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Evaluation of D-1 Fuel Nozzle Failures at Extreme Temperatures

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by

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Testing was conducted to reproduce and verify the failure mode experienced with D-1 nozzles as used with the HEMMT Tanker Aviation Refueling System and the Advanced Aviation Forward Area Refueling System (AAFARS). The D-1 nozzles failed when exposed to high ambient temperatures, which resulted in fuel spillage. D-1 nozzles from different manufacturers and in differing configurations (with and without hose end regulators (HEPR)) were tested along with a Closed Circuit Refueling (CCR) nozzle. Also, the effect of connecting 50 feet of fuel hose to a Carter D-1 nozzle was investigated.

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EXECUTIVE SUMMARY

Problems and Objectives: The objective of this work was to investigate the effect of thermal expansion and vaporization of fuel trapped in the refueling nozzle, and to determine parameters creating the failures by simulating solar heating on nozzles full of fuel.

Importance of Project: Testing was conducted to reproduce and verify the failure mode experienced with D-1 nozzles as used with the HEMMT Tanker Aviation Refueling System and the Advanced Aviation Forward Area Refueling System (AAFARS). The D-1 nozzles failed when exposed to high ambient temperatures, which resulted in fuel spillage. D-1 nozzles from different manufacturers and in differing configurations (with and without hose end regulators (HEPR)) were tested along with a Closed Circuit Refueling (CCR) nozzle. Also, the effect of connecting 50 feet of fuel hose to a Carter D-1 nozzle was investigated.

Technical Approach: A steel rack holding six nozzles was constructed and placed in a refrigerated cold box. A 250-watt infrared heat lamp was suspended approximately 6 inches above each of the nozzles. A thermocouple sensing the temperature of the nozzle skin served as the feedback element to the heat lamp controller for all six of the lamps. The skin temperature controller was set to 125°F. The nozzles were filled with JP-8 fuel at normal hose operating pressures at 80°F. The hose end valve was then closed, trapping the fuel inside the nozzle. The fuel was then heated to 115 to 120°F (temperature change of 35 to 40°F).

Accomplishments: The results of this testing that simulated solar heating of fuel trapped inside the nozzles will result in failure due to over pressurization. In the case of the Whittaker D-1, pre-6500 serial number Carter D-1, and CCR, the nozzle is catastrophically damaged, allowing fuel to pass through freely. The post-6500 serial number Carter D-1, and the pre-6500 Carter D-1 fitted with the new handle assembly, will be partially damaged by over pressurization but will still shut off fuel flow. The pressure-limiting effect of these nozzles, due to bleeding off the expansion volume fuel, appears to provide protection against total failure for temperature changes beyond the 35 to 40°F delta that the nozzles were exposed to during these tests. Nozzles will reach 180 psi (proof pressure) with a 10°F increase in temperature after the fuel is trapped inside. With the regulator, an additional 12 to 18°F is added to the allowable temperature increase, for a 22 to 28°F temperature increase before the proof pressure is reached. However, the standard regulator's ability to absorb the thermal expansion of the fuel can be defeated by operating hose pressures over 30 psi. The pressure in the D-1 nozzle fitted with the 50-foot hose remained within the designed safe pressure limits of the nozzle.

Military Impact: In order to avoid damage to the nozzle, it is recommended that 50 feet of hose be attached to the nozzle before any valve. A study could be conducted to determine if a shorter length of hose could also prevent over pressures. If the use of the hose is not practical, then the Model 64349 Carter D-1s with serial numbers below 6500 should be outfitted with the new handle assembly (Carter PN KIT64348-12). The temperature extremes to which the nozzle population could be exposed could be analyzed in order to determine if the 12 to 18°F extension of the safe operating delta for the regulator-equipped nozzle is worth the expense of fitting the fielded nozzles with regulators. Carter maintains that the pre-6500 nozzles fitted with new handles are the same as the newer nozzles. A study could determine why the older nozzles fitted with the new handles developed higher pressures than the post SN 6500 nozzles before venting fuel. It is possibly that as the new nozzles age, their peak pressure may rise to the level observed for the older nozzles.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, during the period May 1999 through July 1999 under Contract No. DAAK70-92-C-0059. The work was funded and administered by the U.S. Army Tank-Automotive RD&E Center, Petroleum and Water Business Area, Warren, Michigan. Mr. Luis Villahermosa (AMSTA TR-D/210) served as the TARDEC contracting officer's representative and project technical monitor.

Special thanks is given to Ms. Wendy Mills of TFLRF for her help in the preparation and editing of this report.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1.0 SCOPE

Testing was conducted to reproduce and verify the failure mode experienced with D-1 nozzles as used with the HEMMT Tanker Aviation Refueling System and the Advanced Aviation Forward Area Refueling System (AAFARS). The D-1 nozzles failed when exposed to high ambient temperatures, which resulted in fuel spillage.

D-1 nozzles from different manufacturers and in differing configurations (with and without hose end regulators (HEPR)) were tested along with a Closed Circuit Refueling (CCR) nozzle. Also, the effect of connecting 50 feet of fuel hose to a Carter D-1 nozzle was investigated.

2.0 BACKGROUND

All nozzle failures in the field were D-1 nozzles produced by Carter Ground Fueling Co. D-1 nozzles produced by the Whittaker Corporation , which have a similar poppet seal design, are also in the military supply system, but no failures have occurred. The Closed Circuit Refueling Nozzle (CCR) is also used by the Army to refuel aircraft. The CCR is an older design with a lower flow rate delivery nozzle. High internal pressures, which have caused failure of D-1 nozzles, could conceivably result in CCR nozzle failures as well. Therefore, an example of the CCR nozzle manufactured by Carter was also tested to determine if similar conditions could result in failures.

The Carter D-1 nozzles failed in the field, apparently from over pressure produced by the solar heating and resultant thermal expansion of trapped fuel in the nozzle. A photograph of the Carter D-1 nozzle is shown in Figure 1. Fuel becomes trapped in the nozzle if the hand-operated valve, located on the fuel hose unisex coupling, is inadvertently closed with the nozzle charged with fuel under pressure. The failures have been a tensile structural failure of the poppet link (1), which connects the poppet valve to the actuator handle. Figure 2 is a photograph of a poppet link that failed. When this link fails, the nozzle poppet moves to the fully open position.

Numbers in parenthesis indicate references at the end of the document.

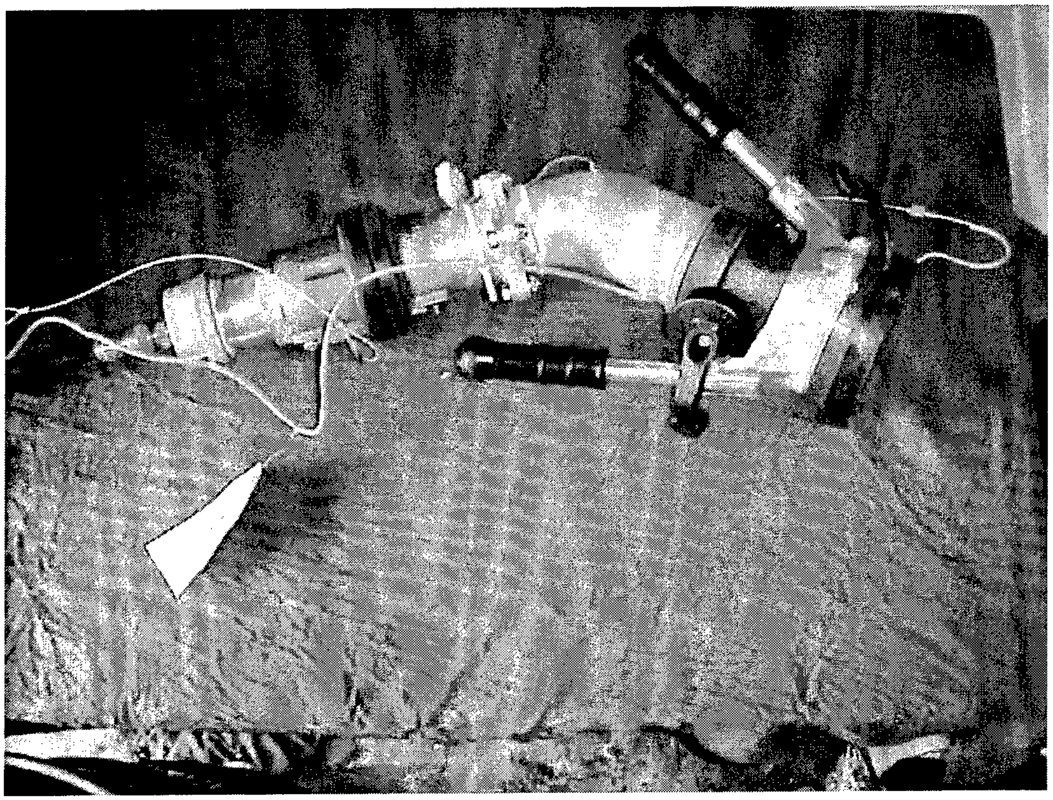


Figure 1. Carter D-1 nozzle

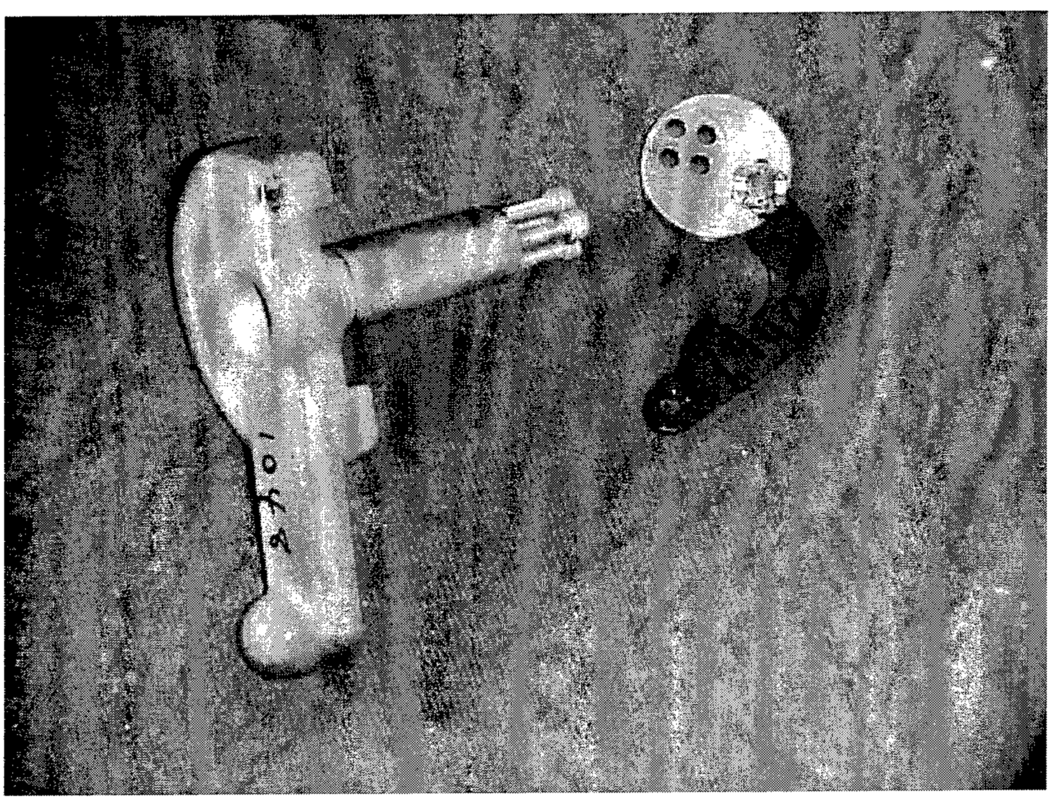


Figure 2. Poppet link that failed

The early production HTARS D-1 nozzles (the only ones to have failed) have no inline pressure regulator for dynamic pressure control. Later versions of HTARS have D-1 nozzles with an inline pressure regulator (HEPR). AAFARS D-1 nozzles, which have not been fielded, also have an inline pressure regulator. Both nozzle configurations were tested to verify that the D-1 nozzle with the pressure regulator responded to the same conditions in the same way as the nozzle without the pressure regulator.

