator to push the atmospheric gasses out of the chamber and resulting in the minimum oxygen level and maximum carbon monoxide levels for this test setup.

To simulate the surrounding material, 0.020” thickness annealed 1100 series aluminum sheeting was chosen, due to the material’s high heat transfer rate, and therefore, relatively quick temperature response time. The aluminum sheet was not strong enough to sustain the force of the gas jets during activation without deformation. A ¾” thick plywood backing plate was designed to sustain the force and allow the aluminum sheet to retain shape during the testing. (Figures 2 and 3 and Photographs 5-8) The backing plate was 14” long and 5 ½” wide, with a 1” wide strip of the same material along the long edges. A bending brake was used to form the aluminum plate to set inside the recess and extend over the side strips, the idea was to contain some of the hot gasses, allowing for more thermal transfer, as well as an attachment point that would not impede the data collection. To situate the thermocouples, holes were bored through the backing plate and a small hole punched in the aluminum transfer plate. The thermocouples were inserted through the backing plate and the fine end placed in contact with the aluminum plate to facilitate recording of the heat transfer from the gas jets during activation.

The generator body mounted thermocouples were adhered directly to the steel body using ½" wide 0.0025" thick heat resistant Kapton tape utilizing a silicone adhesive rated for 260°C (500°F) McMaster-Carr part # 7648A713. The body mounted thermocouple wires were routed around the nozzles, so that they would not be dislocated during activation.

Pressure transducers were threaded into the plywood backing plate directly in line with one of the generator nozzles. The aluminum burst foil was removed from the proper nozzle to ensure a jet pressure reading. The original estimate by Mr. George Goetz on behalf of N2 Towers for the jet pressure that was to be seen at a 1" separation distance was approximately 50 psi. Therefore, a 100 psi pressure transducer was chosen to record the jet pressure for this set of tests. After the first two tests gave results below 10 psi, the 100 psi transducer was exchanged for a 15 psi transducer; the last three tests utilized both transducers.

Instrumentation and Experimental Procedure:

The test set-up is shown in the attached figures 2 and 3 photographs 5-8, showing the relative positioning of the various pieces of test equipment and hardware utilized for the test. The following list describes the various pieces of monitoring equipment used in the test:

Pressure Monitor:

The jet pressure monitoring was recorded using an Omega PX309-15 or a PX309-100 Pressure Sensor. The signal was then processed by an Omega OMB-DAQ-3005 PC-based 1 MHz USB data acquisition system, transferring the data directly to a laptop computer.

Noise Level Meter:

The maximum sound level was recorded using a Quest Technologies 2100 sound level meter set to a range of 70-140 dB, and a "C" weighting method and a fast response time.

Temperature Recorder:

The temperature was recorded using twenty 30 gauge Type K thermocouples attached to two Omega 8800 12 channel data recorders recording at 8 samples/second each saving the data to a 2 GB compact flash drive.

O_2 and CO Gas Monitor:

The monitoring of the levels of oxygen and carbon monoxide inside the test chamber was accomplished using a Q-RAE multi-gas monitor (Photograph

3). This monitor had the capability of measuring oxygen levels in the 0-30% range (0.1% accuracy) and carbon monoxide in the 0-1500 ppm range (1 ppm accuracy). In the generator tests, the gas monitor was operated continuously throughout each test, using a 1 second sampling rate

Temperature/Pressure Test Method:

The following steps were used in the N2 Towers 2”x14” fire suppression generator tests conducted by the UTEC Laboratory in March 2013. These initial trials were conducted with the goal of measuring the Thermal transfer to external structural materials and the jet pressure load on external structural materials during activation of the N2 Towers 2”x14” generators, and the duration of the impulse. The same basic test method was used in each of the tests, though some of the tests omitted certain equipment.

1. The mounting bracket was set-up and equipped with all the required monitoring equipment, as necessary for the test being conducted.

2. The sound level meter was turned on and placed in the proper location as per the test, to measure the maximum noise level achieved. The meter was either situated two feet to the right (camera view) side, outside the test chamber, or inside the test chamber.

3. The two 12 channel temperature recorders were started to record the test (8 samples/second).

4. The gas analyzer was started to record the carbon monoxide level and the oxygen level in the test chamber (1 sample/second).

5. The video camera was started to record the test (30 frames/second).

6. The high speed video camera was started to record the test (300 frames/second).

7. The pressure monitoring system was activated manually to record 3 channels at 2000 samples/second.

8. The cameras were shut off soon after observations were made for each test.

9. The test chamber remained closed until each of the temperature zones was allowed to attain maximum temperature and began to cool. Also, the gas meter was monitored to assure that the CO level had attained the maximum level and had begun to recede before the test chamber was opened.

10. After the temperature of the slowest transfer point and CO level had attained the maximum point and begun to recede, the data recorders were turned off.

Table I:

Temperature/Pressure Test Description

The following list describes the various test set-ups used to evaluate the pressure and temperature differences arising from use of different separation distances between the generator body and the aluminum transfer plate. The thermocouples were placed as indicated on the drawings, except that those on the backing plate were placed in reverse order from left to right (Figures 2 and 3 and Photograph 6). Following the drawings: a row of thermocouples was placed on the generator body centered on one of the nozzle faces along the center row of nozzles with #1 at the igniter end just to the outside of the outermost center nozzle, #2 next to the center, and #3 towards the blank end placed as #1. A row of thermocouples was placed in a row centered on one of the blank faces 90° from those on the nozzle face. The placement of #4 is at the igniter end, #5 next to the center, and #6 at the blank end. Two thermocouples were placed on the igniter end cap with #7 placed towards the circumference and #8 along side the igniter connector. Two were also attached to the blank end cap with #9 along the circumference and #10 to the center. Thermocouple #11 was attached to the mounting bracket at the igniter end ~¾" below the contact between the bracket and the generator body.

The thermocouples attached to the heat transfer assembly were inserted through holes drilled through the plywood backing plate and into holes punched through the aluminum heat transfer panel. The tip of the 30 gauge thermocouple was placed in contact with the aluminum panel to record the heat transfer to the aluminum panel. The tips of the thermocouples were not affixed to the plate, therefore, during the impulse, the probe may have shown higher temperatures than the panel itself increased, but most should have settled back into contact with the plate when the gas jet force diminished. The thermocouples were placed in three rows, one centered above the middle row of nozzles (#15, #16, #17), one 1 ¼" "above" (#12, #13, #14) and one 1 ¼" "below" (#18, #19, #20). The outer sets were set 1" inside the center of the outer set of nozzles. A spacing thus was given of 8" between outer thermocouples and 2 ½" between outside rows. This placed the outer set of thermocouples (#12, #15, #18) at 3" from the blank end cap edge and (#14, #17, #20) at 3" from the igniter end edge.

Two ports were drilled and tapped ¼" NPT through the plywood backer plate and aluminum transfer panel for pressure transducers. The pressure transducers were threaded into the plywood from the outside and centered over a nozzle from the center row of the 2"x14" generator. The burst foil was punctured in the nozzle directly below the pressure transducer. When only one transducer was used, it was threaded into the hole towards the igniter end (Photograph 6). In each of the tests, the igniter end of the generator could be seen to the left-hand side of the video. In the last three tests, both the 15 psi and 100 psi transducers were used (Photograph 9). For the last two tests, the transducers were threaded into the side port of a ¼" NPT stainless steel tee, and a ¼" close nipple used to connect to the ports in the plywood backing plate

(Photograph 10). This was done to alleviate the possibility of the data collected being skewed by the hot gasses striking the sensor diaphragm.

The thermocouple wires were passed through two ½" diameter holes in the side of the test chamber. The pressure transducer(s) and the firing line were passed through a single 1" diameter hole in the side of the test chamber. After the first test, drilled and split rubber stoppers were used to lessen the free exchange with the outside atmosphere.

The ¼" ID tubing from the gas monitor was passed through a tight-fitting hole in the Lexan on the side of the test chamber. A small piece of wire was skewered through the end of the tubing inside the chamber to eliminate the possibility of the pressure pulse pushing the tubing out of the chamber.

Test #130304 - 00:

Adam Richardson and George Goetz from N2 Towers, Inc were present for the test.

The generator was placed in the brackets and the heat transfer assembly set to 3" from the generator body. The thermocouples (#1 - #14) were applied as stated above and the 100 psi transducer threaded into the test apparatus. The pressure recorded was 4.3 psi. As this was far lower than expected, it was decided to use the 15 psi transducer for the following test. The sound level meter was not used for this test. The maximum level of carbon monoxide recorded was 156.5 ppm and the minimum oxygen level reached was 12.1%.

Test #130305 - 01:

Adam Richardson and George Goetz from N2 Towers, Inc and Art Tutson and Laura Porres from Boeing Environmental Control Systems were present for the test.

The generator was placed in the brackets and the heat transfer assembly set to 2" from the generator body. The thermocouples (#1 - #20) were applied as stated above and the 15 psi transducer threaded into the test apparatus. The pressure recorded was 5.2 psi. The sound level meter was placed outside the test chamber 2 feet to the right (camera view) of the front right corner of the test chamber. The peak sound level recorded this test was 128.3dB. The maximum level of carbon monoxide recorded was 136.0 ppm and the minimum oxygen level reached was 12.7%.

Test #130305 - 02:

Adam Richardson and George Goetz from N2 Towers, Inc and Art Tutson and Laura Porres from Boeing Environmental Control Systems were present for the test.

The generator was placed in the brackets and the heat transfer assembly set to 1" from the generator body. The thermocouples (#1 - #20) were applied as stated above and the 15 psi transducer threaded into the test apparatus. The pressure recorded exceeded the capacity of the transducer and the waveform was clipped at 16.7 psi. As this exceeded the capacity of the transducer the 100 psi transducer was used for the following test. The sound level meter was placed inside the test chamber at the front right (camera view) of the test chamber. Upon activation, the gas jets from the generator flipped the sound level meter inside the test chamber, therefore it was attached to the test stand in subsequent tests. The peak sound level recorded this test was 138.0dB. The maximum level of carbon monoxide recorded was 166.3 ppm and the minimum oxygen level reached was 13.3%.

Test #130305 - 03:

Adam Richardson and George Goetz from N2 Towers, Inc and Art Tutson and Laura Porres from Boeing Environmental Control Systems were present for the test.

The generator was placed in the brackets and the heat transfer assembly set to 1" from the generator body. The thermocouples (#1 - #20) were applied as stated above and the 100 psi transducer threaded into the test apparatus. The pressure recorded was 52.1 psi. The 100 psi transducer was used for this test on channel 04. The crosstalk on channel 00 (calibrated for a 5 psi transducer) was mistakenly reported immediately after the test. This crosstalk amounted to 2.8 psi as can be seen in Chart 5.

The sound level meter was placed inside the test chamber attached to the front right (camera view) of the test stand. The peak sound level recorded this test was 138.2dB. The maximum level of carbon monoxide recorded was 137.7 ppm and the minimum oxygen level reached was 12.8%.

Test #130306 - 04:

Adam Richardson and George Goetz from N2 Towers, Inc and Art Tutson and Laura Porres from Boeing Environmental Control Systems were present for the test.

The generator was placed in the brackets and the heat transfer assembly set to 1" from the generator body. The thermocouples (#1 - #20) were applied as stated above and both the 15 psi transducer and the 100 psi transducer were threaded into the test apparatus. The pressures recorded were 14.0 and 31.0 psi, respectively. The large difference between the two readings was unknown and both transducers were tested for calibration using static air pressure from a compressor line; each gave proper readings. After activation, the tape holding Thermocouple #5 released. The sound level meter was placed inside the test chamber attached to the front right (camera view) of the test stand. The peak sound level recorded this test was 138.4dB. The maximum level of carbon monoxide recorded was 129.5 ppm and the minimum oxygen level reached was 13.1%.

Test #130306 - 05:

Adam Richardson and George Goetz from N2 Towers, Inc and Art Tutson and Laura Porres from Boeing Environmental Control Systems were present for the test.

The generator was placed in the brackets and the heat transfer assembly set to 1” from the generator body. The thermocouples (#1 - #20) were applied as stated above and both the 15 psi transducer and the 100 psi transducer were threaded into tees attached to the test apparatus to limit potential thermal effects on the pressure transducers. The 15 psi transducer exceeded the maximum and clipped the waveform at 16.7 and pressure recorded on the 100 psi transducer was 58.1 psi. The sound level meter was placed inside the test chamber attached to the front right (camera view) of the test stand. The peak sound level recorded this test was 138.3dB. The maximum level of carbon monoxide recorded was 110.2 ppm and the minimum oxygen level reached was 13.2%.

Test #130306 - 06:

Adam Richardson and George Goetz from N2 Towers, Inc and Art Tutson and Laura Porres from Boeing Environmental Control Systems were present for the test.

The generator was placed in the brackets and the heat transfer assembly set to 1” from the generator body. The thermocouples (#1 - #20) were applied as stated above and both the 15 psi transducer and the 100 psi transducer were threaded into tees attached to the test apparatus to limit potential thermal effects on the pressure transducers. The pressures recorded were 13.0 and 22.4 psi, respectively. The sound level meter was placed inside the test chamber attached to the front right (camera view) of the test stand. The peak sound level recorded this test was 137.2dB. The maximum level of carbon monoxide recorded was 137.7 ppm and the minimum oxygen level reached was 13.1%.

Table II:

Pressure Test Results

	Sound Level (dB)	Separation Distance (in)	Data Channel	Peak Electrical Noise (V)	Peak Electrical Noise (psi)	Peak Trace (V)	Peak Trace (psi)
Test 00	-	3	100 psi	0.56	11.25	0.21	4.29
Test 01	128.3	2	15 psi	4.96	14.88	1.75	5.24
Test 02	138.0	1	15 psi	5.55	16.64	5.55	16.65
Test 03	138.2	1	100 psi	2.81	56.27	2.61	52.18
Test 04	138.4	1	15 psi	5.55	16.64	4.67	14.02
			100 psi	2.01	40.21	1.55	31.09
Test 05	138.3	1	15 psi	5.58	16.73	5.58	16.73
			100 psi	2.63	52.52	2.91	58.12
Test 06	137.2	1	15 psi	5.56	16.67	4.33	13.00
			100 psi	2.06	41.30	1.12	22.43

The highlighted cells show the readings that were clipped – exceeding the maximum reading for the instrument being used.