One Carter D-1 nozzle was attached to 50 feet of hose and tested to determine whether or not the over pressures could develop if the valve were left open. Under normal operating conditions, the hose end unisex ball valve is not closed.

3.0 OBJECTIVE

The objective of this work was to investigate the effect of the thermal expansion and vaporization of the fuel trapped in the refueling nozzle, and to determine parameters creating the failures by simulating solar heating on nozzles full of fuel.

4.0 TEST APPARATUS AND PROCEDURE

A steel rack holding six nozzles was constructed and placed in a refrigerated cold box. Figure 3 is a photograph of the test stand with a nozzle shown in the "number 1" test position. A 250-watt infrared heat lamp was suspended approximately 6 inches above each of the nozzles. A thermocouple sensing the temperature of the nozzle skin was located in the number 1 position and served as the feedback element to the heat lamp controller for all six of the lamps. The skin temperature controller was set to 125°F. The 125°F skin temperature test condition set point was experimentally determined by exposing a nozzle to the sun for several hours during a June afternoon in San Antonio. A bead-type thermocouple was held against the skin of a Carter D-1 nozzle to make the measurement. This same type of thermocouple was later used to measure the nozzle skin temperatures of each nozzle during testing.

A 500-psi pressure transducer was installed in each nozzle, as well as an internal fuel temperature thermocouple utilizing the two 0.25-inch pipe threaded holes in the D-1 nozzles. Each temperature and pressure reading was recorded at 1 Hz using a PC data acquisition system.

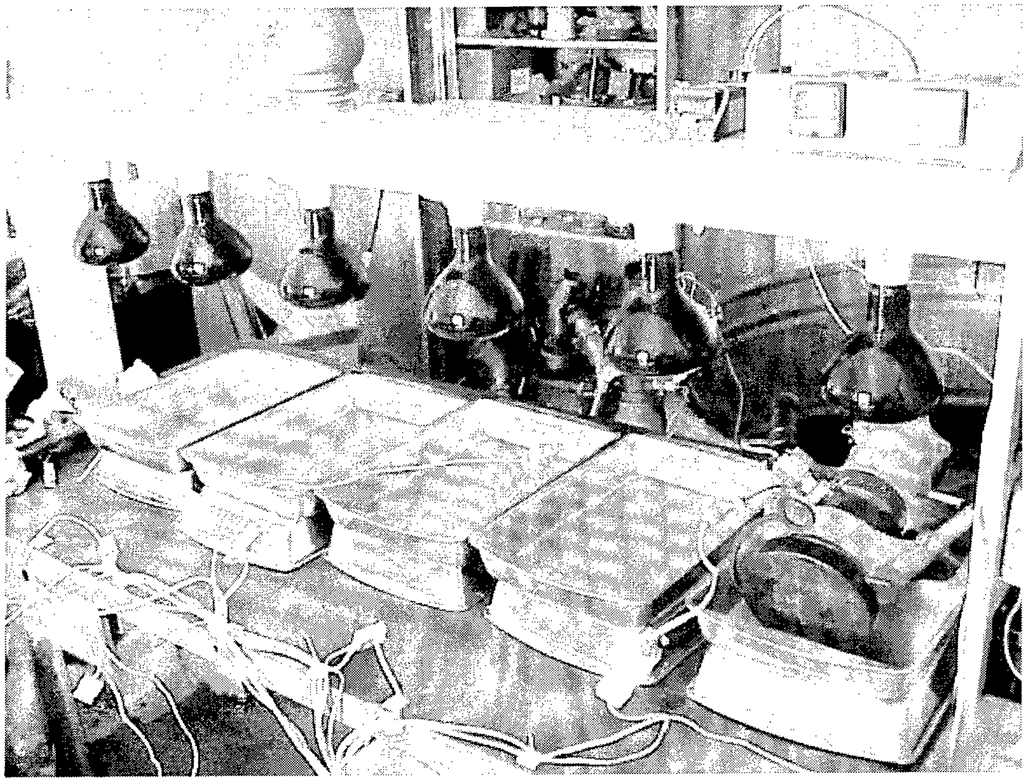


Figure 3. Test stand with a nozzle shown in the "number 1" test position

The CCR nozzles did not have the two 0.25-inch NPT holes, which were used for the instrumentation of the D-1s. For the CCR nozzle two unisex couplings were threaded into opposite ends of a 2-inch pipe nipple in which the pressure transducer and thermocouple were installed via 0.25-inch NPT holes made in the side of the pipe nipple.

In order to simulate the fuel hose normally connected to each nozzle and provide a means to charge the nozzles with fuel, six "pigtail" assemblies were made. Each pigtail consisted of a valved unisex coupling that had pipe thread on the opposite end, which was capped. Each pipe cap was drilled and tapped to accept a 0.75-inch hose Parker male connector. Two feet of 0.75-inch hose was attached to the cap and terminated on the opposite end with a dry break quick connect.

The mating aircraft side receivers for the D-1 and CCR nozzles were each mounted to the bottom of an approximately 5-gallon reservoir. Just prior to testing, each nozzle was filled with JP-8 fuel by pumping from the reservoir and circulating the fuel through the pigtail and nozzle. The fuel-charging system was located in the cold box and its temperature was the same as the controlled air temperature, 80°F. The fuel was allowed to circulate several minutes while the pressure transducer was loosened, allowing air to be bled. The fuel-delivery valve was then closed, which allowed the pressure in the nozzle to build to the desired charge pressure set on the circulating pump pressure regulator. This pressure regulator was set to 30 psi for the majority of the nozzle testing and 88 psi for some testing. The unisex valve located on the pigtail would then close, the nozzle was placed in the rack, and the thermocouples and pressure transducer was connected to the computer.

One Carter D-1 nozzle was tested with 50 feet of fuel delivery hose attached. This nozzle and hose were charged in a manner similar to the others, but the unisex pigtail was mated to the fuel delivery hose rather then the nozzle body. When the fuel was circulating through the hose and nozzle assembly, an effort was made to purge air bubbles in the hose towards the nozzle and into the reservoir. The hose was then coiled inside a 5-foot diameter circular "water trough", as shown in Figure 4. The water trough kept the hose from straightening when fuel pressure was applied.

Four 250-watt infrared heat lamps were placed approximately 1.5 feet from the coiled hose. The lamps were controlled to 125°F using a bead thermocouple located on the hose.

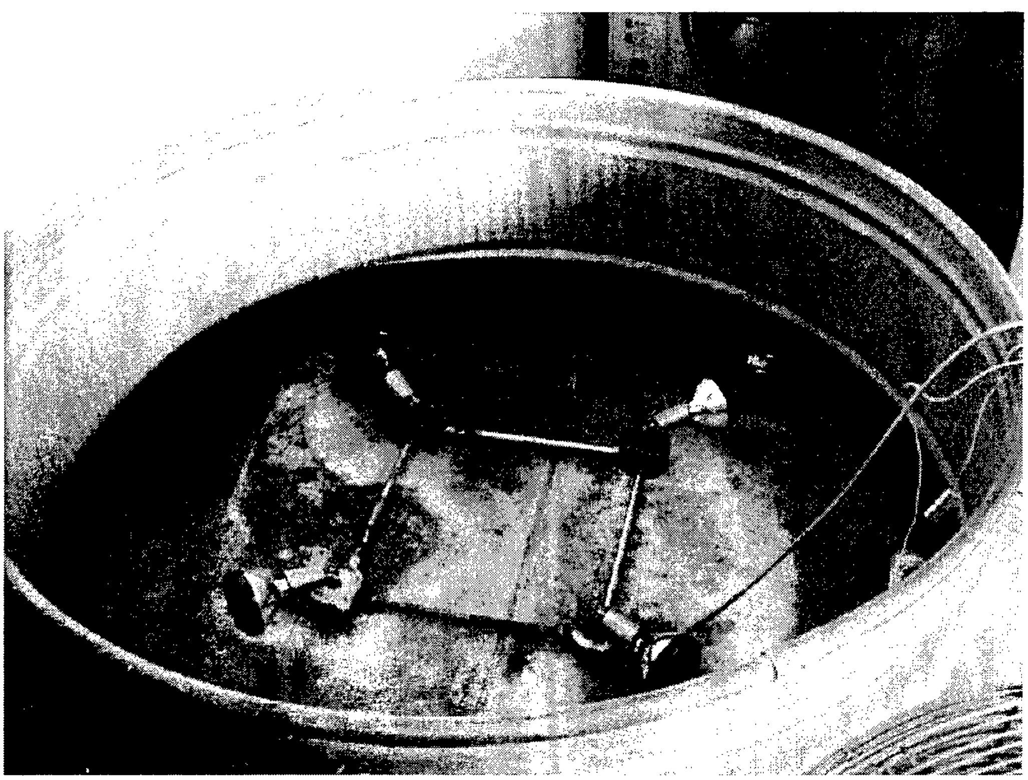


Figure 4. Hose coiled inside a 5-foot diameter circular "water trough"

5.0 NOZZLE TESTING RESULTS

Six groups of nozzles were tested. The test results are summarized in Table 1. The test description refers to the nozzle group and the number of the repeat cooling/heating cycle for that group. For example, "G2-3" is the second group and the third heating cycle. In the nozzle description, "C" is for Carter and "W" for Whittaker. "R" represents a hose end regulator, and "NR" is a modified HEPR regulator supplied by Carter. Carter D-1 nozzles with serial numbers under 6500 are designated as "O" for the old style valve handle and poppet link. Carter D-1 nozzles with serial numbers above 6500 were fitted with a redesigned handle and poppet link made to revised specifications, which include a maximum hardness specification along with the minimum. This change was made to preclude brittle failures of the link. The peak pressure and temperatures shown were the maximum attained. Initial pressure refers to the pressure in the nozzle body before switching on the heating lamps. Refrigeration in the test cell was switched off at this time. The charge pressure was developed in the nozzle when filled with fuel while the nozzle valve was closed, which dead headed the flow. A properly functioning valve should indicate either 90-88 psi or 30 psi (the set point on the charging pump regulator) when deadheaded in this manner. A pressure less than full deadhead indicated that the nozzle was not completely shutting off. Nozzles that failed to shut off completely are noted as "damaged" in the remarks column. "Operational" indicates that the nozzle valve handle and poppet move and appear to function normally. "Initial Poppet", "Final Poppet", and "Change" refer to the measurement of the poppet valve face relative to the nozzle body. The assembly manual specifies that the Carter D-1 be set from 0.070 to 0.110 inches, and the Whittaker D-1 from 0.490 ± 0.014 inches. Distortion of the nozzle body and linkage due to over pressure decreases the poppet height value of the Carter D-1. Nozzle height values for the Whittaker increase as a result of over pressure, since this measurement is relative to a location behind the poppet face. There are no poppet height measurements for the first two nozzle groups. The Carter D-1 poppet measurement is made relative to an elastomer surface, which introduced variability to the results. For example, the G6-1 final height for the OC-D1-NH-R is 0.058 inches. The same measurement taken the next day for the initial readings of test G6-2 is 0.069 inches (a variance of 0.009 inches).