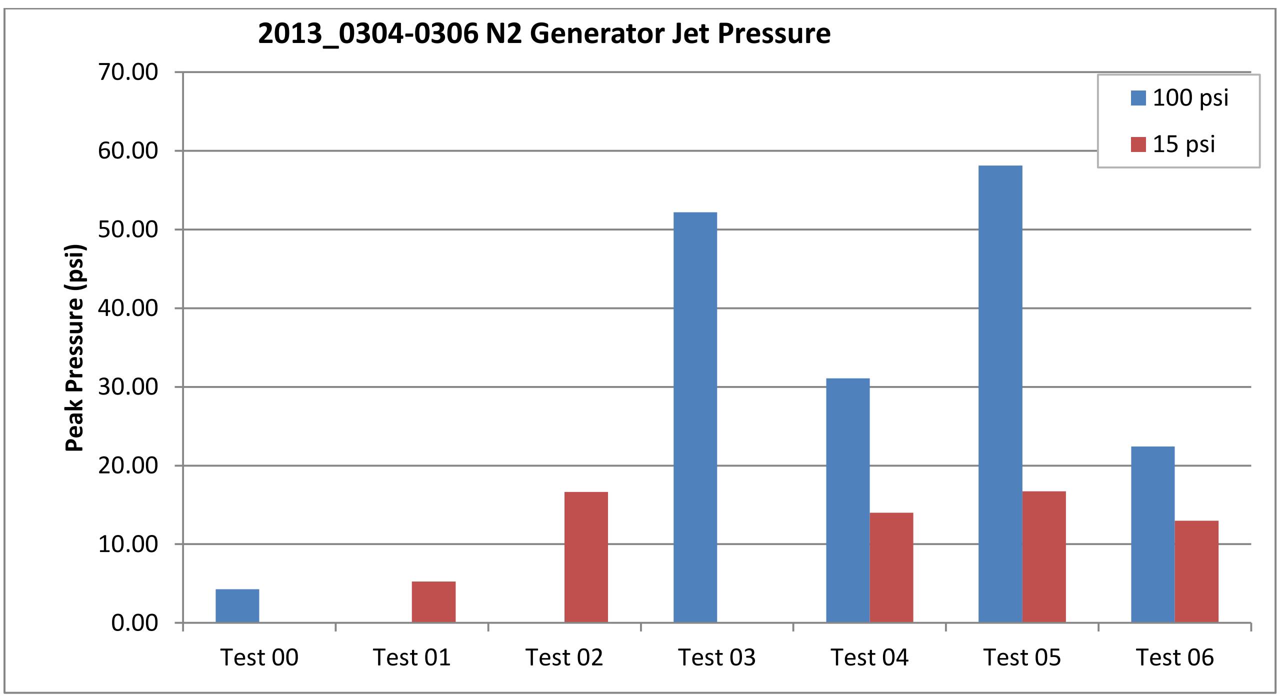


Chart 1: Graph showing the relative jet pressures recorded and the spike attributed to electrical noise at the beginning of the test.

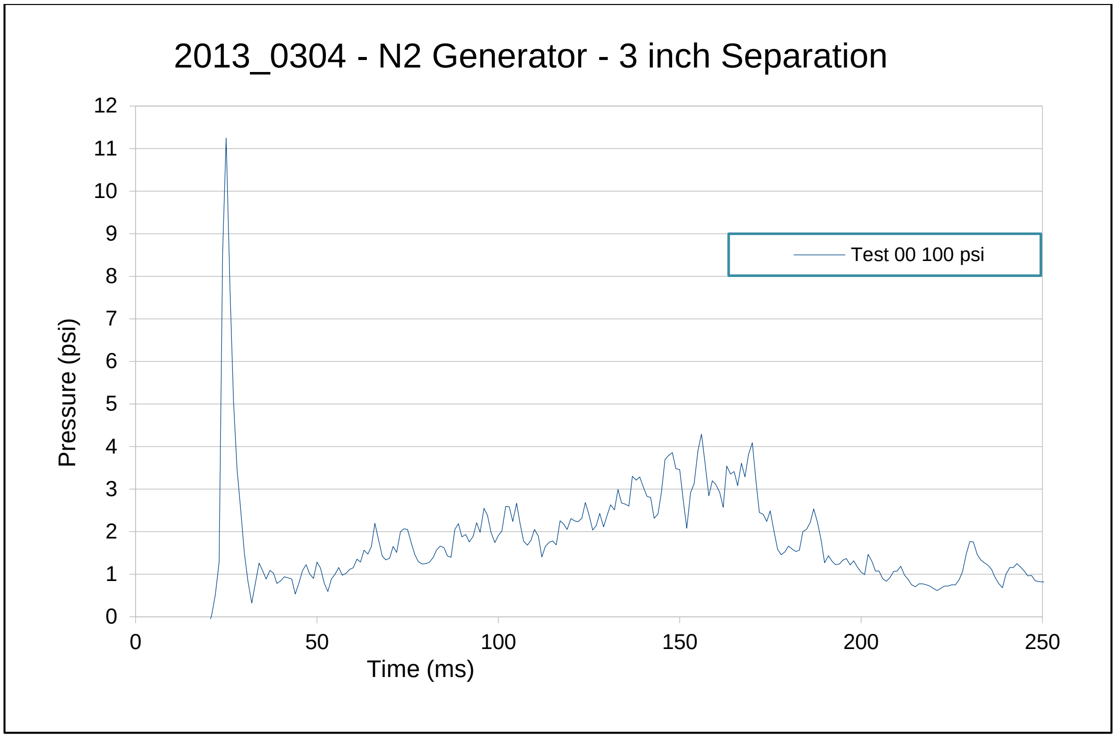


Chart 2: Graph showing the pressure recorded from the 100 psi transducer at 3 inches from the generator.

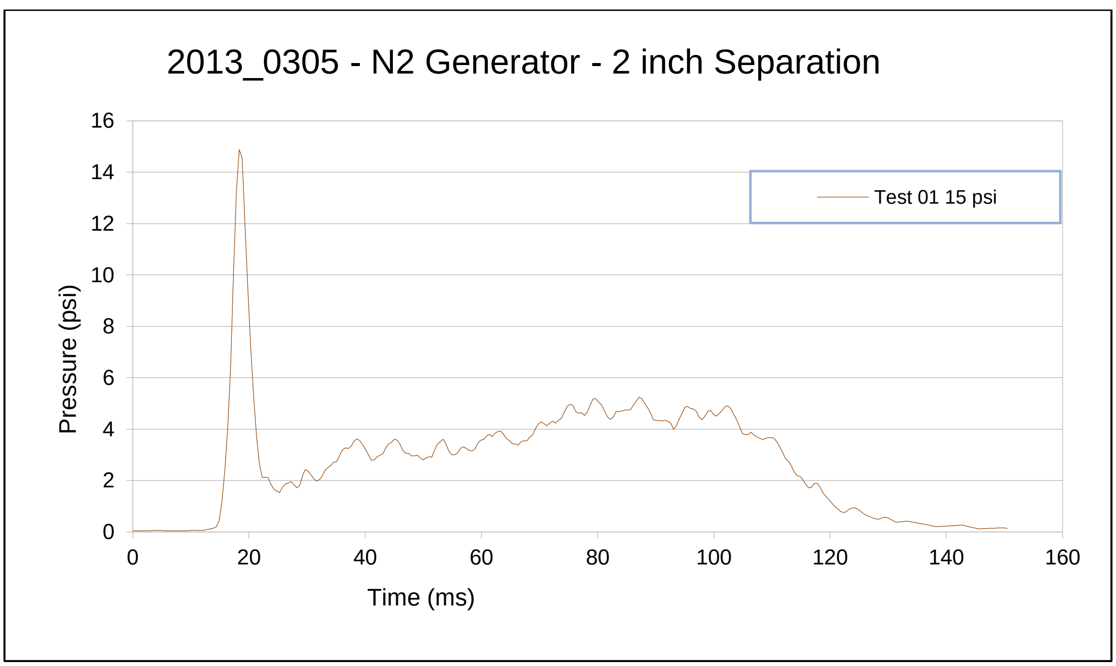


Chart 3: Graph showing the pressure recorded from the 15 psi transducer at 2 inches from the generator.

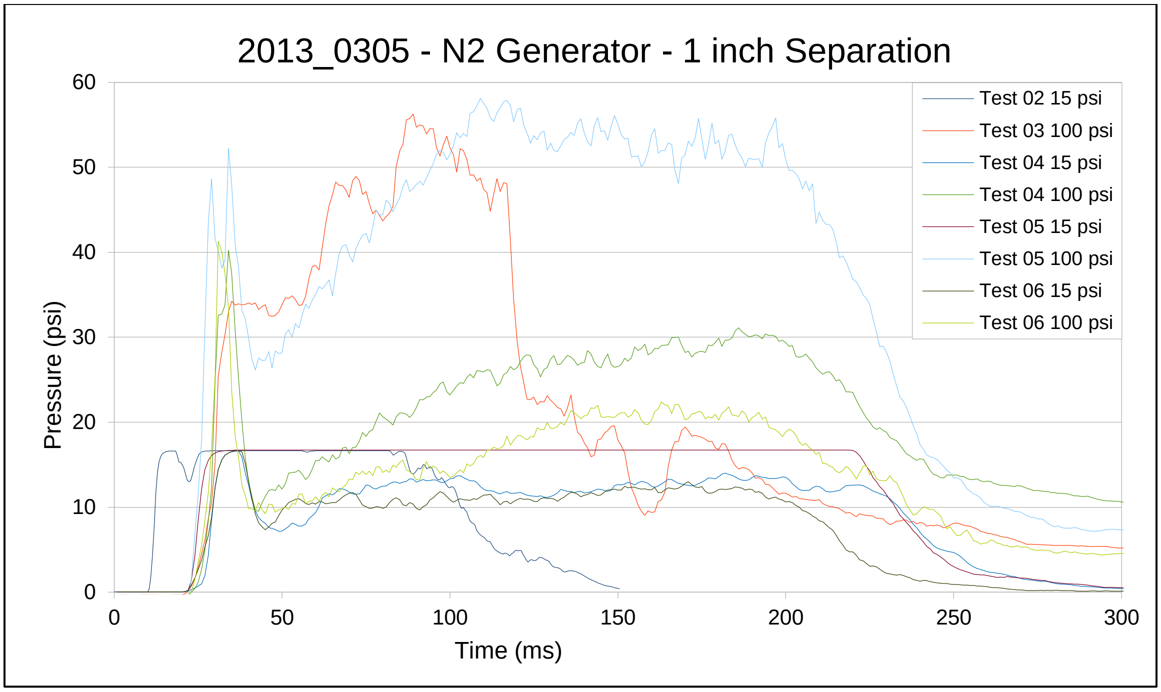


Chart 4: Graph showing all of the pressure traces recorded at 1 inch from the generator.

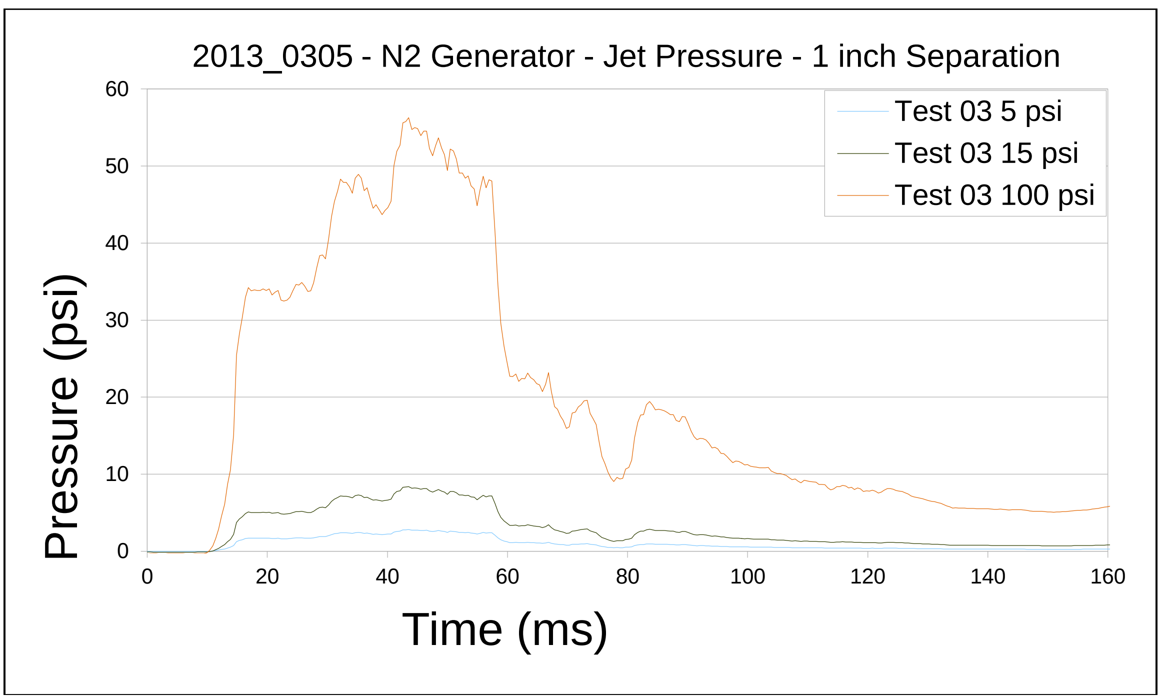


Chart 5: Graph showing the pressure traces recorded at 1 inch from the generator during Test 03. The trace from the 100 psi transducer was the proper channel, the 5 psi channel was mistakenly reported immediately after the test.

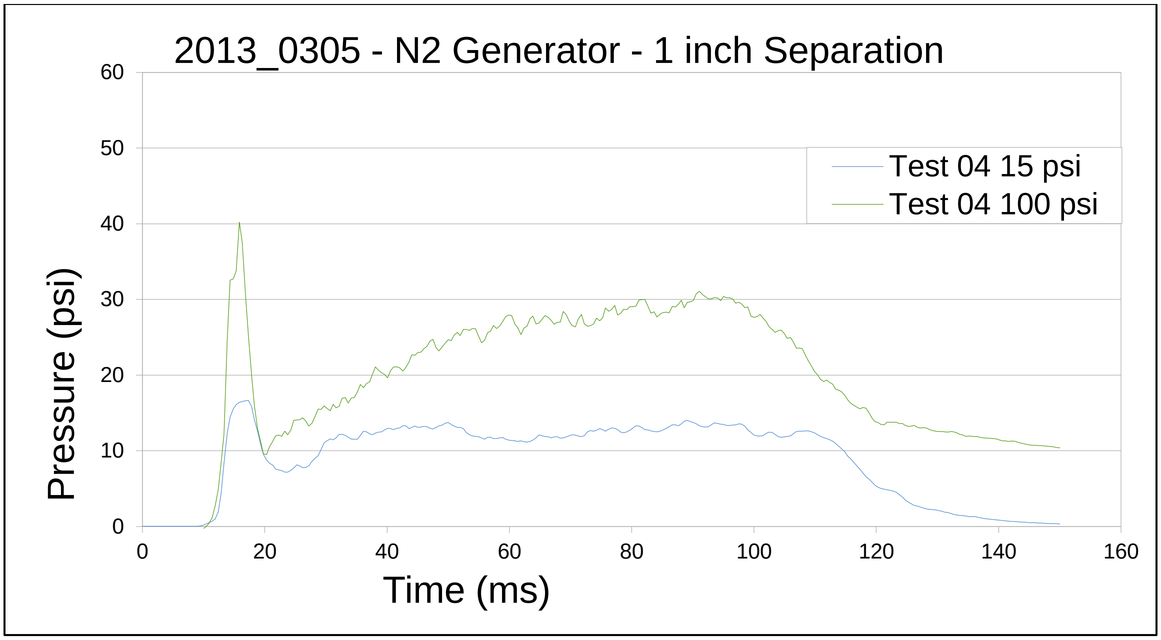


Chart 6: Graph showing the pressure traces recorded at 1 inch from the generator during Test 04.