Figure 5 compares the maximum pressures developed for each of the nozzle configurations tested. Since each bar is an average of several tests at different peak temperatures, the average peak fuel temperature is shown above each bar.

TEST DESCR	NOZZLE DESCR	SER NUM	PEAK PRESS psi	FUEL TEMP F	SKIN TEMP F	CHARGE PRESS psi	INITIAL PRESS psi	FINAL PRESS psi	NOZZLE LEAKAGE ml	INITIAL POPPET inches	FINAL POPPET inches	POPPET CHANGE inches	REMARKS
G1-1	NC-D1	6992	225	108	128	90	29.8	NR	NR	NR	NR	Na	operational
	NC-D1-R	6985	85	110	127	90	29.8	NR	NR	NR	NR	Na	operational
	NC-D1-H	6998	90	112	141	90	79	NR	NR	NR	NR	Na	operational
	W-D1	218	790	109	126	90	38.6	NR	NR	NR	NR	Na	operational
	CCR	6505	685	108	119	90	11.5	NR	NR	Na	Na	Na	operational
G1-2	NC-D1	6992	229	113	128	90	12.7	90	17	NR	NR	Na	operational
	NC-D1-R	6985	118	115	128	90	31.8	90	1.5	NR	NR	Na	operational
	NC-D1-H	6998	105	108	134	90	86.7	90	17.5	NR	NR	Na	operational
	W-D1	218	616	109	118	90	30.6	90	9	NR	NR	Na	operational
	CCR	6505	1044	104	112	90	33.7	0	0	Na	Na	Na	broken inside, no external leakage
G1-3	NC-D1	6992	205	114	140	90	33	NR	26	NR	NR	Na	operational
	NC-D1-R	6985	300	110	135	90	43	NR	22	NR	NR	Na	op,1130 psi hose side of reg
	NC-D1-H	6998	110	105	120	90	68	NR	3	NR	NR	Na	operational
	W-D1	218	880	100	110	90	11	NR	25	NR	NR	Na	"O' ring seal failed with loss of fluid
G2-1	NC-D1	7011	250	119	135	88	35.6	68	13.5	NR	NR	Na	Damaged, operational
	NC-D1-R	6986	310	121	126	88	38.6	66	14	NR	NR	Na	Damaged, operational
	NC-D1-H	7000	106	118	119	88	76.6	87	<1	NR	NR	Na	operational
	NC-D1-R	6985	220	127	131	88	12.9	54	8	NR	NR	Na	Damaged, operational
	W-D1	216	740	119	116	88	23.9	86	<1	NR	NR	Na	operational
	CCR	6492	1070	108	122	88	48.1	0	>900	NR	NR	Na	failed with loss of fluid
G2-2	NC-D1	7011	210	110	135	68	4.7	55	13.5	NR	NR	Na	Damaged, operational
	NC-D1-R	6986	249	148	135	66	10.3	42	2.5	NR	NR	Na	Damaged, operational
	NC-D1-H	7000	129	120	135	87	86.6	86	2	NR	NR	Na	operational
	NC-D1-R	6985	260	141	155	54	8.1	25	<1	NR	NR	Na	Damaged, operational
	W-D1	216	740	131	121	86	7	80	<1	NR	NR	Na	operational
G2-3	NC-D1	7011	210	120	132	55	0	52	15.5	NR	NR	Na	Damaged, operational
	NC-D1-R	6986	230	125	135	42	0	40	2.5	NR	NR	Na	Damaged, operational
	NC-D1-H	7000	127	122	135	86	78.9	86	<1	NR	NR	Na	operational
	NC-D1-R	6985	230	125	143	25	0	20	2.5	NR	NR	Na	Damaged, operational
	W-D1	216	725	120	135	80	0	82	<1	NR	NR	Na	operational
	OC-D1	1940	475	NR	NR	NR	NR	0	>20	0.105	failed	Na	link failed at 475 psi
G3-1	OC-D1	2339	465	120	127	88	10.8	0	22	0.065	failed	Na	link failed at 465 psi
	NC-D1	6981	310	124	127	88	29.5	35	4	0.083	0.06	0.023	Damaged, operational
	NC-D1	6978	340	124	126	88	45.2	84	22	0.096	0.055	0.041	Damaged, operational
	NC-D1-R	7003	265	128	124	30	13.6	30	2	0.087	0.072	0.015	operational
	W-D1	193	860	119	111	85	24.5	30	>20	0.498	0.553	-0.055	Damaged, operational
	W-D1-R	215	400	125	126	45	3.2	28	1	0.484	0.533	-0.049	Damaged, operational
G4-1	NC-D1-R-NR	6995	268	132	166	30	21	30	0	0.075	0.043	0.032	operational
	OC-D1-R-NR	1852	408	141	166	30	14	30	2	0.078	0.058	0.02	operational
	OC-D1-R	3603	417	138	175	30	19	30	2.5	0.082	0.048	0.034	operational
G4-2	NC-D1-R-NR	6995	170	112	127	30	10.8	30	0	0.055	0.052	0.003	operational
	OC-D1-R-NR	1852	281	119	130	30	11.5	30	5	0.065	0.061	0.004	operational
	OC-D1-R	3603	250	125	117	30	13.8	30	2.5	0.044	0.044	0	operational
G4-3	NC-D1-R-NR	6995	153	104	125	30	8.1	30	0	0.057	0.052	0.005	operational
	OC-D1-R-NR	1852	327	112	129	30	8.3	30	3	0.069	0.054	0.015	operational
	OC-D1-R	3603	369	113	113	30	12.9	30	2.5	0.055	0.041	0.014	operational
G4-4	NC-D1-R-NR	6995	278	108	117	88	26.7	88	0	0.053	0.045	0.008	operational
	OC-D1-R-NR	1852	508	114	122	88	54.5	88	<1	0.06	0.04	0.02	operational
	OC-D1-R	3603	495	113	123	88	34.4	88	2.5	0.059	0.046	0.013	operational
G4-5	NC-D1-NR-R	6995	271	121	133	30	12.4	30	0	0.053	0.053	0	operational
	OC-D1-NR-R	1852	478	132	150	30	19.6	0	<1	0.05	0.04	0.01	handle shaft bent
	OC-D1-R	3603	476	127	130	30	26.9	30	2.5	0.055	0.045	0.01	operational
G4-6	NC-D1-NR-R	6995	260	121	133	30	21.6	30	0	0.053	0.049	0.004	operational
	OC-D1-NR-R	1852	0	126	151	0	1.5	0	86	0.042	0.043	-0.001	dropped point, failed in previous run
	OC-D1-R	3603	445	128	131	30	23.1	30	2.5	0.048	0.045	0.003	handle shaft bent
G5-1	OC-D1-NH-R	1940	150	111	133	30	11.7	30	<1	0.077	0.074	0.003	operational
	OC-D1-NH	1048	422	114	126	30	16.6	30	4	0.074	0.055	0.019	damaged, operational
G6-1	OC-D1-NH-R	1940	262	121	126	30	13.6	30	<1	0.076	0.058	0.018	operational
	OC-D1-NH	1048	447	124	123	30	8.7	30	6	0.073	0.053	0.02	damaged, operational
	OC-D1-NH-R	5142	60	127	129	30	17.4	0	25	0.079	0.077	0.002	dropped point due to leaking handle seal
	OC-D1-NH	5204	340	121	138	30	16.6	30	<1	0.083	0.043	0.04	operational
G6-2	OC-D1-NH-R	1940	253	112	119	30	7.6	30	<1	0.069	0.045	0.024	operational
	OC-D1-NH	1048	424	121	118	30	14.8	30	<1	0.045	0.002	0.043	damaged, operational
	OC-D1-NH-R	5142	203	121	119	30	17.6	30	<1	0.075	0.065	0.01	repaired handle seal
	OC-D1-NH	5204	402	114	114	30	16.7	30	<1	0.06	0.02	0.04	operational
G6-3	OC-D1-NH-R	1940	340	134	141	30	11.2	30	3	0.055	0.035	0.02	operational
	OC-D1-NH	1048	428	134	132	30	12.7	30	10	0.035	0.003	0.032	damaged, operational
	OC-D1-NH-R	5142	400	139	133	30	19	30	6	0.075	0.025	0.05	operational
	OC-D1-NH	5204	410	128	140	30	13.6	30	3	0.03	0.007	0.023	operational

OC Carter D-1 nozzle with the old style valve handle
NC Carter nozzle with the new style valve handle
W Whittaker D-1 nozzle
NH New type of valve handle
H 50 foot of hose attached to nozzle

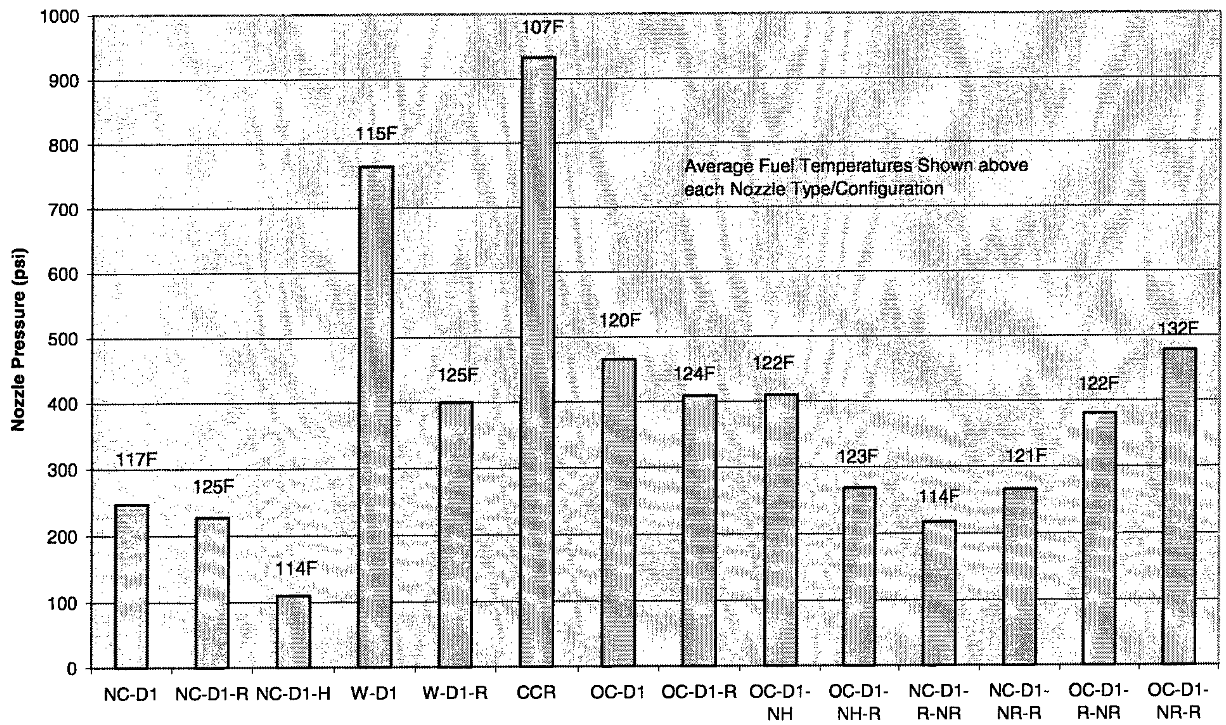


Figure 5. Averaged nozzle pressures for each type of nozzle or configuration

5.1 The Carter D-1 with Hose

The Carter D-1 with the 50-foot hose (NC-D1-H) never developed a pressure over 130 psi (Figure 6). Test temperatures varied from 105 to 123°F, with pressures averaging approximately 108 psi. Leakage, following a high 17-ml for the first test, was less than 2 ml after the remaining tests. This is the only nozzle/configuration tested in which the pressures always remained below the D-1 specification of 180-psi proof and 240-psi burst pressure.

5.2 The New Carter D-1

The post-6500 Carter D-1 nozzle responded differently to over pressures than the pre-6500 nozzles. Figure 7 plots pressure versus temperature, illustrating the nozzle's "pressure regulating" feature. Pressure never rises above 250 psi in this particulate test despite the increasing fuel temperature. Pressure is limited by bleeding off a small amount of fuel. Fuel leakage results roughly correlate with clipping of the pressure. The individual results for the new Carter nozzle (Figure 8) illustrate the consistent limiting of pressure to approximately 250 psi. After the test, these nozzles functioned normally, although the decrease in poppet height indicates that over pressure distorted the nozzle body, handle, and/or linkage.

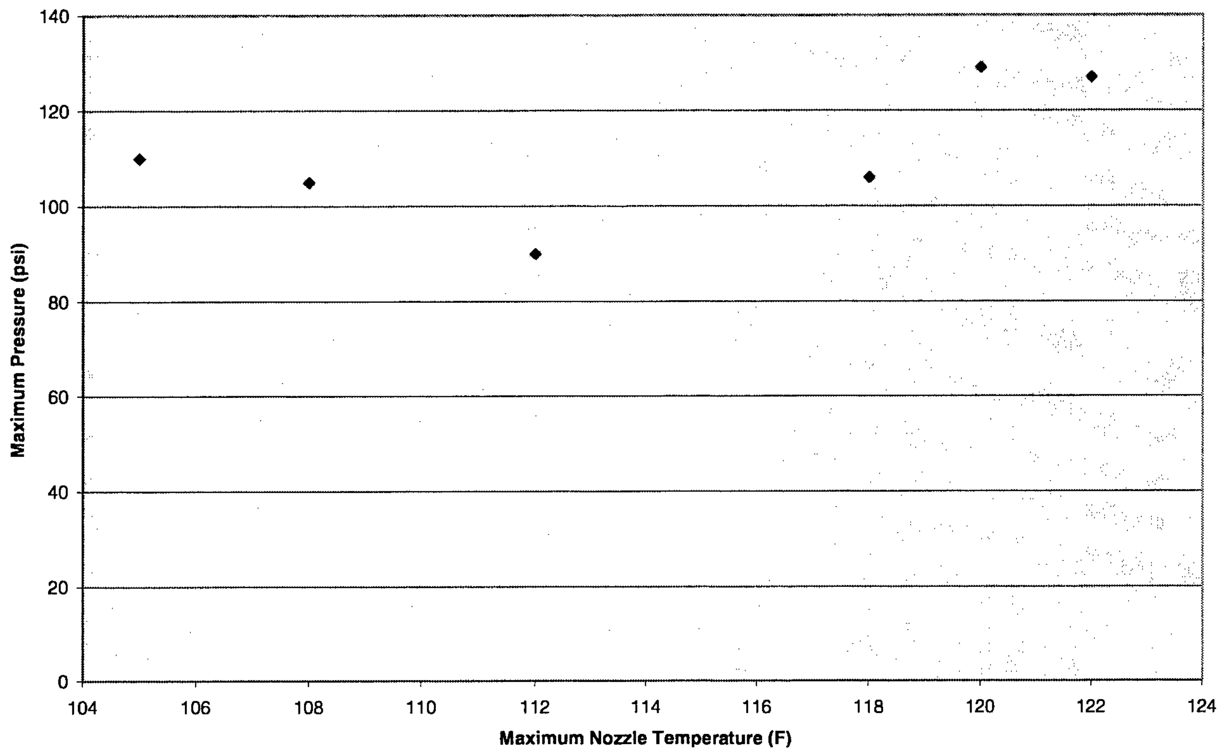


Figure 6. Maximum pressure versus nozzle temperature NC-D1-H

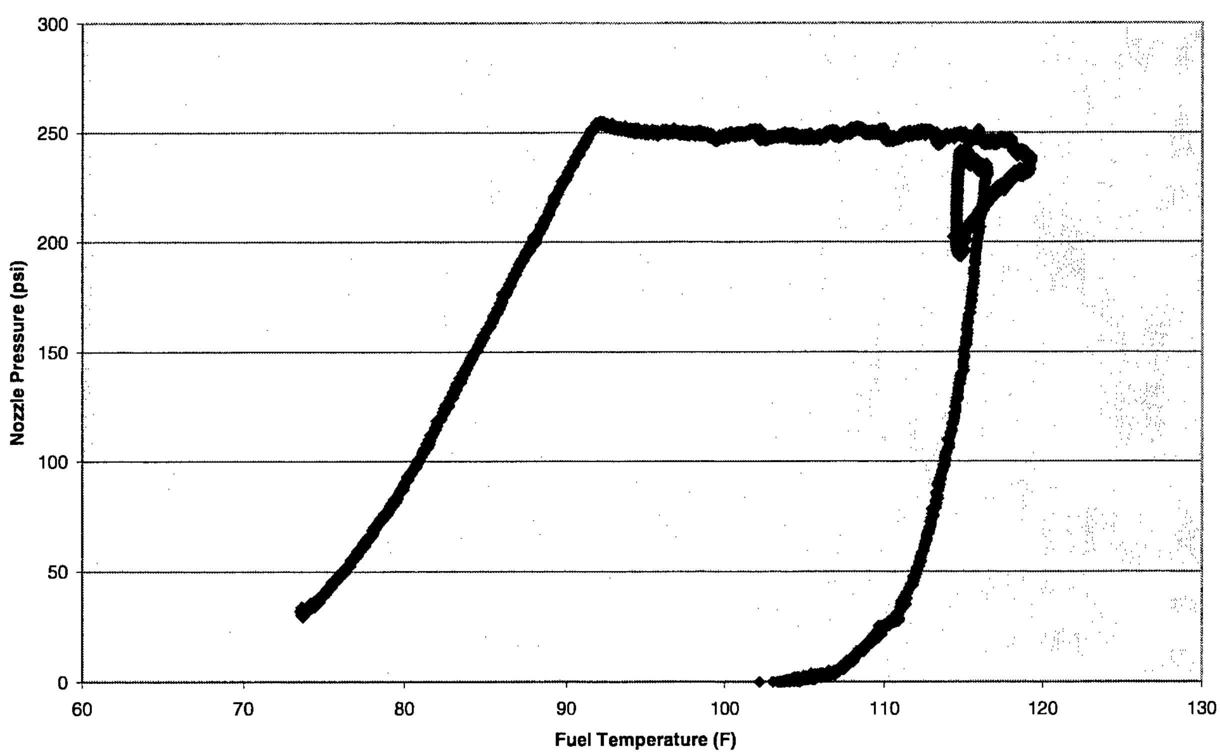


Figure 7. Nozzle pressure versus temperature NC-D1

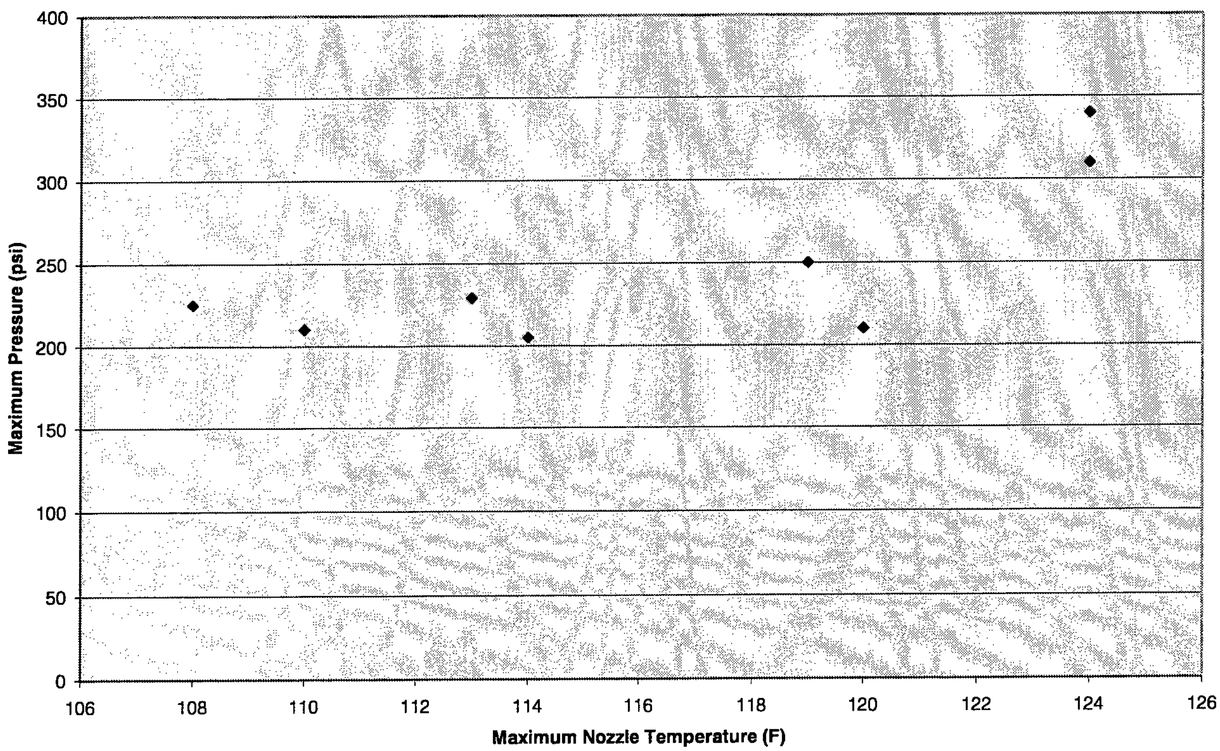


Figure 8. Maximum pressure versus nozzle temperature NC-D1

5.3 The Old Carter D-1

After testing several new nozzles without simulating the field failures, a meeting was held with engineers from Carter Manufacturing to discuss the realization that the handles and links on one of the pre 6500 nozzles were different. All of the field failures of the link had been with the earlier versions of the nozzle. Therefore, nozzle SN 1940 obtained from Ft. Hood was tested, and a failure of the link occurred. The Carter engineers witnessed the test and confirmed that the failure mode was identical to the fielded nozzles they had examined(1).

The pressure-versus-temperature plot for an old Carter D-1 is shown in Figure 9. The pressure rises quickly to 435 through 450 psi when failure of the link occurs. A temperature increase of 13°F results in a pressure increase to the design burst pressure. A temperature increase of 40°F from the time the fuel is trapped results in the failure of the link. Figure 10 is a photograph of a broken link. The link fails in tension, leaving the poppet in the fully open position.