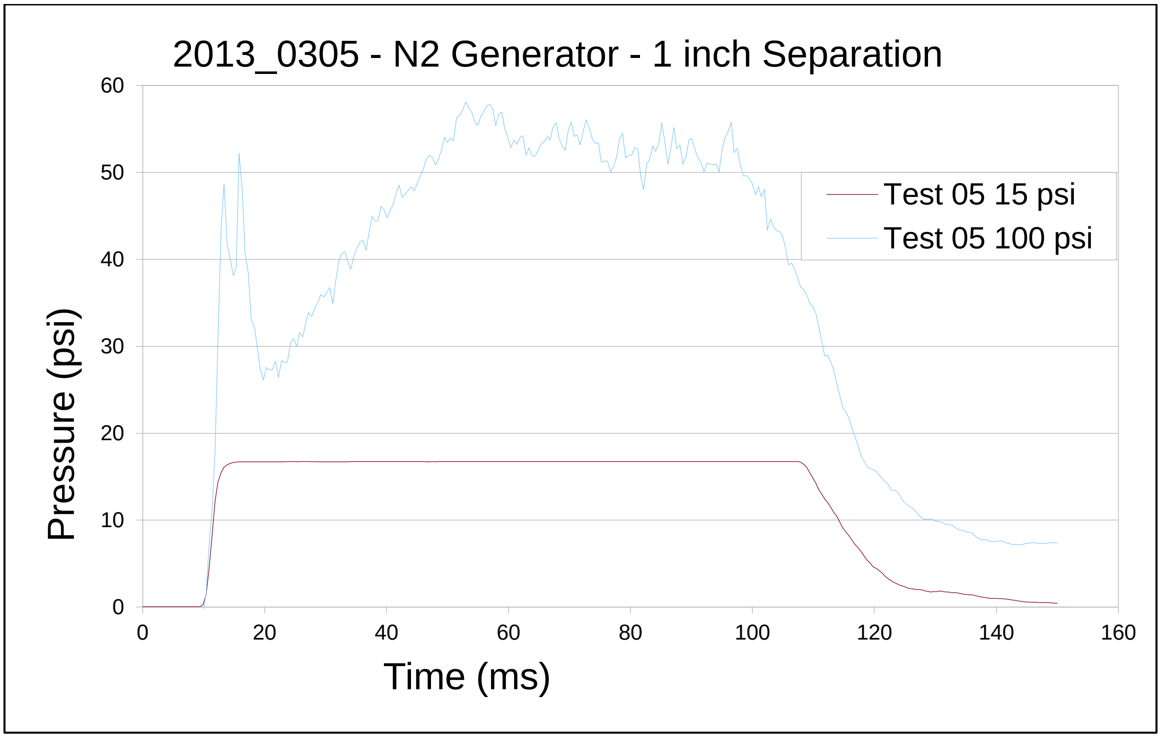


Chart 7: Graph showing the pressure traces recorded at 1 inch from the generator during Test 05. The 15 psi transducer clipped during the bulk of the event.

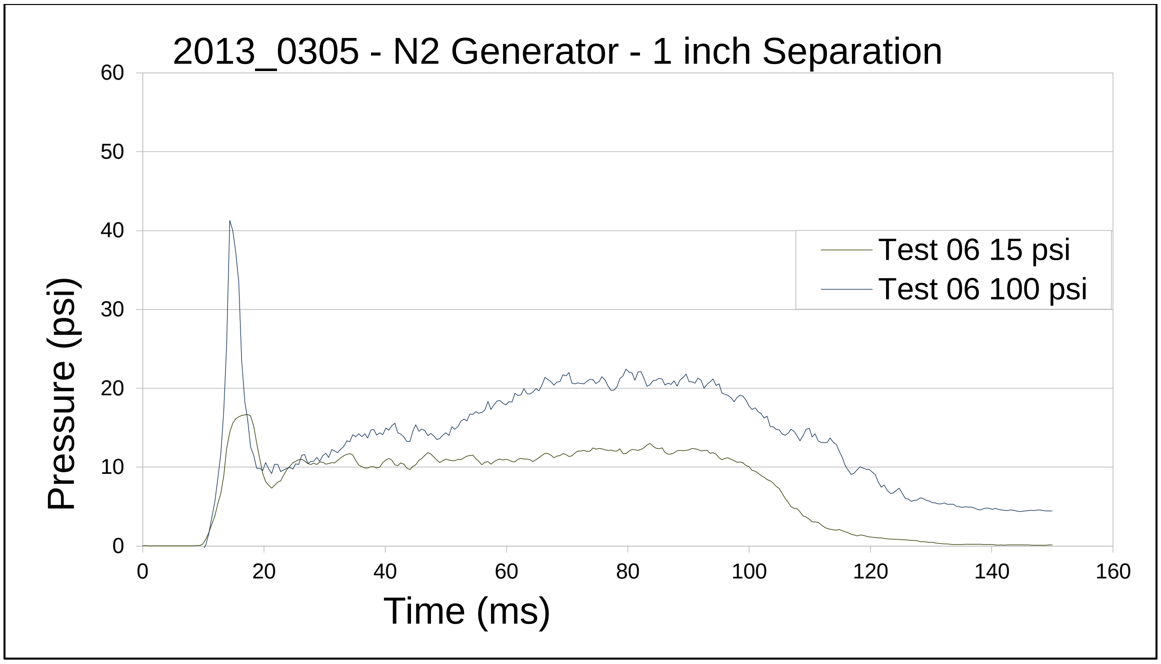


Chart 8: Graph showing the pressure traces recorded at 1 inch from the generator during Test 06.

Table III:

Temperature Test Results

	Generator Body - Nozzle Face (Igniter End ↔ Blank End)			Generator Body - Blank Face (Igniter End ↔ Blank End)			End Cap - Igniter		End Cap - Blank		Bracket	Transfer Plate - Upper Row (Blank End ↔ Igniter End)			Transfer Plate - Center Row (Blank End ↔ Igniter End)			Transfer Plate - Lower Row (Blank End ↔ Igniter End)		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Test 00	200[1]	200	200	200	200	200	161.9	184.9	179.4	174.0	73.9	87.2	88.3	84.4	-	-	-	-	-	-
Test 01	200	200	200	200	200	200	147.8	159.7	164.3	163.0	66.8	153.0	126.5	113.0	125.6	178.2	176.9	159.6	170.4	55.5
Test 02	200	200	200	200	200	200	151.6	164.3	166.7	156.4	69.2	154.4	142.7	110.1	114.1	197.1	185.9	152.7	59.7	97.8
Test 03	200	200	200	200	200	200	165.9	172.0	180.2	168.5	70.9	113.9	66.2	69.4	132.7	181.7	139.4	200.0	196.8	120.7
Test 04	210.0	311.9	221.3	238.3	53.4[2]	237.7	170.3	166.0	158.7	157.8	66.9	70.3	62.3	70.9	74.8	97.2	86.6	153.2	92.4	50.4
Test 05	214.5	316.9	238.3	226.4	317.7	239.5	164.4	166.9	182.3	170.6	63.7	106.8	124.3	105.8	89.9	108.4	135.3	91.9	116.4	60.7
Test 06	219.0	315.1	233.4	239.4	297.2	239.5	166.2	165.5	168.1	177.8	68.1	93.9	61.6	52.3	69.7	88.4	77.1	198.8	72.3	56.7
Average	214.5	314.6	231.0	234.7	307.5	238.9	161.2	168.5	171.4	166.9	68.5	111.4	96.0	86.6	101.1	141.8	133.5	159.4	118.0	73.6
Std Dev	3.001	1.822	6.466	5.534	10.25	0.8	6.547	5.701	7.927	6.69	2.428	24.92	30.16	19.78	23	43.83	34.46	26.77	43.73	23.74

[1] During Tests 00-03 the temperature recorder was inadvertently set to a maximum of 200°C. This was fixed for subsequent testing.

[2] Thermocouple #5 became dislocated during Test 04.

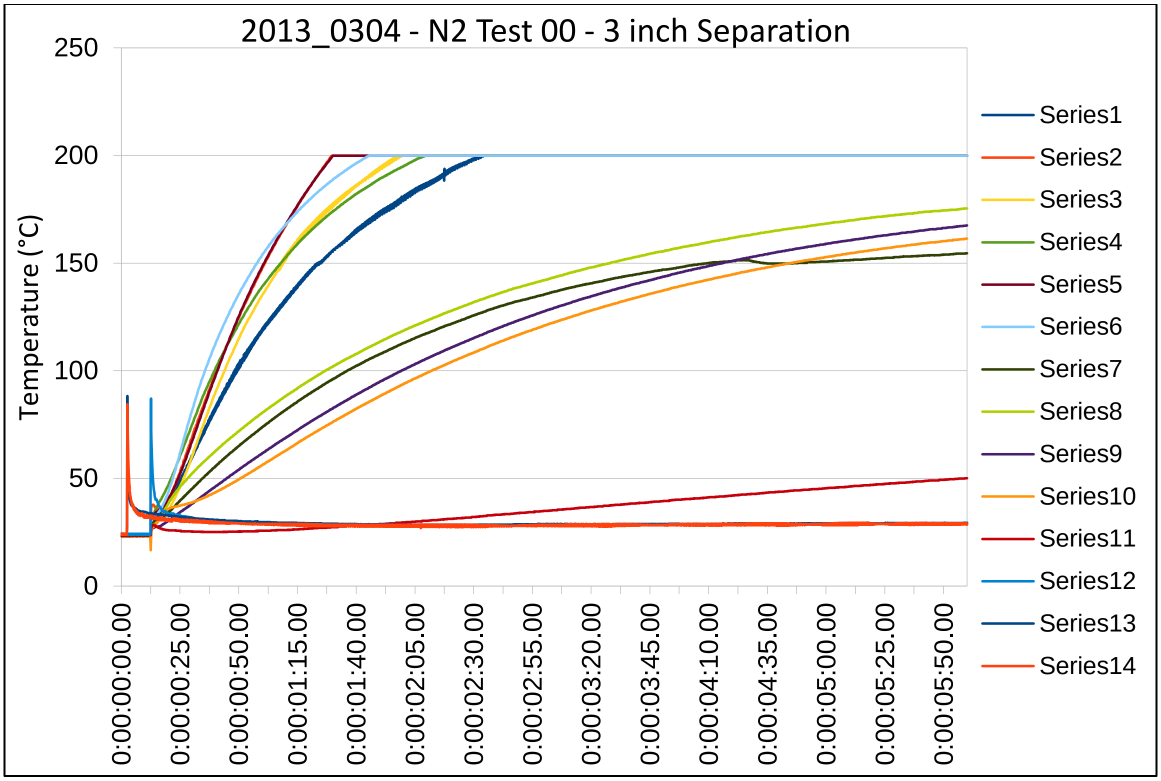


Chart T1: Temperature profiles recorded during Test 00.

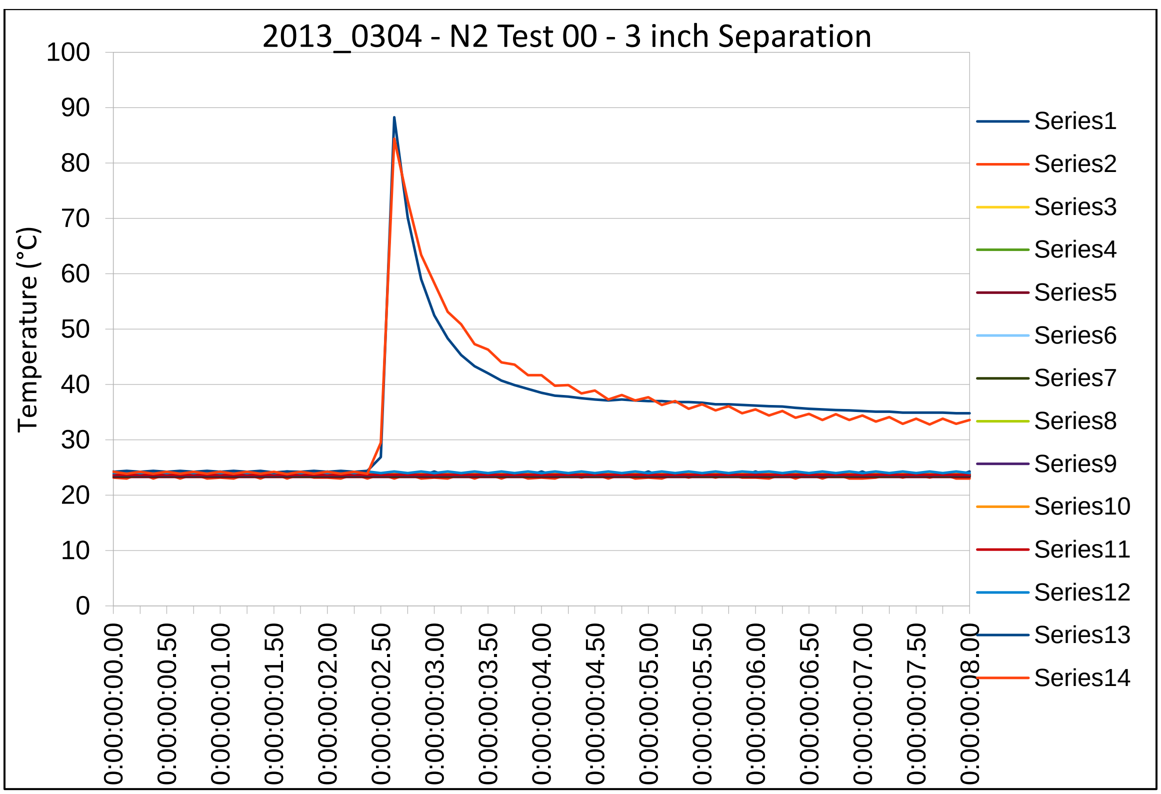


Chart T2: Temperature profile of the heat transfer panel during Test 00.

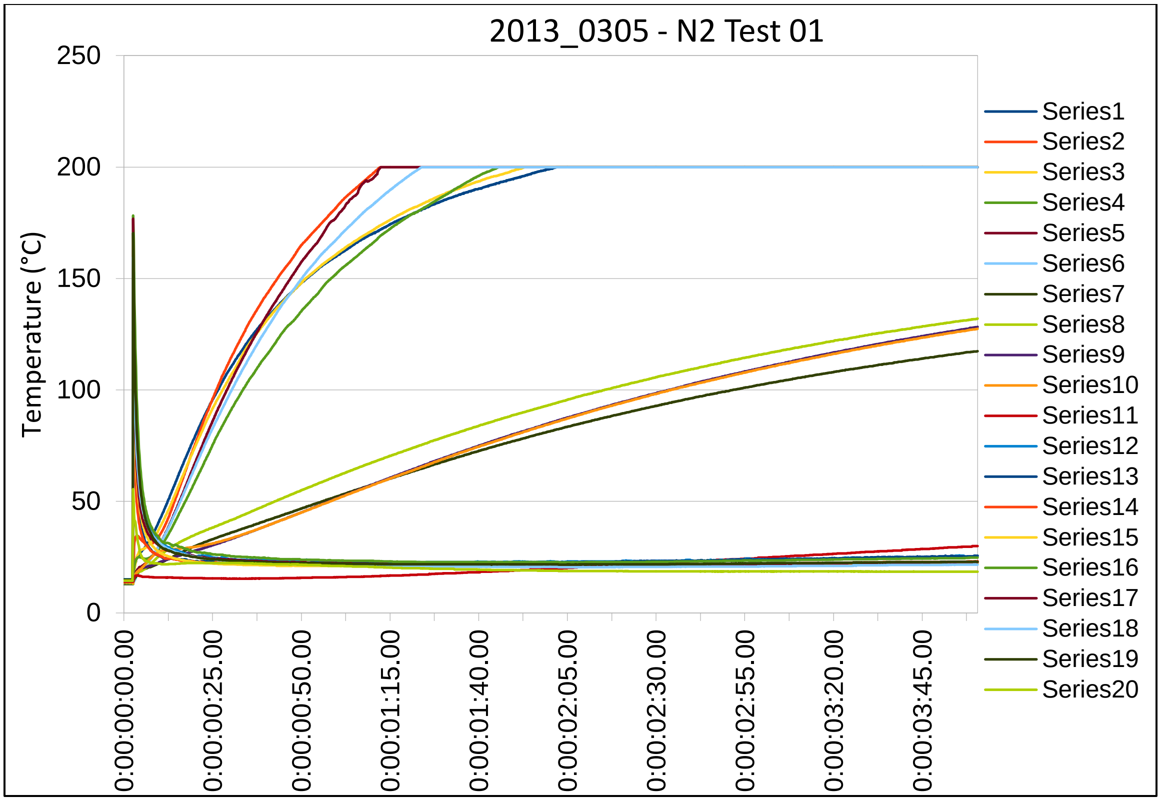


Chart T3: Temperature profiles recorded during Test 01.

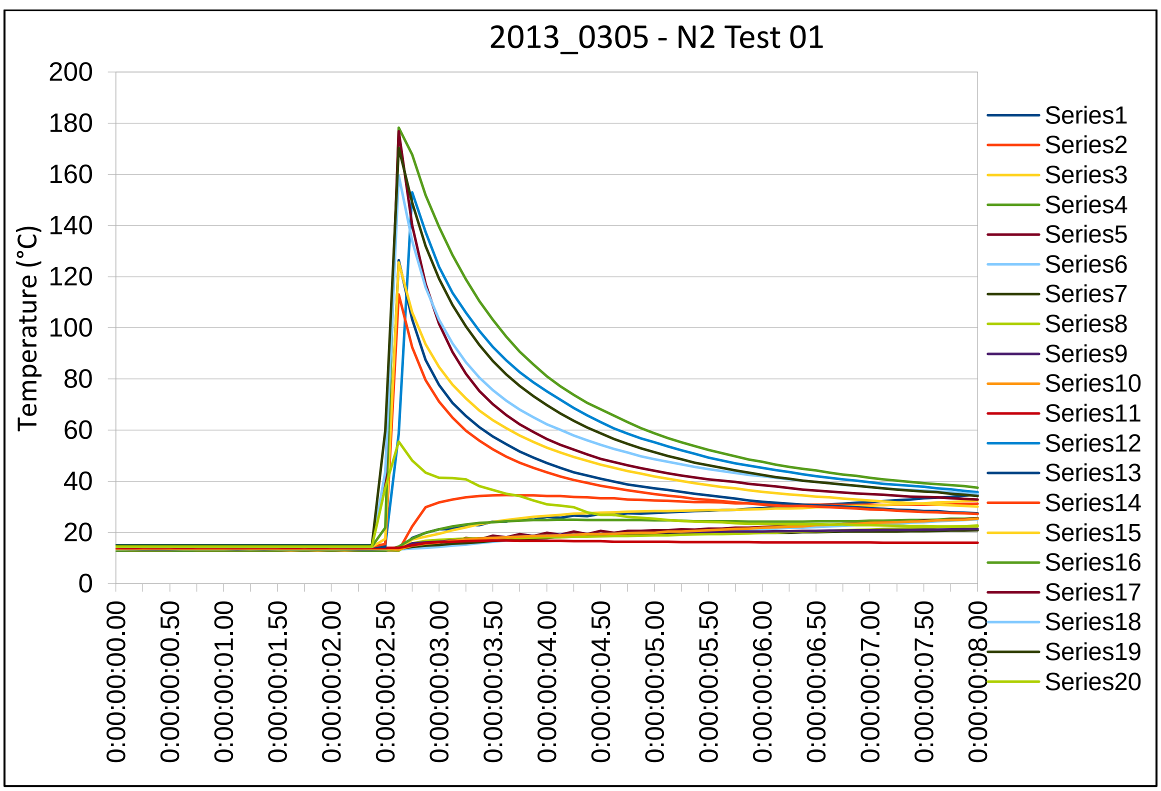


Chart T4: Temperature profile of the heat transfer panel during Test 01.

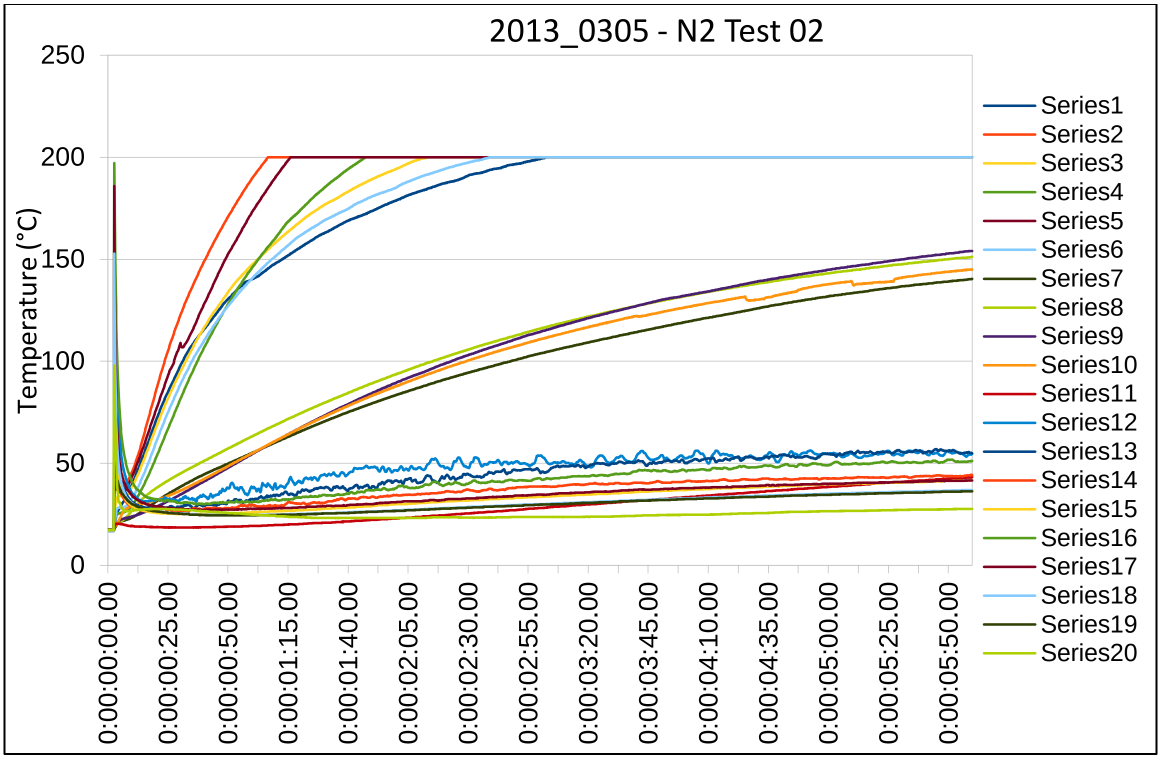


Chart T5: Temperature profiles recorded during Test 02.

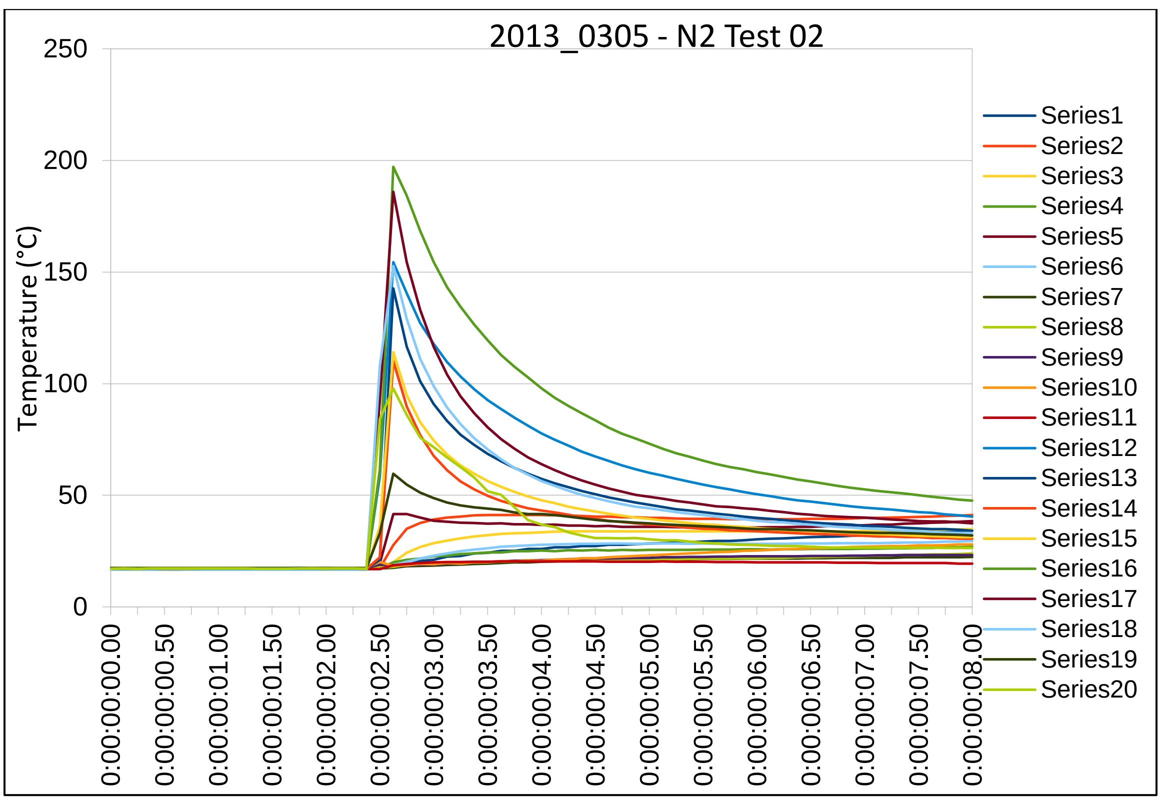


Chart T6: Temperature profile of the heat transfer panel during Test 02.

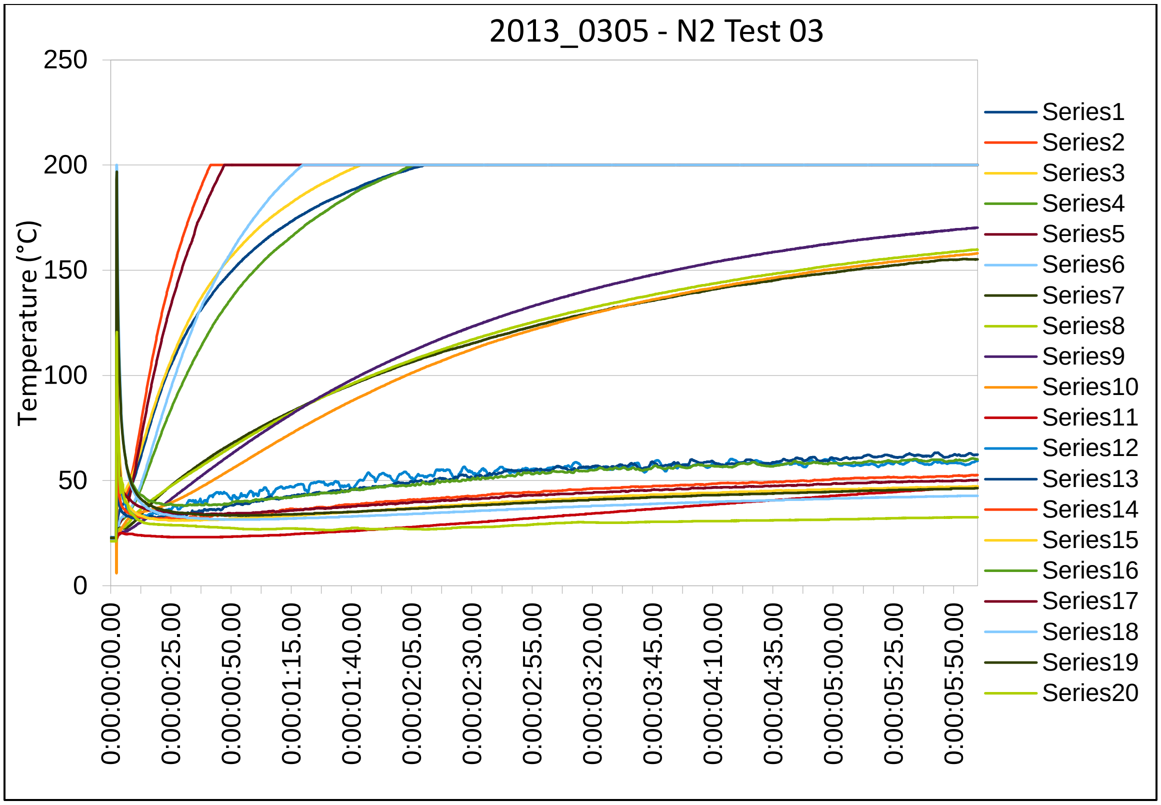


Chart T7: Temperature profiles recorded during Test 03.