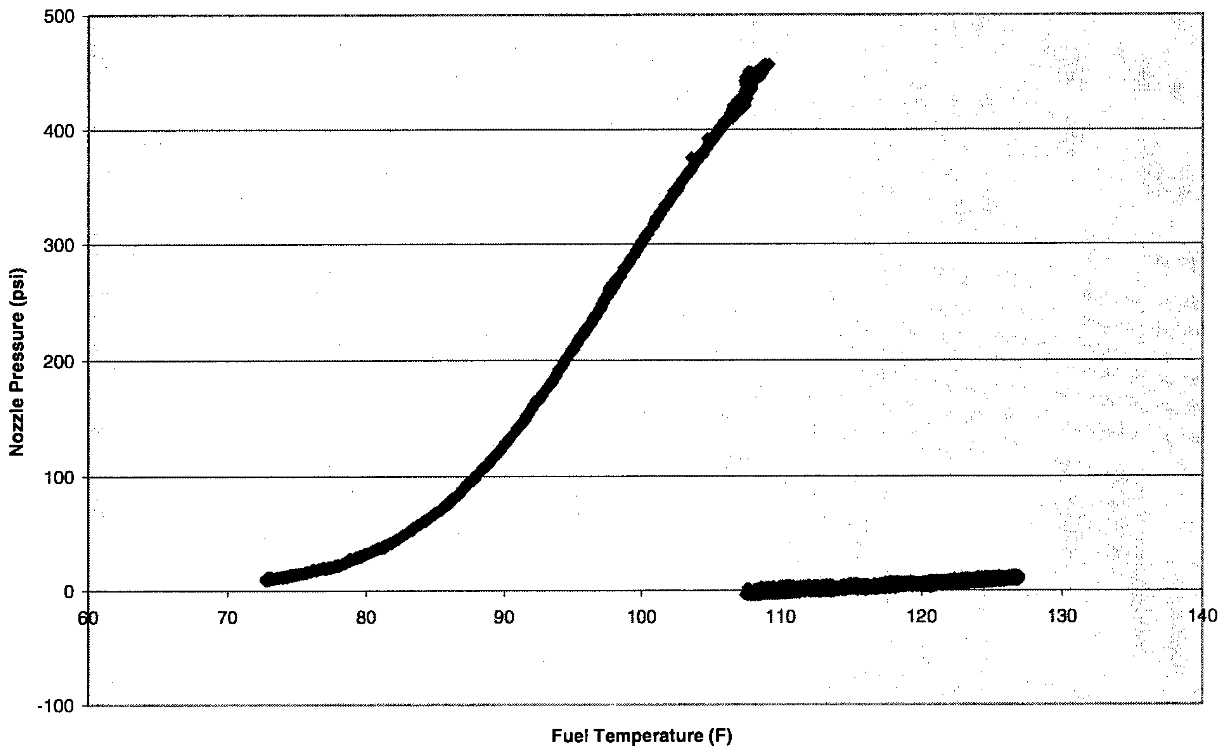


Figure 9. Nozzle pressure versus temperature OC-D1

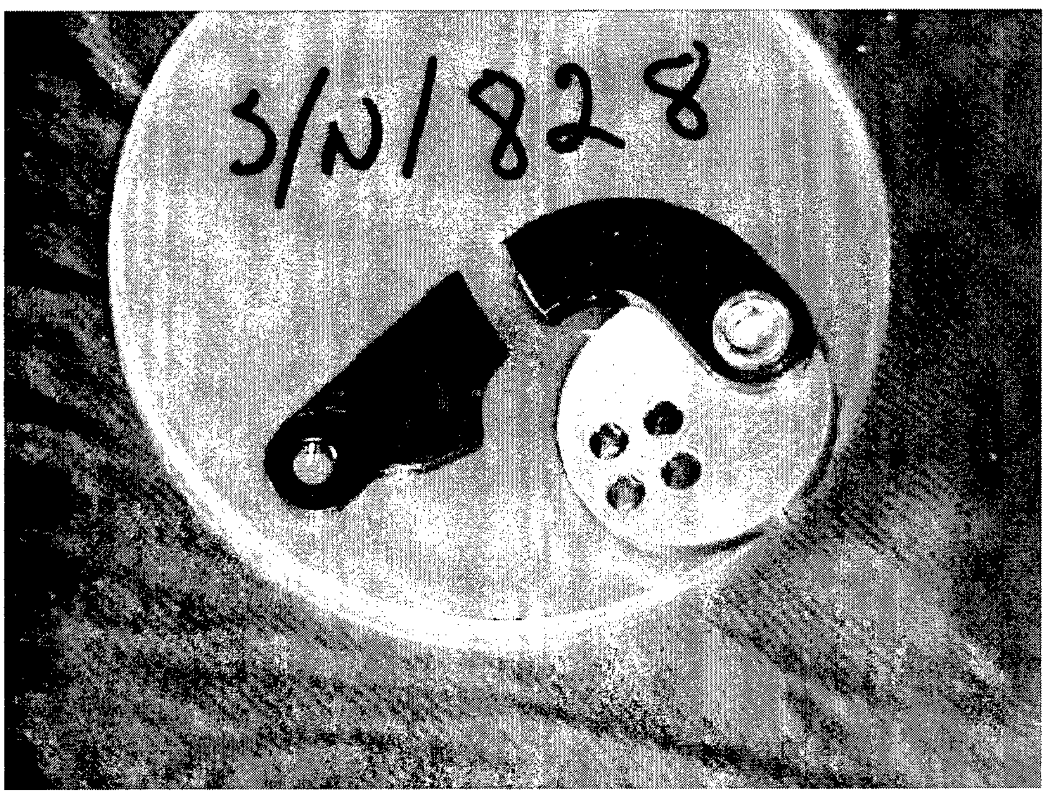


Figure 10. Broken link

5.4 The Effect of Pressure Regulators

Once the failure of the fielded nozzles in the test rig could be reproduced, methods to prevent the over pressures were investigated. It is current practice to field the D-1 nozzle with a hose end pressure regulator (HEPR). The regulator is set to hold the pressure to 55 psi. Some older systems do not have this valve installed. In the normal mode of operation, the regulator controls the downstream pressure to the set point by varying the position of a valve. The position of the valve is determined by a balance of forces on a piston. One side of the piston is exposed to the fuel pressure, and the other side sees atmospheric pressure and the force of a spring. As the inlet pressure rises toward the 55-psi set point, the piston moves to the atmospheric/spring side, compressing the spring further and constraining the flow, which increases the pressure drop across the valve until a balance of forces is attained. The regulator requires a fuel flow in order to regulate.

With the fuel trapped inside the nozzle, as in these tests, the regulator could supply an expansion volume for the fuel as it is heated. This is not the normal mode of operation for the regulator. It was determined by filling a regulator with water, then pushing the piston down against the spring so that the movement of the piston could take up approximately 20 ml of fuel expansion. Taking into account the internal volumes of the nozzle, elbows, unisex coupling and the regulator, it was calculated that 18°F of temperature rise could be absorbed by the regulator using published thermal expansion data for JP-8 (2).

Figures 11 and 12 illustrate the effect of the regulator on the pressure response of a nozzle, in this case the new D-1. In Figure 12, the pressure regulator piston begins to absorb the expansion volume at about 30 psi and limits the pressure rise to 40 psi for a 16°F temperature increase. The nozzle without a regulator reached the proof pressure of the nozzle (180 psi), with an 18°F temperature increase from when the 80°F fuel was trapped inside (Figure 11). The regulator adds 16°F to the allowable temperature increase for a total of 34°F.

For the regulator to function as an expansion space, it must not be exposed to a hose pressure greater then 30 psi before the unisex valve is closed. Pressures above 30 psi make the regulator piston move off its fully open seat (Figure 13). A D-1 nozzle with a HEPR was charged to 90 psi. When the unisex valve was closed, the pressure rose rapidly as the fuel heated up with no break in the rise starting at 30 psi.