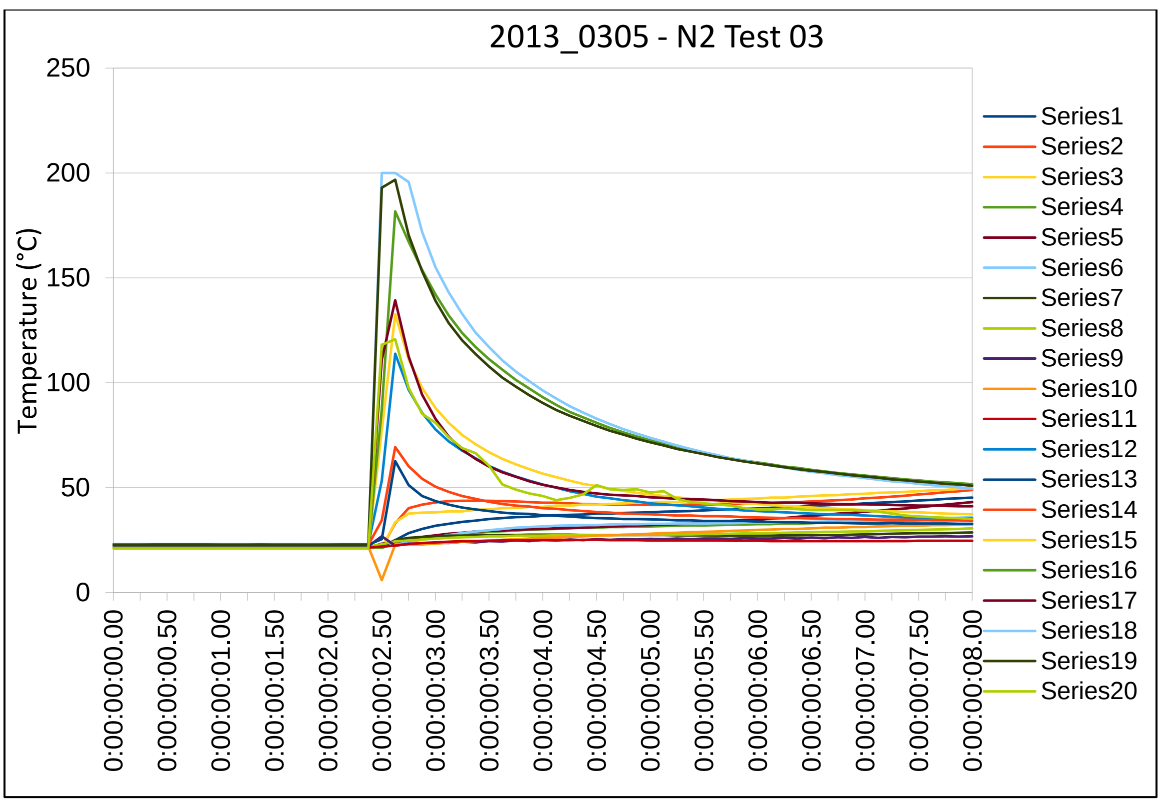


Chart T8: Temperature profile of the heat transfer panel during Test 03.

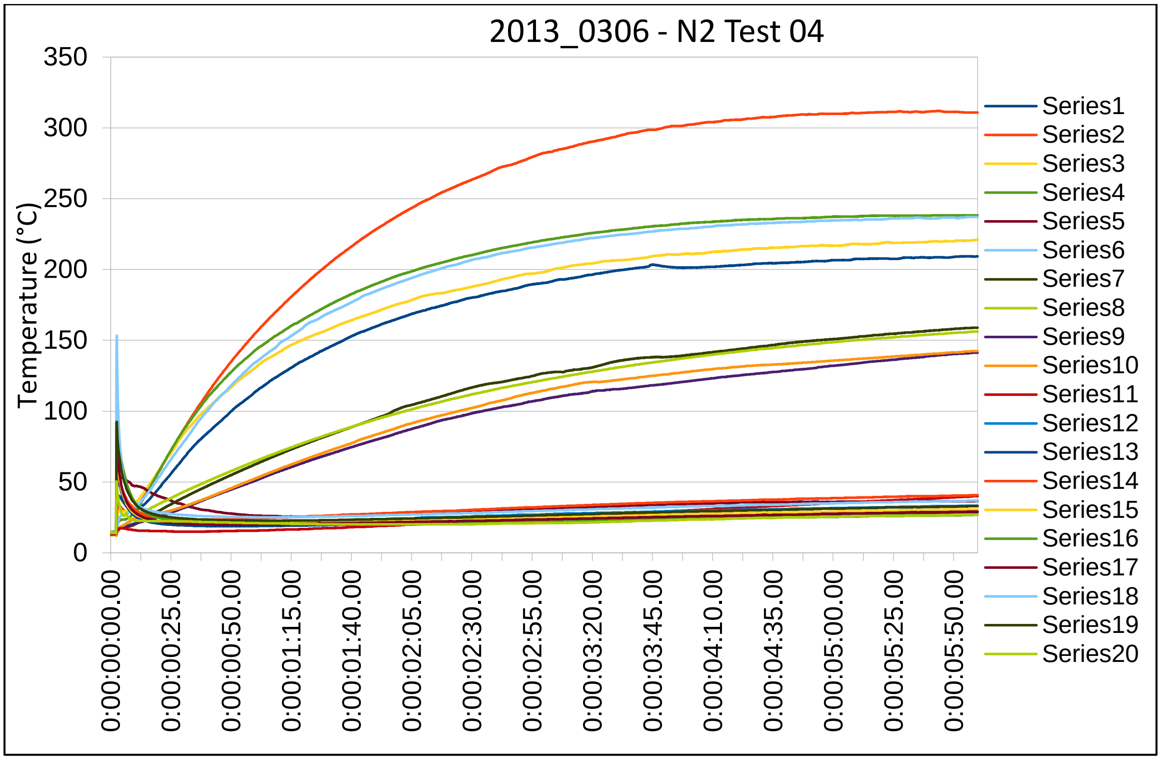


Chart T9: Temperature profiles recorded during Test 04.

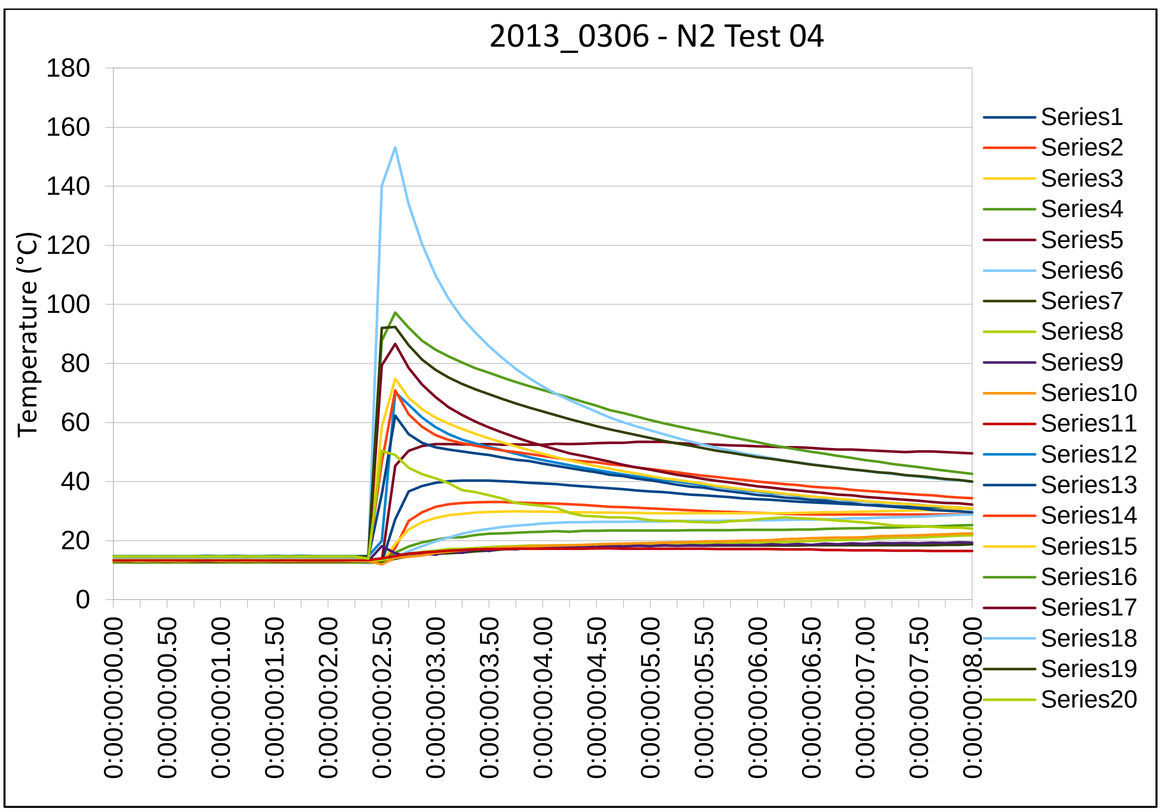


Chart T10: Temperature profile of the heat transfer panel during Test 04.fg

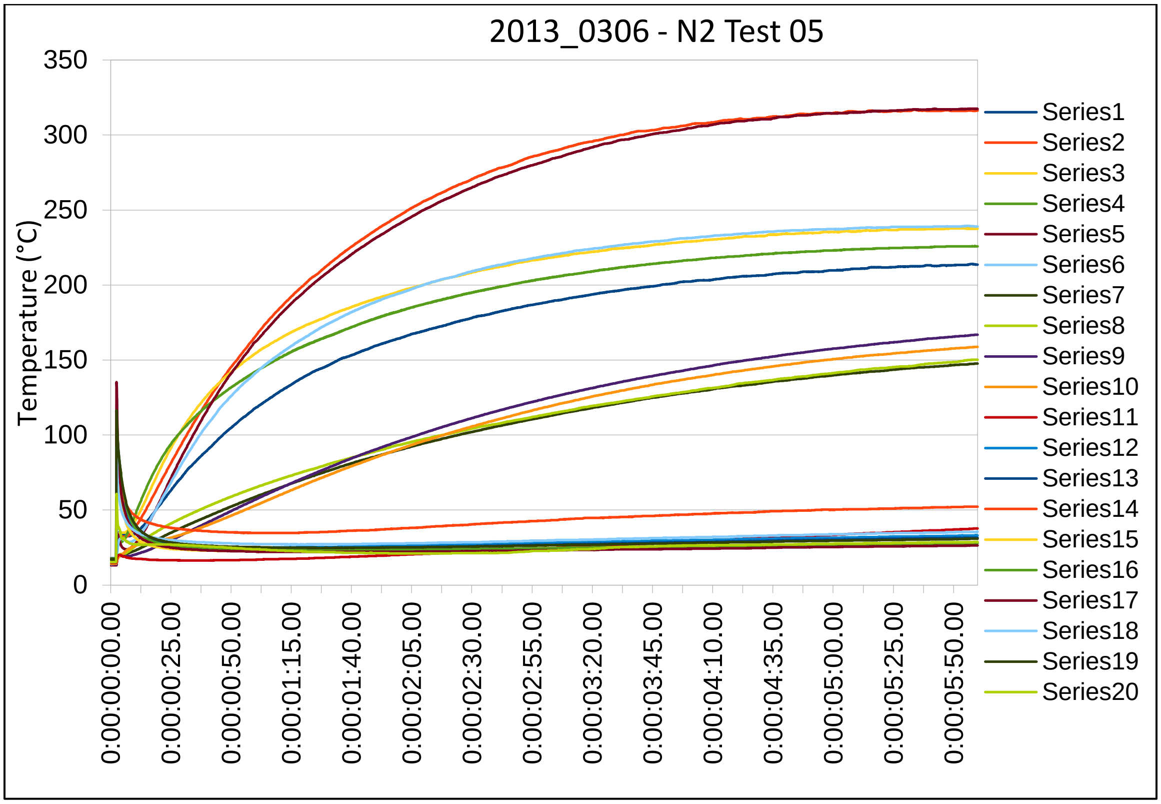


Chart T11: Temperature profiles recorded during Test 05.