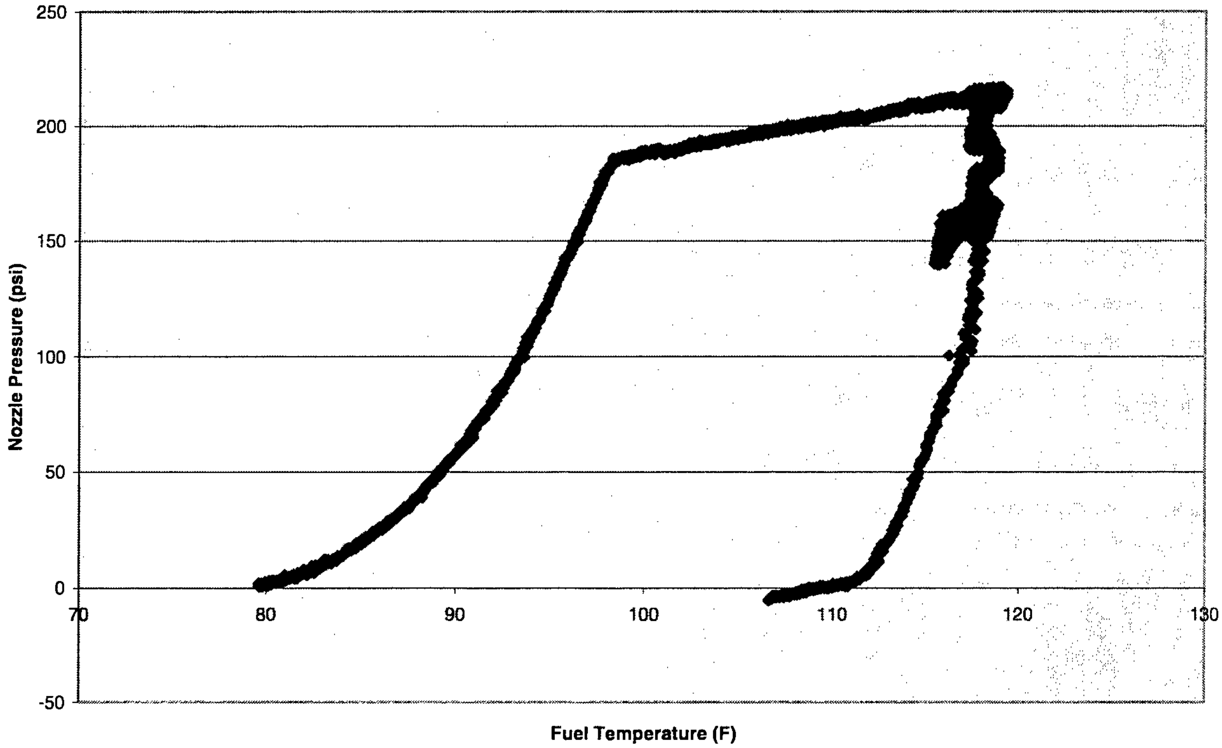


Figure 11. Pressure versus temperature NC-D1

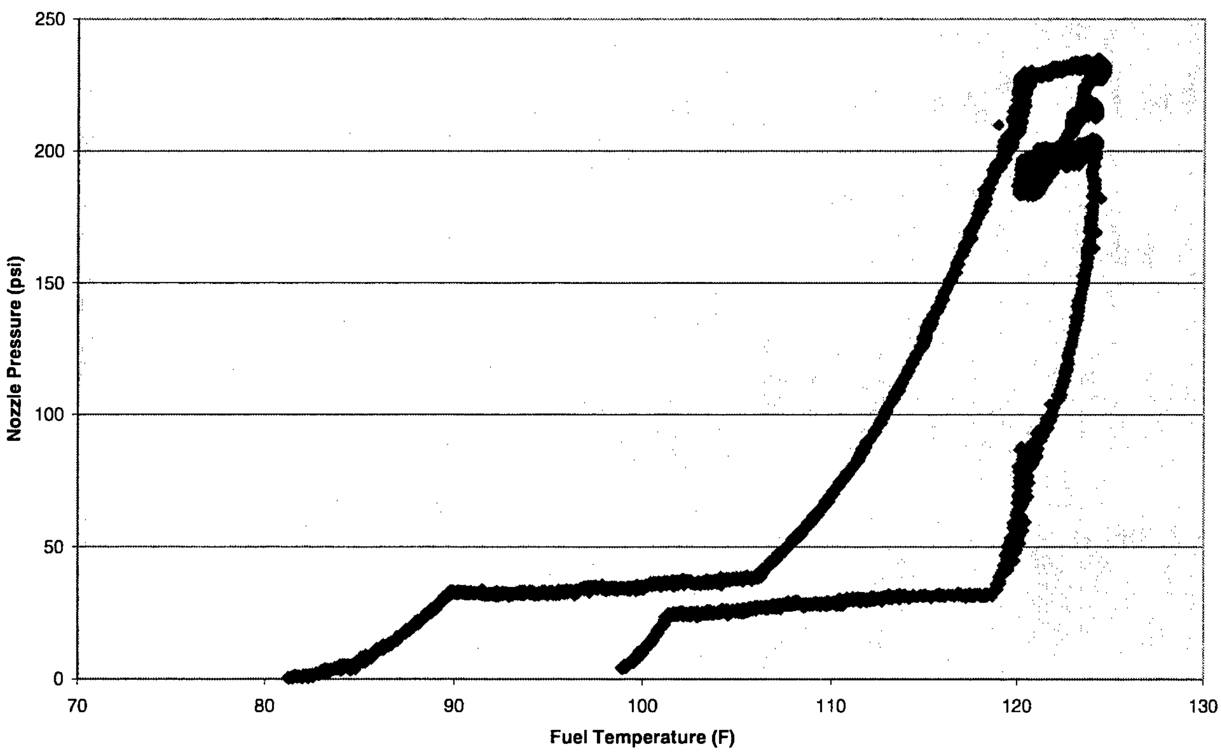


Figure 12. Pressure versus temperature NC-D1-R

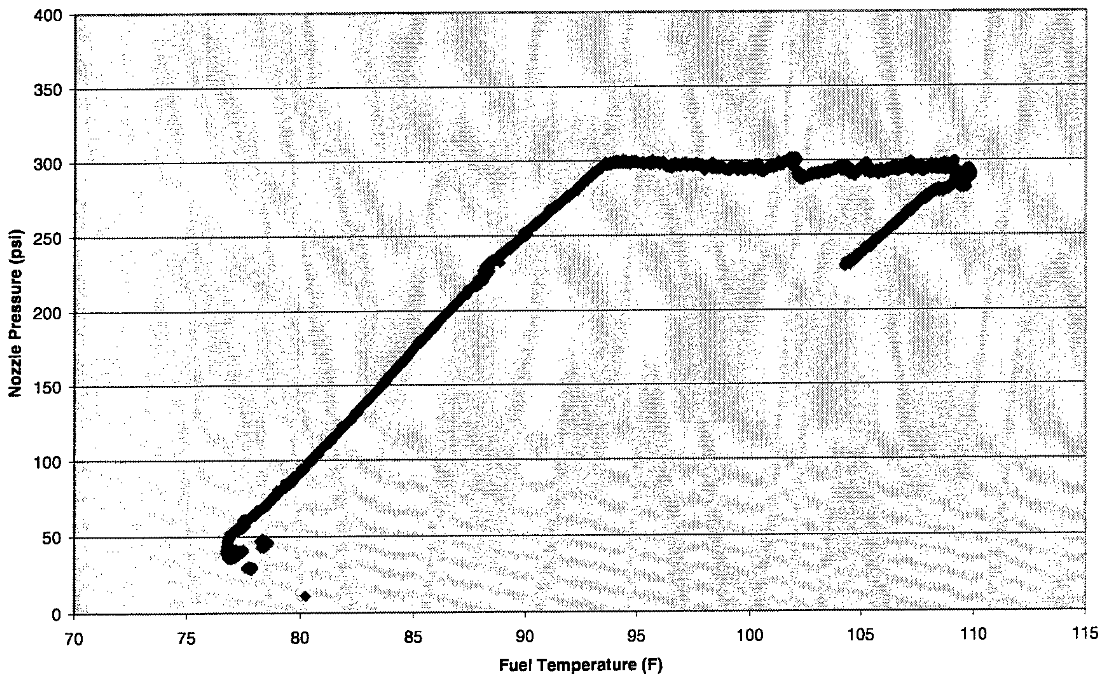


Figure 13. Nozzle pressure versus temperature NC-D1-R

The standard regulator's ability to absorb the expansion fuel volume could be reduced or completely blocked by normal operating pressures in the system. To address this problem, Carter modified a HEPR by putting in a stronger spring. With this unit, approximately 100 psi is required before the piston will begin to move. Figure 14 shows the effect of both the standard regulator and new regulator in series. Starting at 30 psi the standard regulator controlled the pressure for about 8°F before the piston travel reached its limit. Starting at 105 psi, the new regulator controlled the pressure rise out to 155 psi before the piston hit the stop, which limited the pressure for an additional 12°F. The effective temperature span of the new regulator is less than the single regulator due to the additional fuel volume added to the total system volume. Therefore, there is more fuel expansion to absorb per degree temperature increase.

5.5 The Effect of the New Handle/link Retrofit on the Pre SN 6500 Carter D-1

Carter furnished SwRI with several of the new style handles and links to retrofit the pre 6500 nozzles. The effect can be seen by comparing Figure 15 (the pressure plot of an old Carter and new handle) to the Figure 9, which shows the pressure rising to 450 psi before the link failed. The new handle clips the pressure rise at approximately 420 psi, which is similar to the new Carter D-1 self-regulating action at approximately 250 psi. All the nozzles were damaged as indicated by the decreased poppet height, and some were difficult to operate after being over-pressured to 450 psi. However, the link did not fail, and the poppet valve would seal to the 30 psi charging pressure at the end of each test. The self-regulating action of the new handle, due to bleeding off fuel, allows the fuel temperature to increase indefinitely without a failure, whereas the original link would fail at a 40°F increase in temperature.

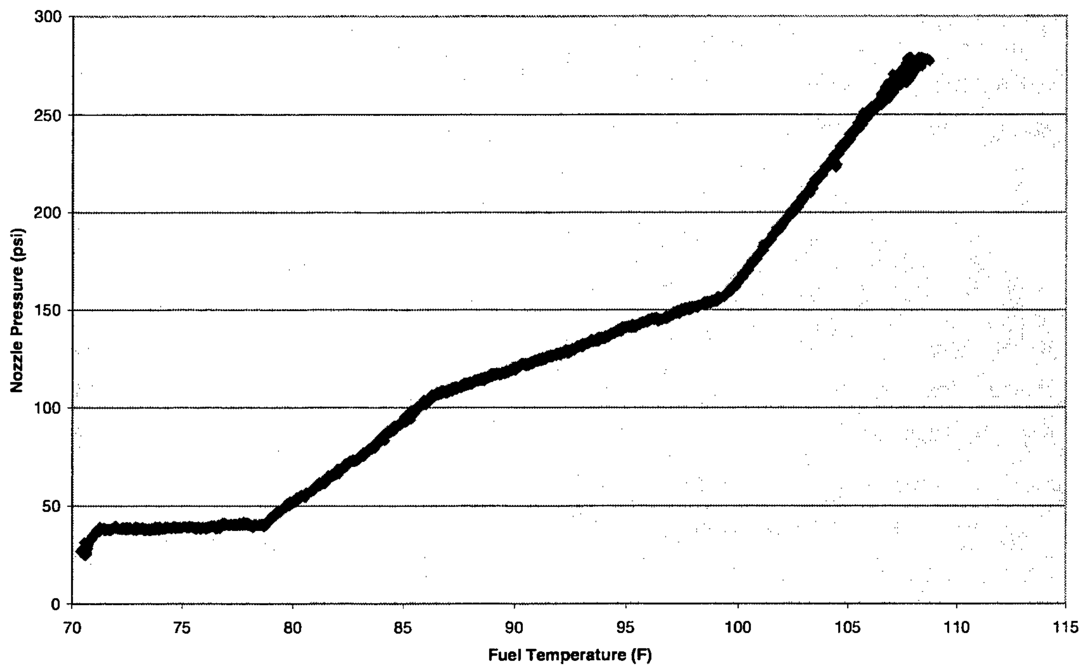


Figure 14. Nozzle pressure versus temperature NC-D1-R-NR

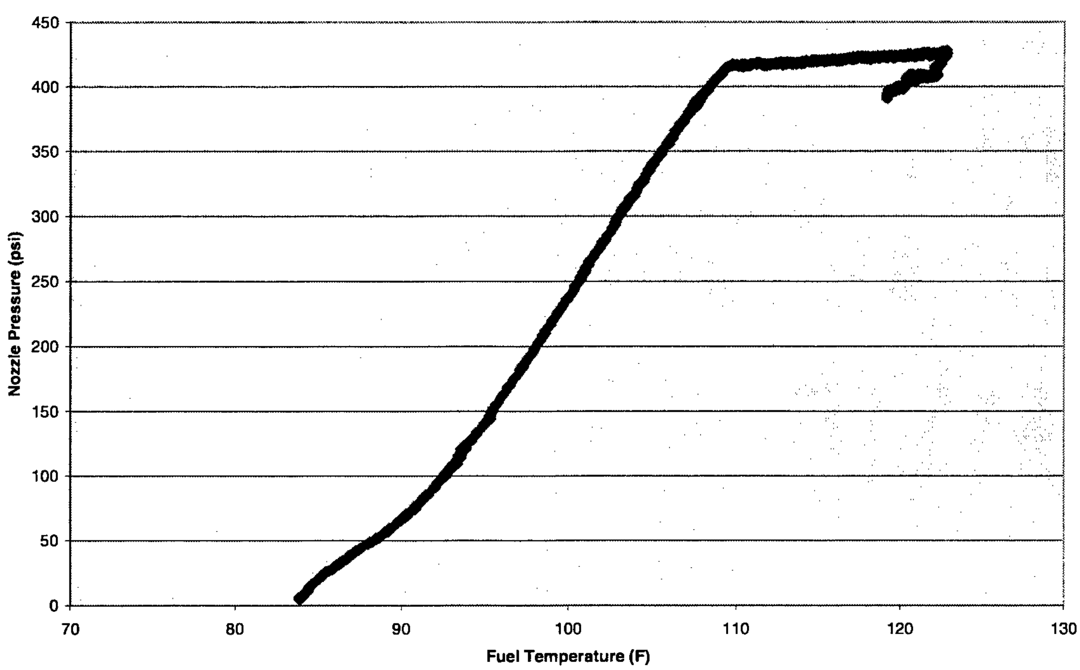


Figure 15. Nozzle pressure versus temperature OC-D1-NH

5.6 The Whittaker D-1 Nozzle

As shown in Figure 16, the pressure in the Whittaker D-1 nozzle quickly rose to 880 psi as a result of a 19°F fuel temperature increase and then failed, losing all the trapped fuel. Figure 17 is a photograph of the seal "O" ring that was forced out of its groove by the over pressure. The Carter engineers stated that this is a common failure mode for the Whittaker nozzle exposed to an over pressure. In tests prior to the one in which the "O" failed, the nozzle withstood pressures over 700 psi during testing and still pressurized to the initial 90 psi charging pressure.

The effect of the regulator on the Whittaker D-1 was similar to the Carter D-1. As shown in Figure 18, the regulator absorbed about 18°F of the fuel expansion volume. The nozzle was exposed to over 45°F of temperature change and pressure rose to 400 psi. The charge pressure was limited to 25 psi to prevent defeating the regulator, and at the end of the test it would only charge to 20 psi, indicating an inability to seal completely.

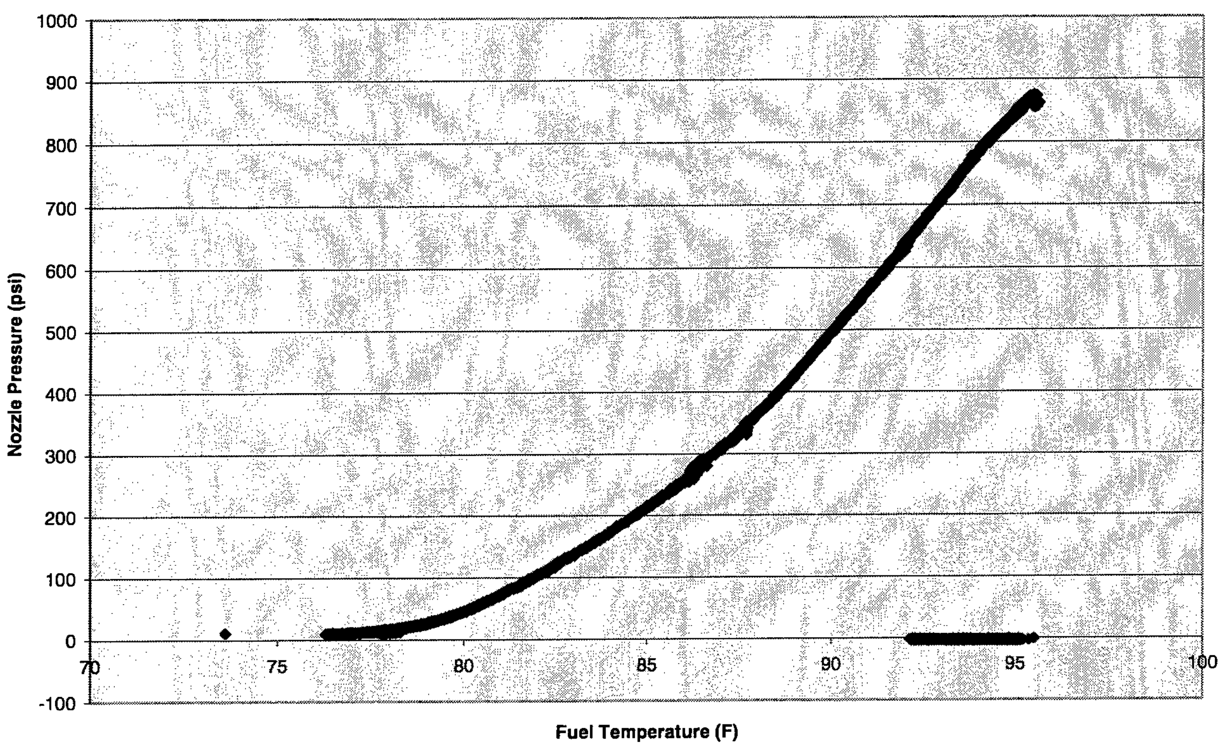


Figure 16. Nozzle pressure versus temperature W-D1

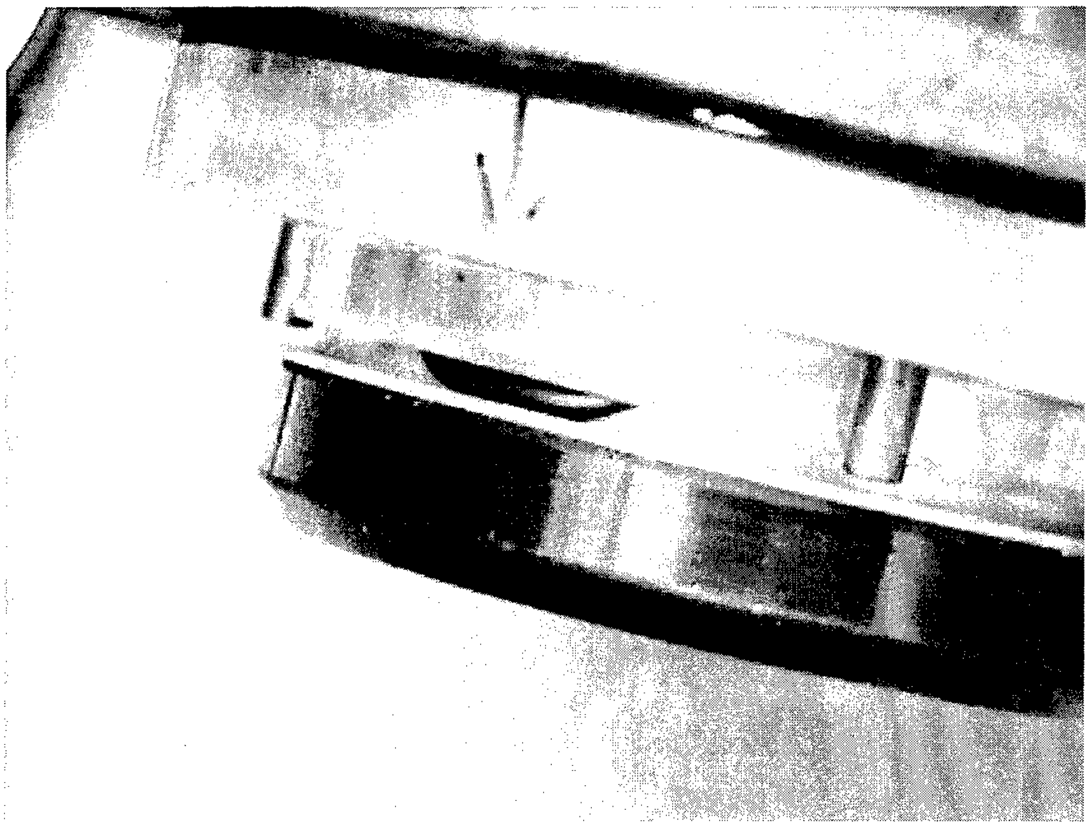


Figure 17. Blown seal

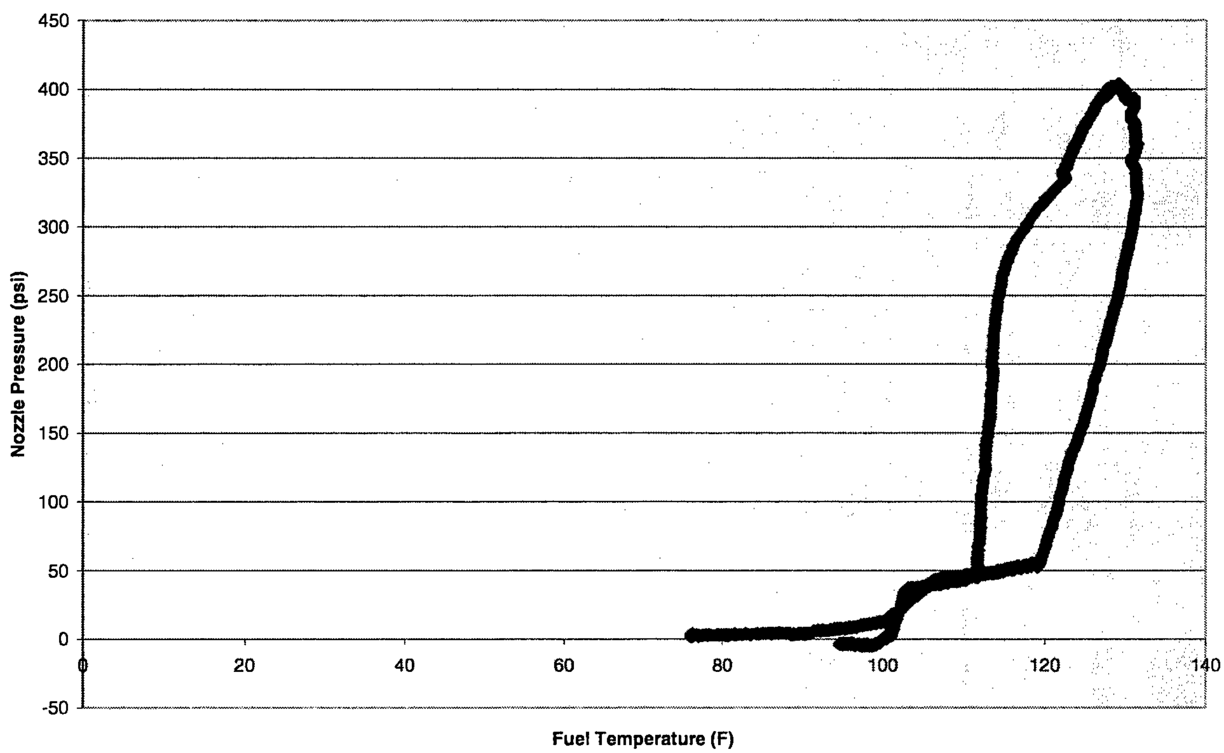


Figure 18. Nozzle pressure versus temperature W-D1=R

5.7 The Carter CCR Nozzle

The Carter CCR nozzle testing was limited to a few tests. During the second test, a pressure of 1040 psi damaged the valve mechanism, preventing the nozzle from operating, but there was no external leakage. Figure 19 is a photograph of the part damaged by the over pressure. The valve handle pins normally act on the plastic ring, which in turn moves the valve poppet. The over pressure resulted in deformation of the plastic by the handle pins. The resulting lost motion of the valve handle prevented the valve from opening. Carter engineers inspected the valve and concluded that it had been over pressured.