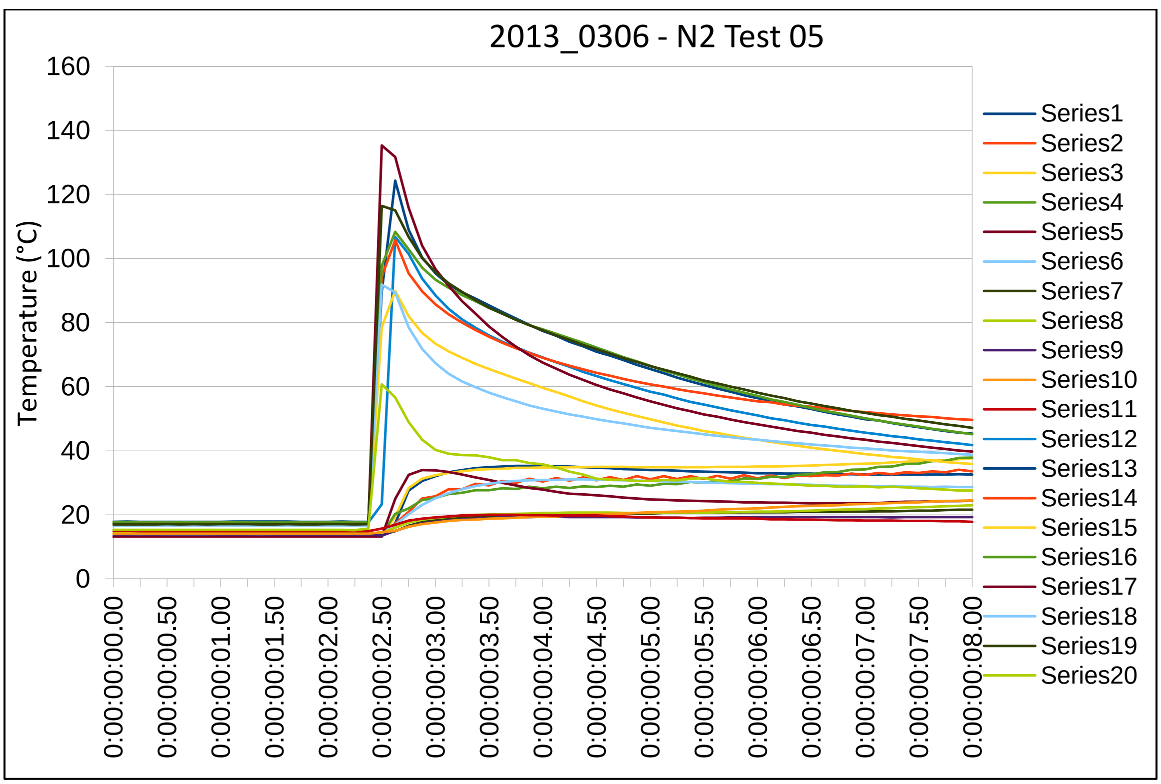


Chart T12: Temperature profile of the heat transfer panel during Test 05.

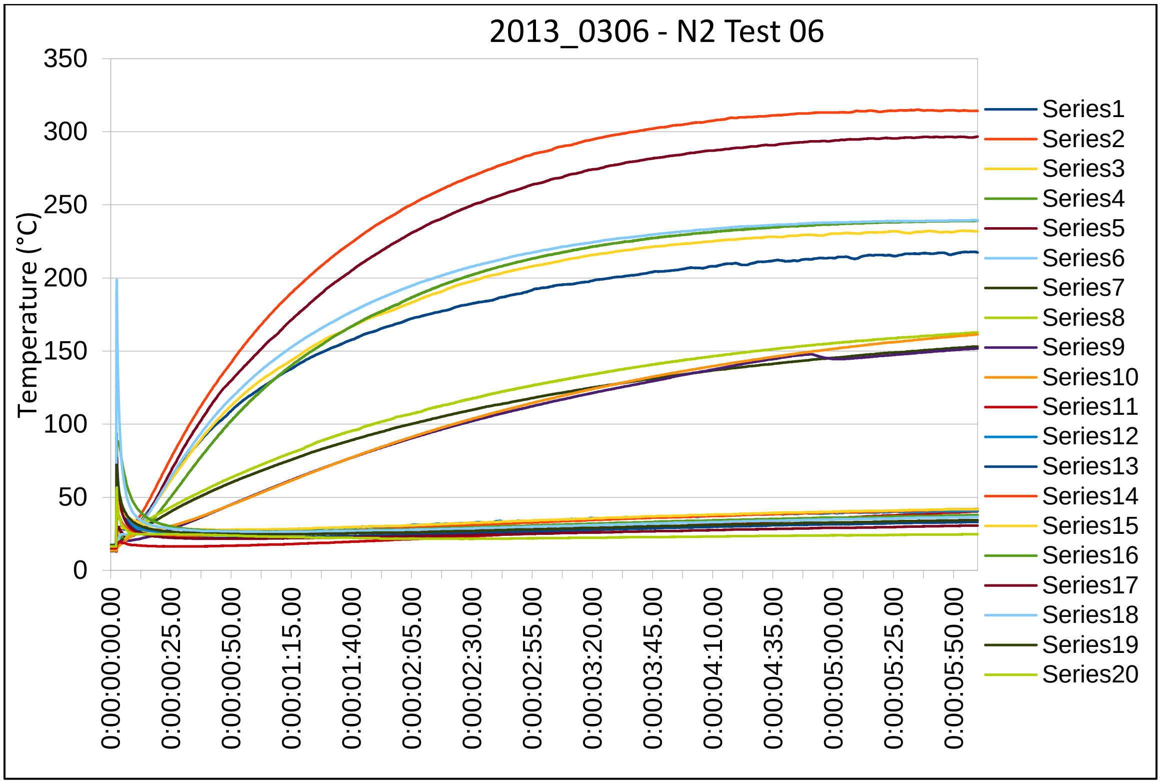


Chart T13: Temperature profiles recorded during Test 06.

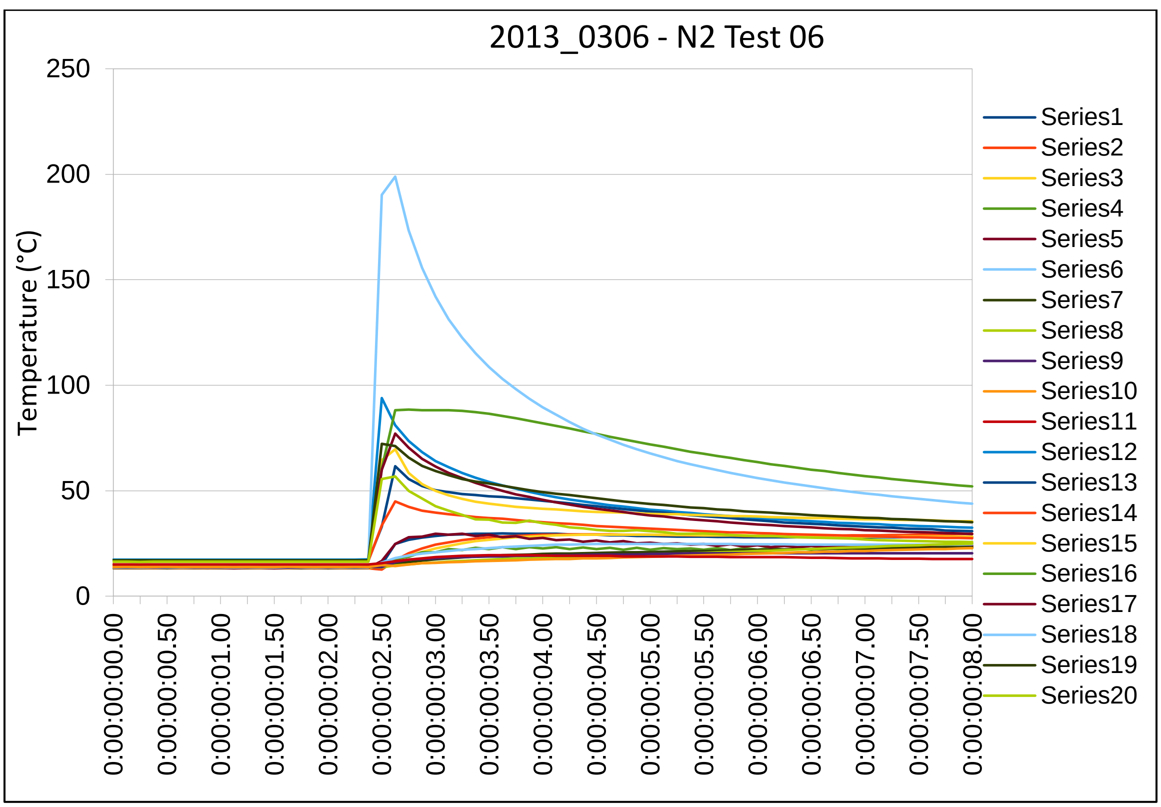


Chart T14: Temperature profile of the heat transfer panel during Test 06.

Table IV:

O_2 and CO Gas Monitor Test Results

		Test Date	Start Time	End Time		Maximum CO(ppm)	Minumum OXY(%)
Test 00		03/04/13	15:46	16:08		156.5	12.1
Test 01		03/05/13	11:25	11:46		136.0	12.7
Test 02		03/05/13	13:31	14:04		166.3	13.3
Test 03		03/05/13	14:52	15:15		137.7	12.8
Test 04		03/06/13	10:02	10:30		129.5	13.1
Test 05		03/06/13	11:27	11:48		110.2	13.2
Test 06		03/06/13	13:35	14:05		137.7	13.1

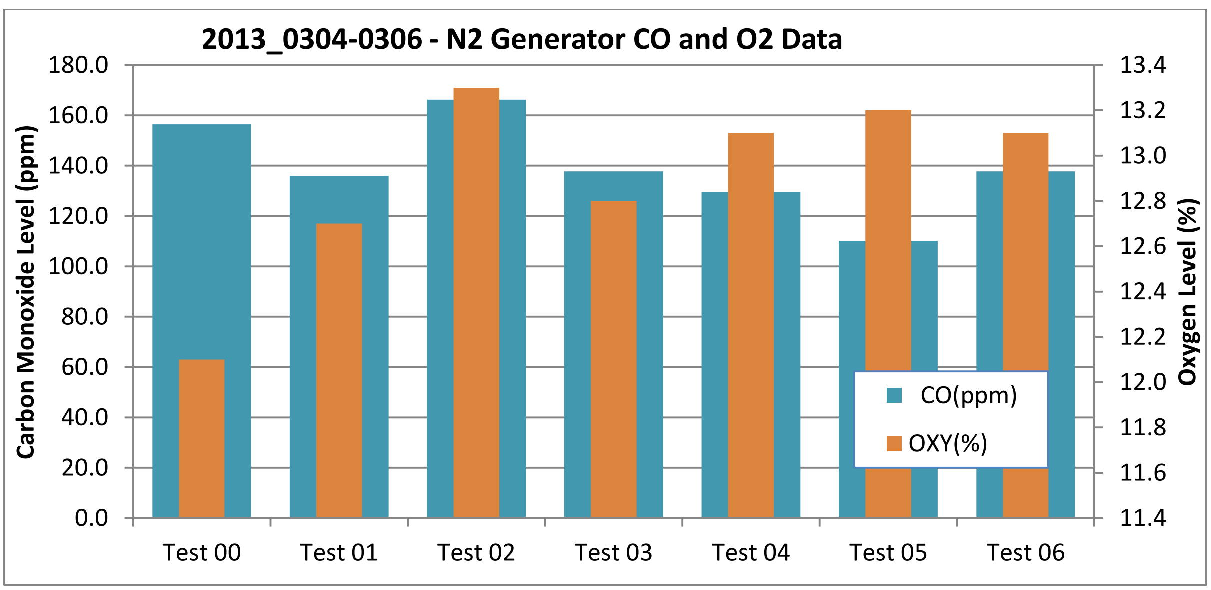


Chart G1: Graph showing the relative extreme analysis for each test.

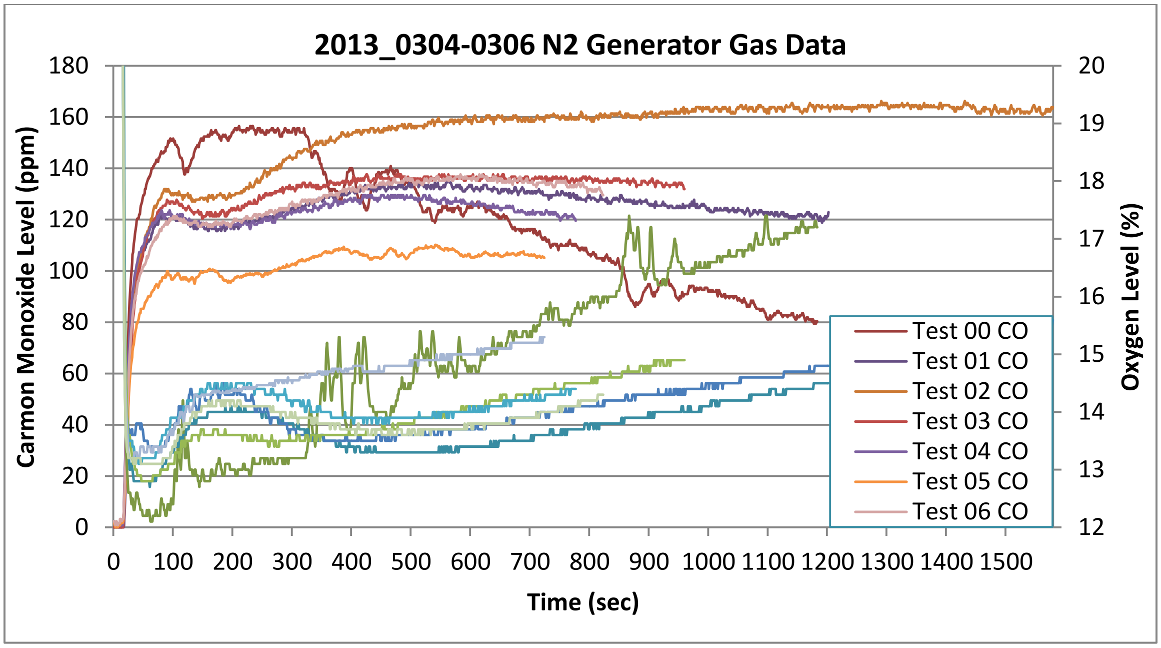


Chart G2: Graph showing an overlay of the oxygen and carbon monoxide levels from all seven tests.

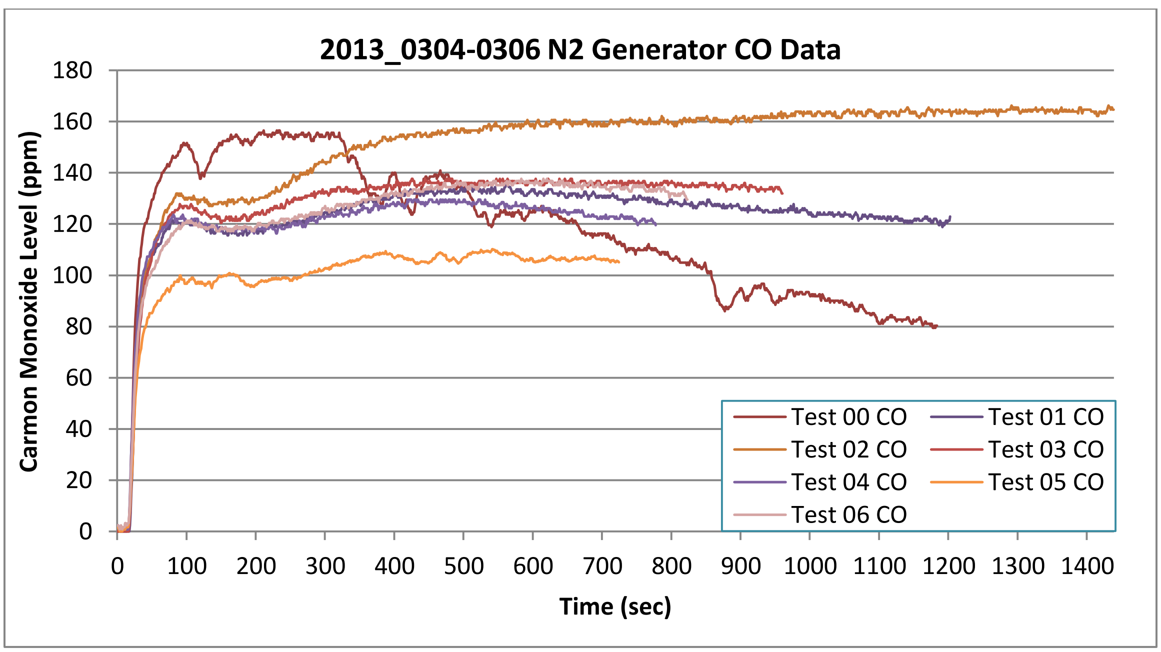


Chart G3: Graph showing an overlay of the carbon monoxide levels inside the test chamber after activation of one 2”x14” N2 generator from all seven tests.

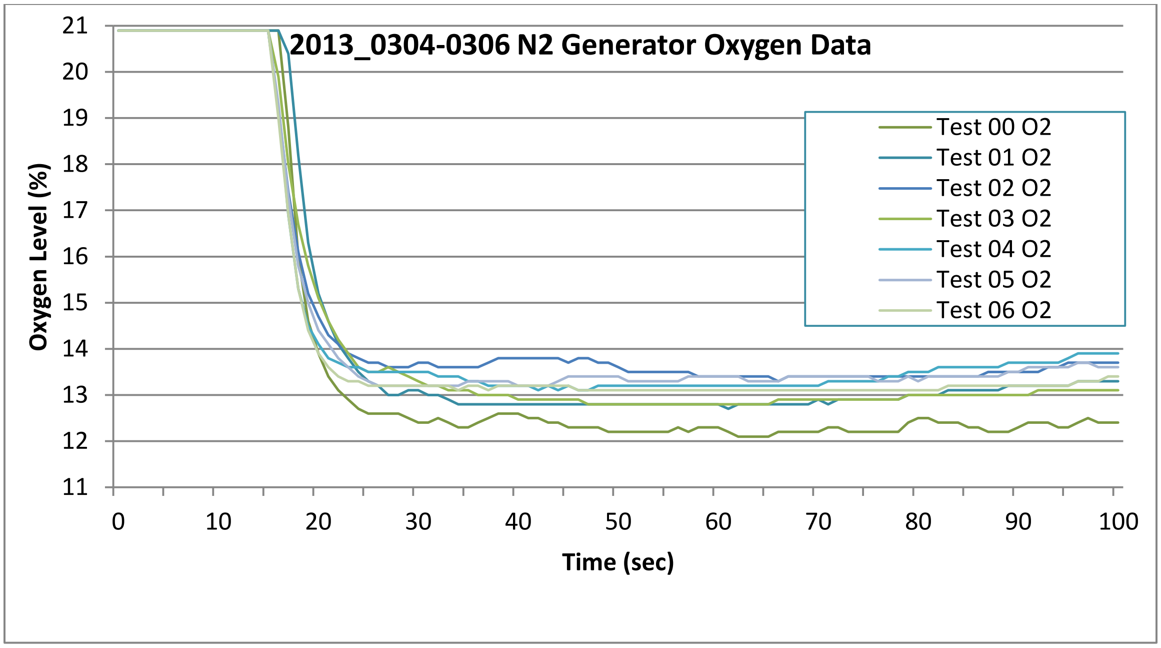


Chart G4: Graph showing an overlay of the oxygen level inside the test chamber after activation of one 2"x14" N2 generator from all seven tests.

Figures:

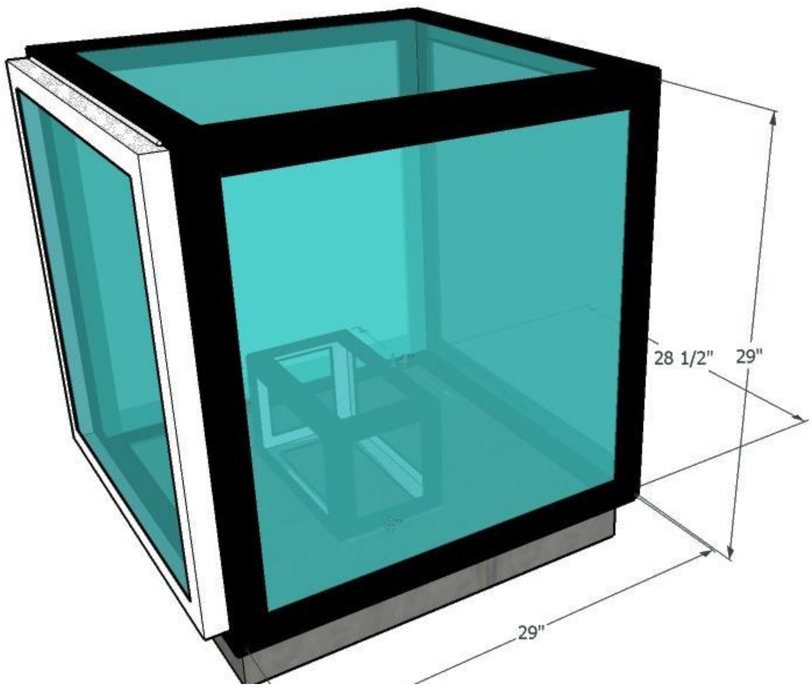


Figure 1: Drawing of the test chamber.

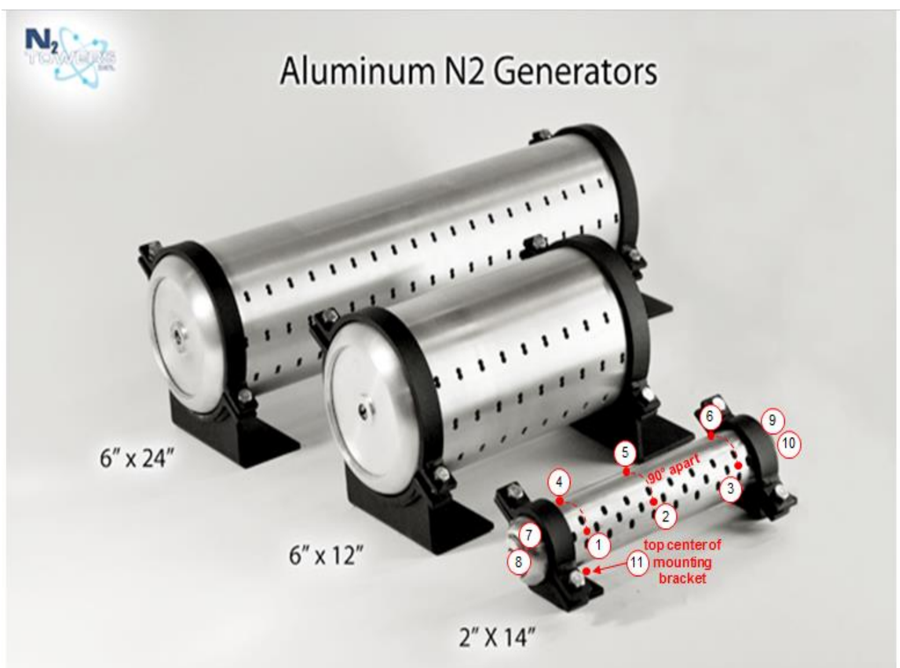


Figure 2: A reference listing the location of the thermocouple placement on the generator, #1 - #11 supplied by Boeing engineers.

Test Fixture

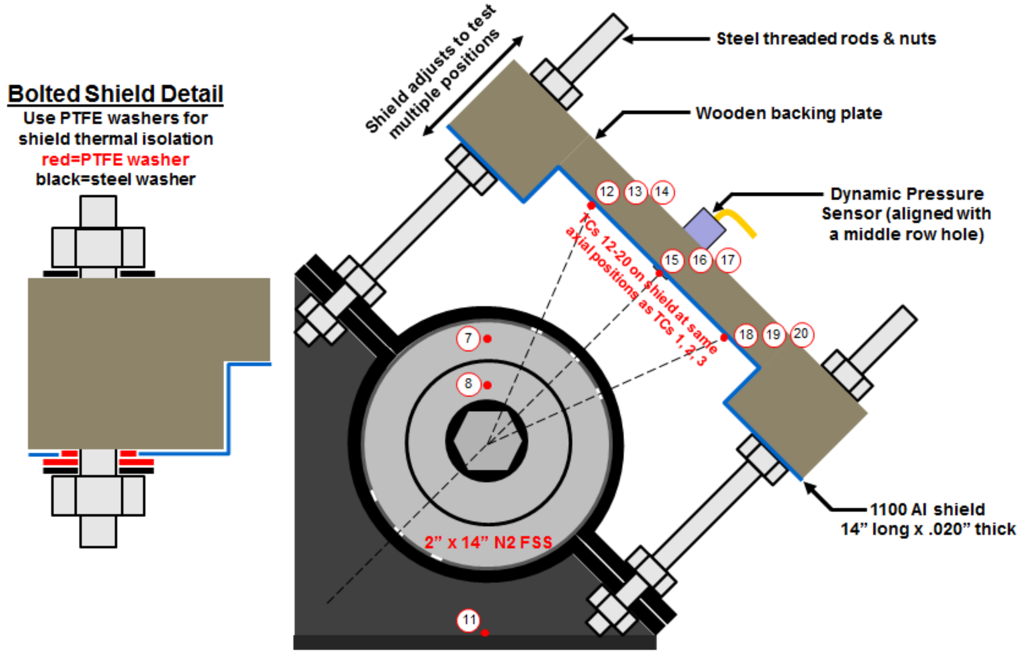
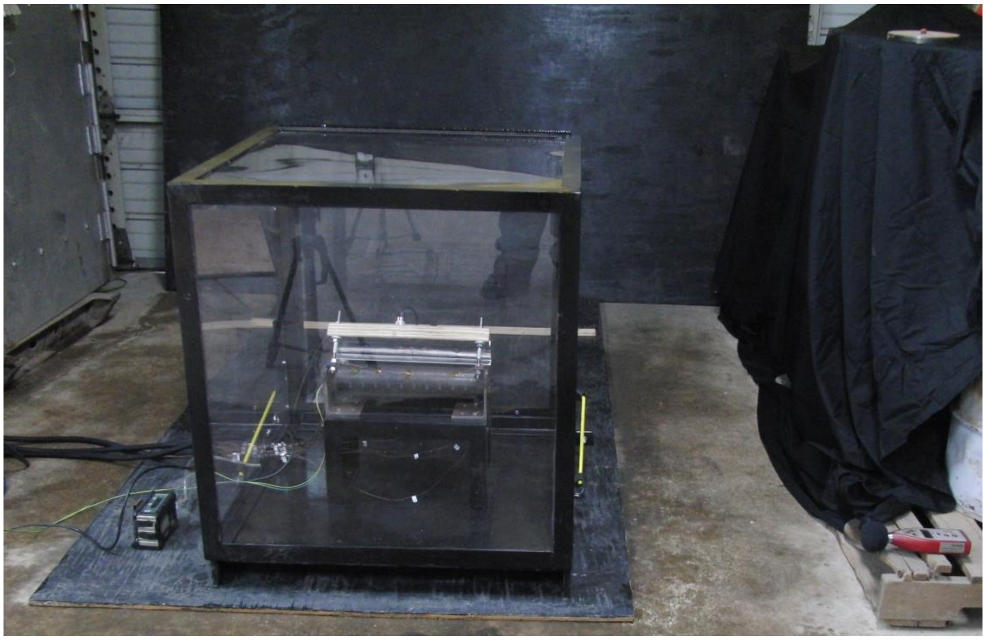
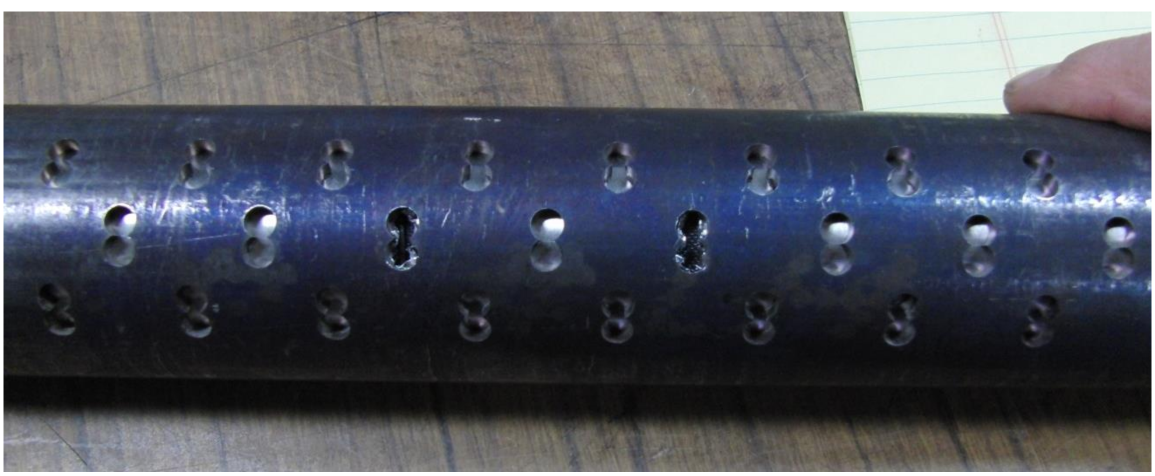


Figure 3: Drawing supplied by Boeing engineers showing the test fixture construction and thermocouple placement (#12-#20).

Photographs:



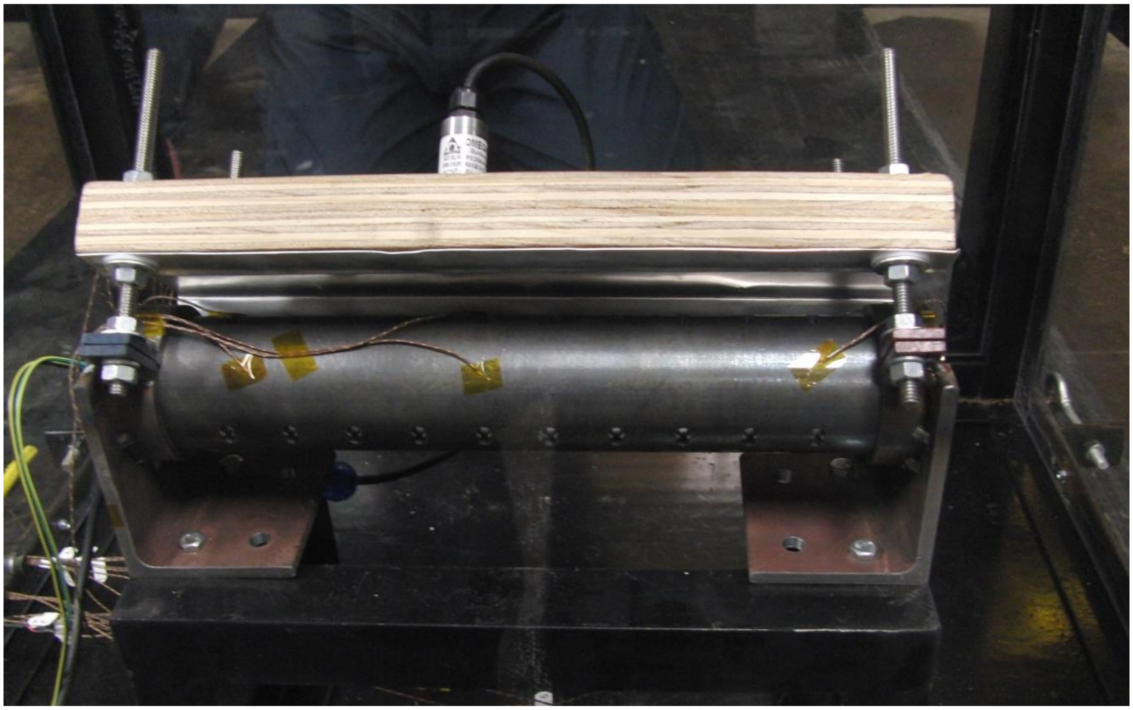
Photograph 1: Photograph of the test setup. The test chamber can be seen in the center of the photo. The sound level meter is located in the lower right corner of the photograph as placed in Test 01. The test fixture can be seen mounted inside the center of the test chamber. The gas monitor can be seen just to the left of the chamber.



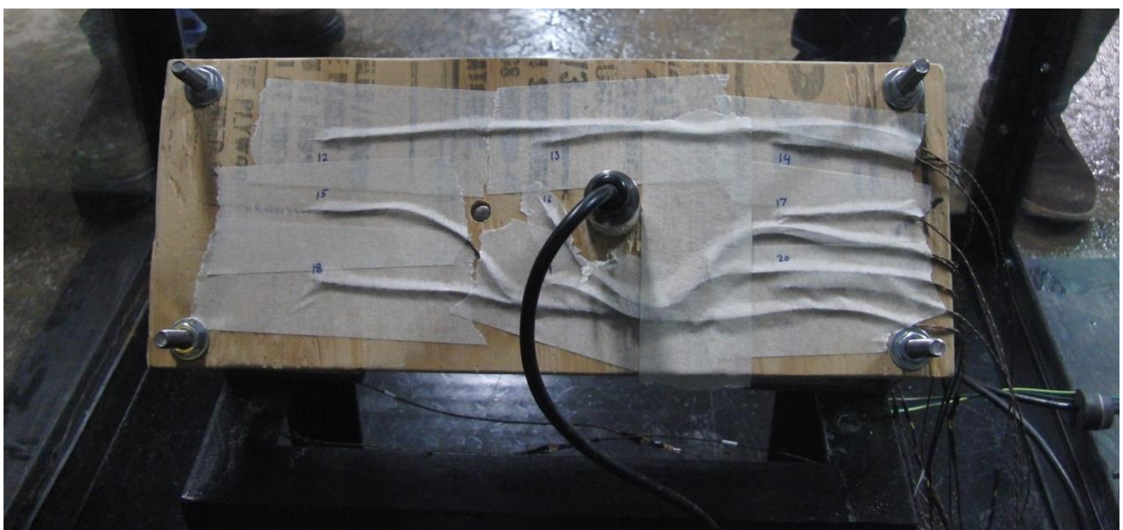
Photograph 2: Close photograph of N2 Generator before testing, showing the puncturing of the burst foil in the two nozzles to be directly in line with the two pressure transducers to be used in Test 04.

Photograph 3: Pro-Rae Multi-Gas Monitor used to monitor and record the CO and Oxygen levels during the test.

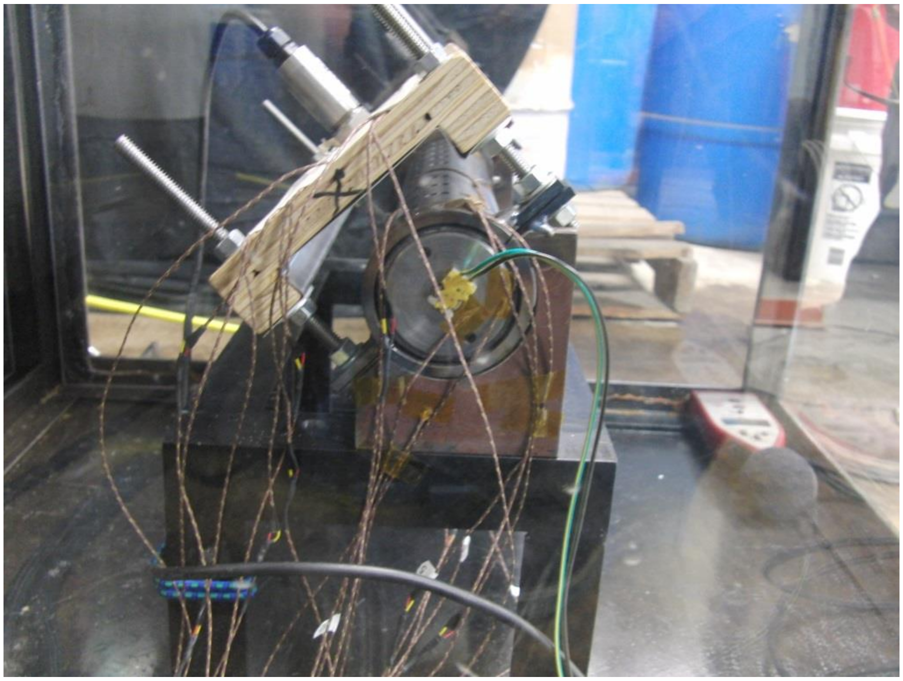
Photograph 4: Two 12 channel Omega RD8800 thermocouple data acquisition devices were used to record the temperature data.



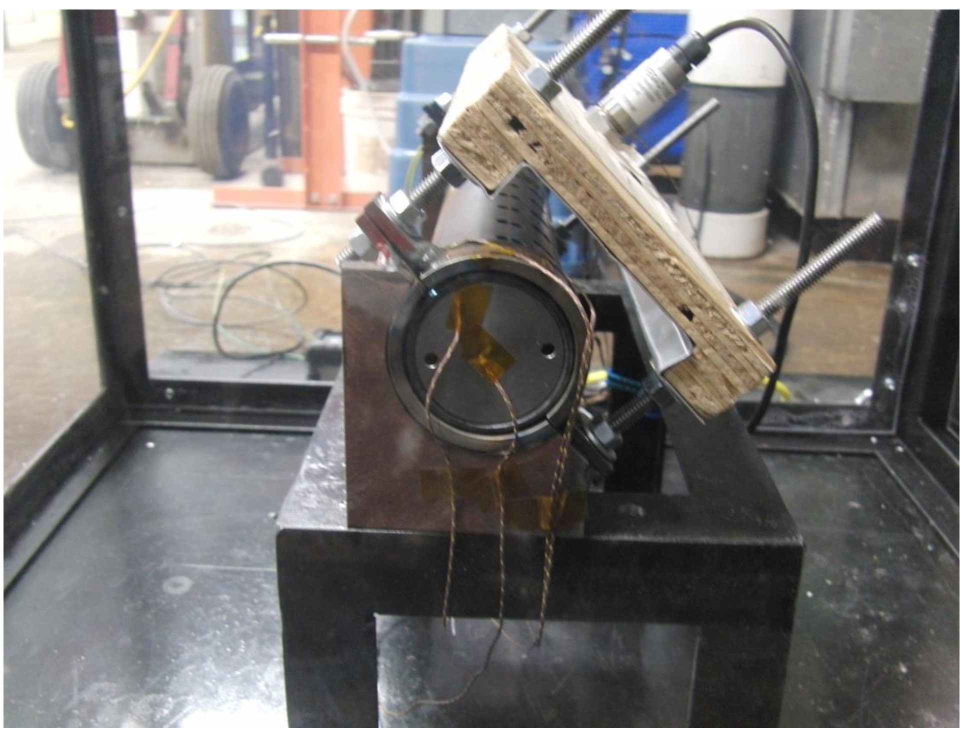
Photograph 5: View from the front of the test fixture, showing the arrangement of the thermocouples attached to the generator body. The igniter end of the generator is towards the left side of the photo.



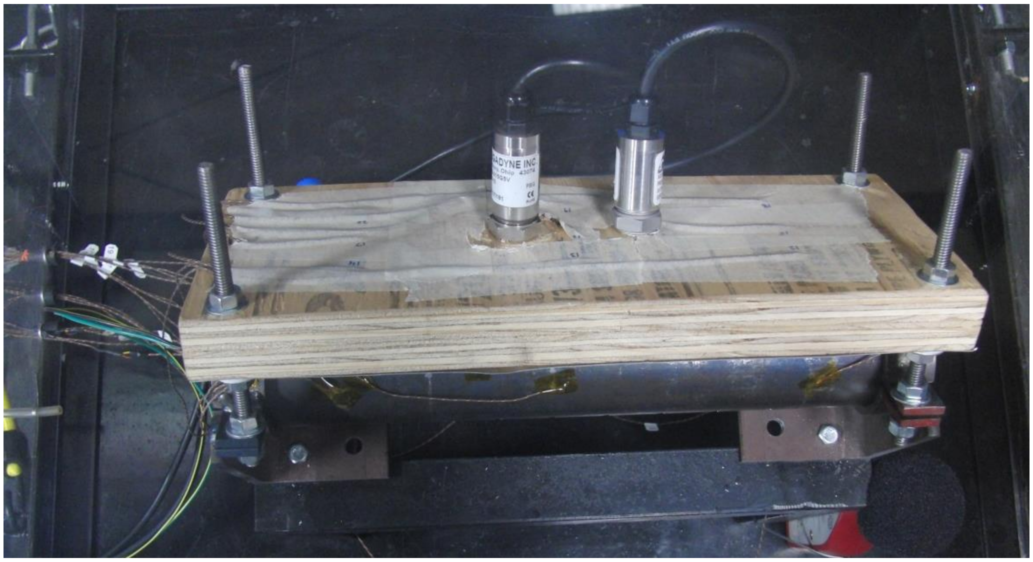
Photograph 6: Photo of the outside of the backing plate. The arrangement of the thermocouples and the single pressure transducer can be seen.



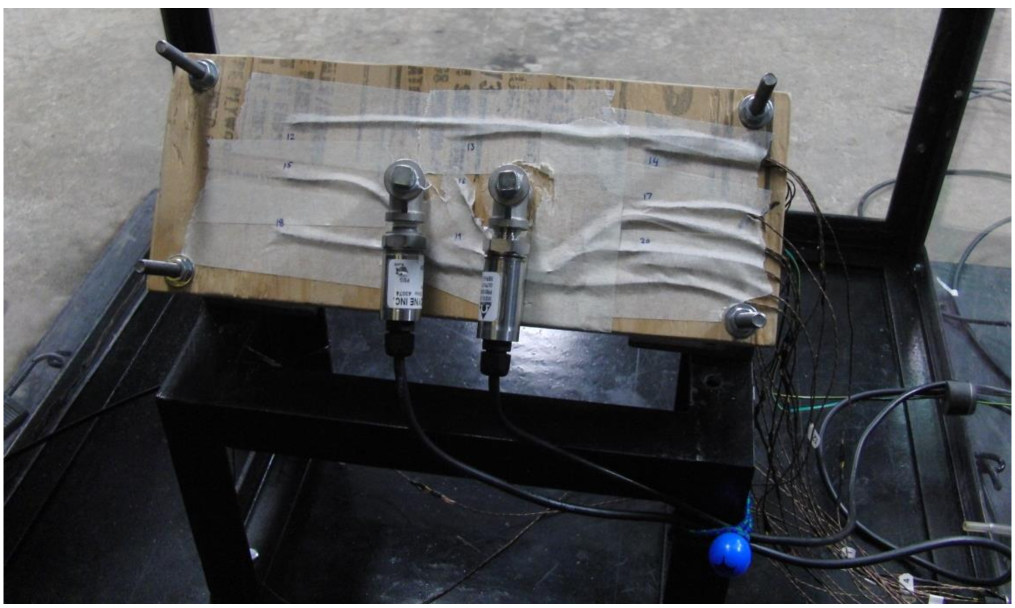
Photograph 7: Igniter end view of the test fixture showing arrangement of thermocouples and a 1 inch separation distance. The sound level meter can be seen in the front right corner of the test chamber as set in Test 02. The door opens from the bottom of the chamber to the left in this photograph.



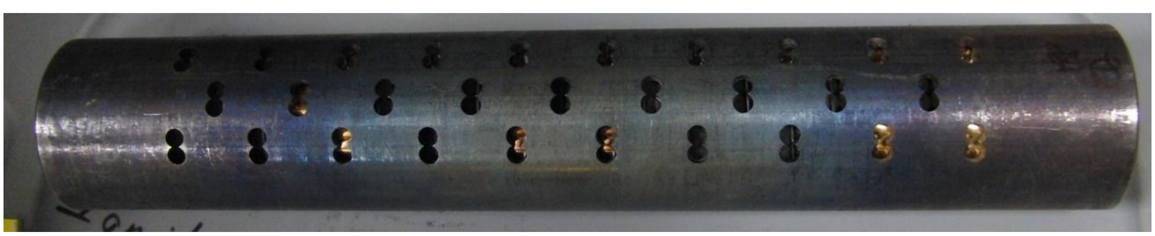
Photograph 8: Blank end view of the test fixture, showing the placement of the thermocouples and 1 inch separation distance.



Photograph 9: Top view of the test fixture showing the installation of both pressure transducers for Test 04.



Photograph 10: Rear view of the test fixture showing the installation of both pressure transducers into the tees for Tests 5 and 6.



Photograph 11: Photo showing typical burst foil removal ratio of 70% for the 0.004” thick burst foil. Subsequent testing will be performed with 0.002” material.