6.0 DISCUSSION AND CONCLUSIONS

This test program demonstrated that simulated solar heating of fuel trapped inside the nozzles will result in nozzle failure due to over pressurization. In the case of the Whittaker D-1, pre-6500 Carter D-1, and CCR, the nozzle is catastrophically damaged, allowing fuel to pass through freely. The post-6500

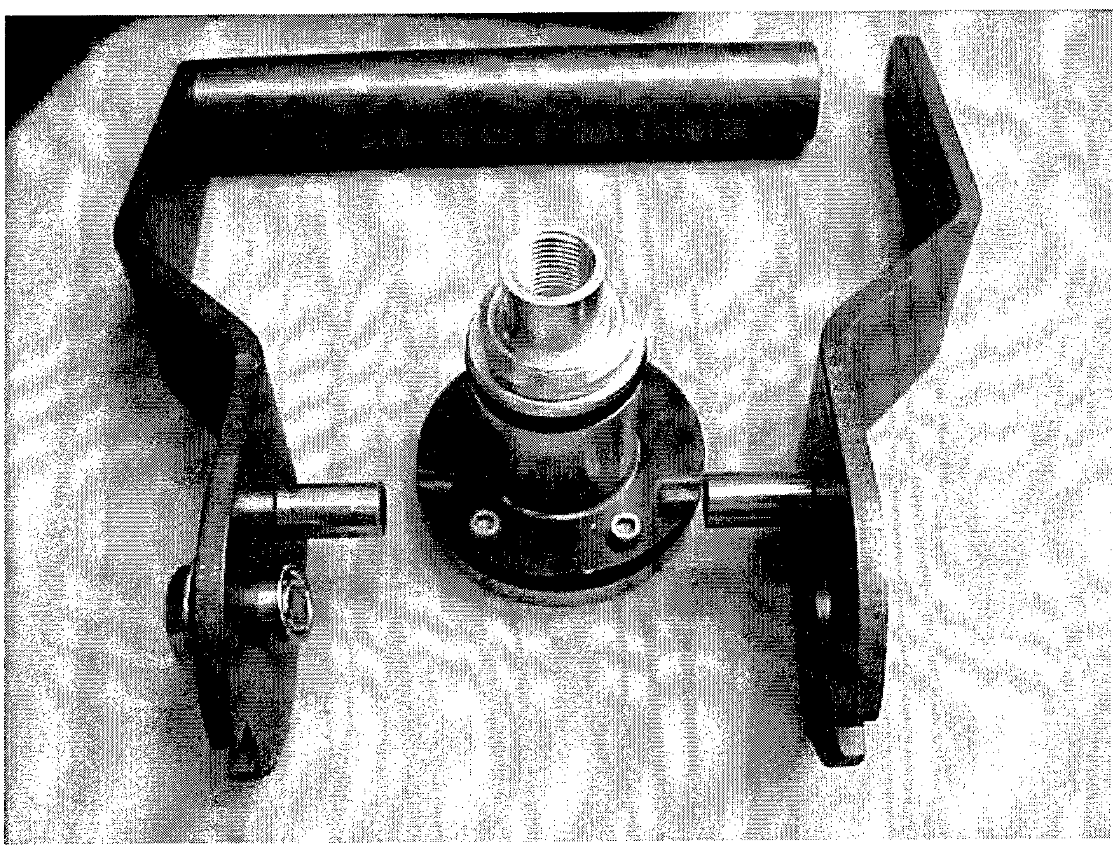


Figure 19. Damaged valve mechanism of CCR part

the pre-6500 Carter D-1 fitted with the new handle assembly, will be partially damaged by over pressurization but will still shut off fuel flow. The pressure-limiting effect of these nozzles, due to bleeding off the expansion volume fuel, appears to provide protection against total failure for temperature changes beyond the 35 to 40°F delta that the nozzles were exposed to during these tests. Nozzles will reach proof pressure with a 10°F increase in temperature after the fuel is trapped inside. With the regulator, an additional 12 to 18°F is added to the allowable temperature increase, for a 22 to 28°F temperature increase before the proof pressure is reached. However, the standard regulator's ability to absorb the thermal expansion of the fuel can be defeated by operating hose pressures over 30 psi, and in the case of the new regulator, 100 psi. The pressure in the D-1 nozzle fitted with the 50-foot hose remained within the designed safe pressure limits of the nozzle.

7.0 RECOMMENDATIONS

In order to avoid damage to the nozzle, it is recommended that 50 feet of hose be attached to the nozzle before any valve. A study could be conducted to determine if a shorter length of hose could also prevent over pressures. If the use of the hose is not practical, then the Model 64349 Carter D-1s with serial numbers below 6500 should be outfitted with the new handle assembly (Carter PN KIT64348-12). The temperature extremes to which the nozzle population could be exposed could be analyzed in order to determine if the 12 to 18°F extension of the safe operating delta for the regulator-equipped nozzle is worth the expense of fitting the fielded nozzles with regulators.

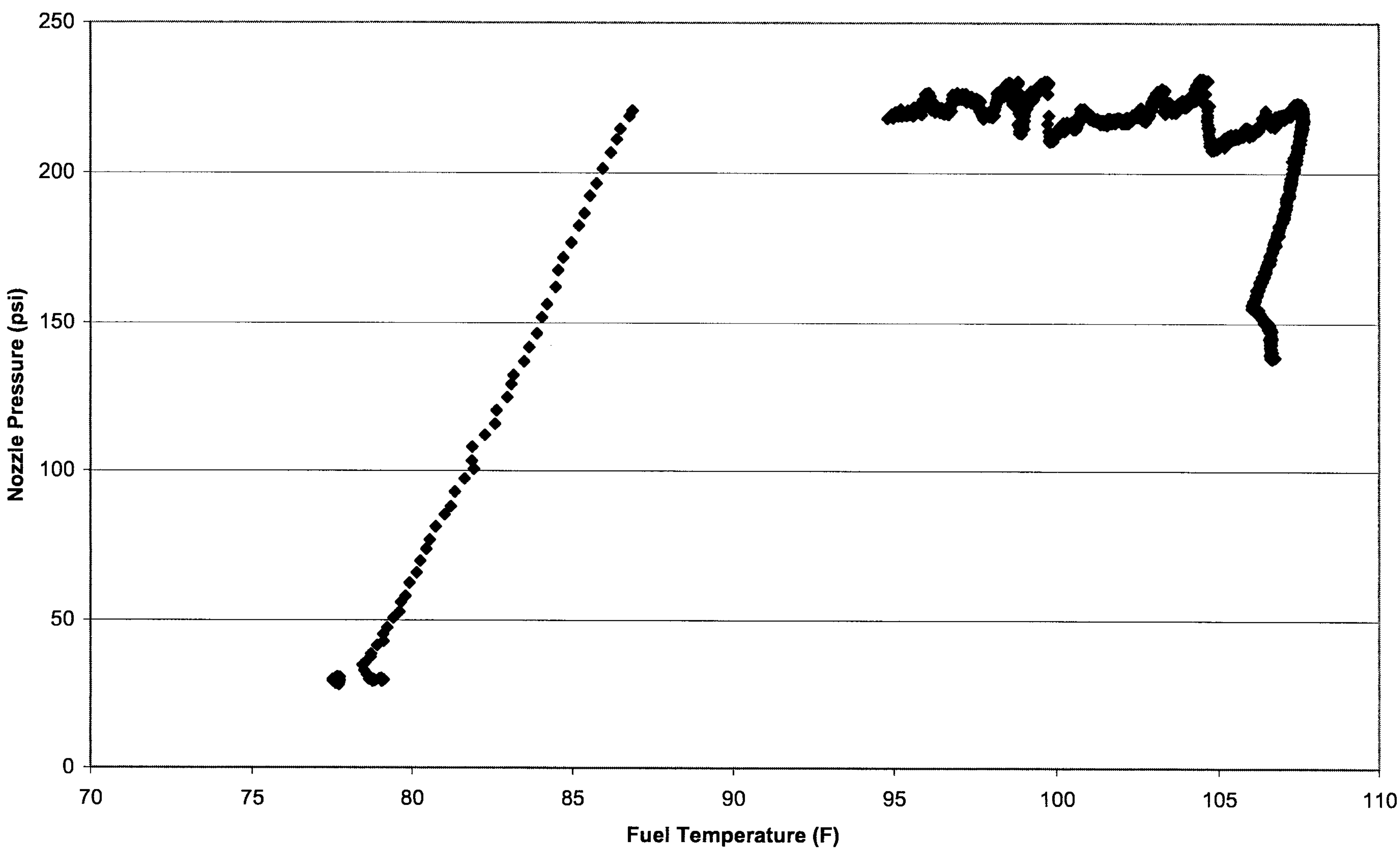
Carter maintains that the pre-6500 nozzles fitted with new handles are the same as the newer nozzles. A study could determine why the older nozzles fitted with the new handles developed higher pressures than the post SN 6500 nozzles before venting fuel. It is possibly that as the new nozzles age, their peak pressure may rise to the level observed for the older nozzles.

8.0 REFERENCES

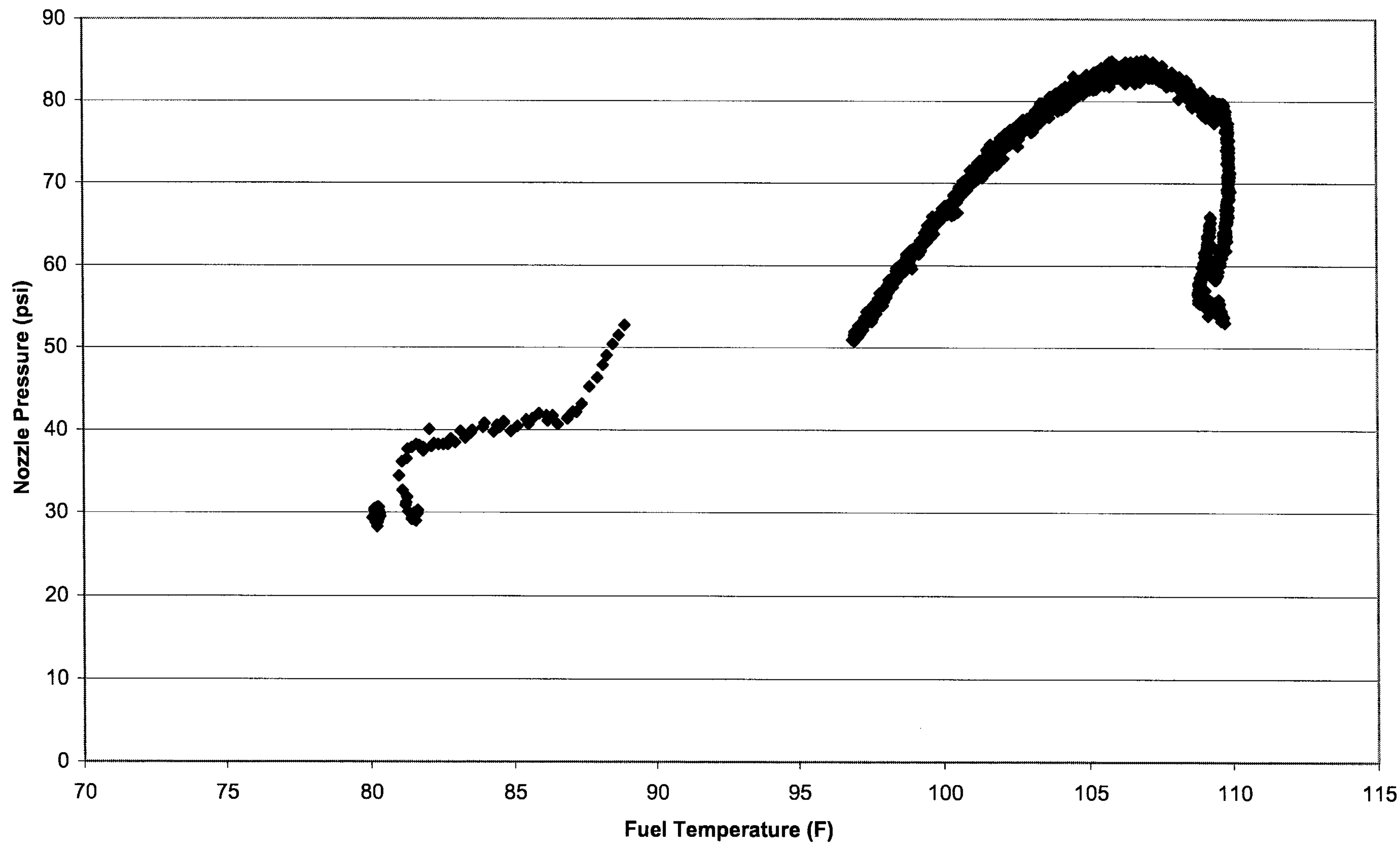
1) Wong, J., Failure Report D-1 Nozzle 64349", Carter Ground Fueling Company, August 3, 1998.
2) Coordinating Research Council, Report No. 530, "Handbook of Aviation Fuel Properties", 1983.

APPENDIX A
Nozzle Pressure vs. Temperature

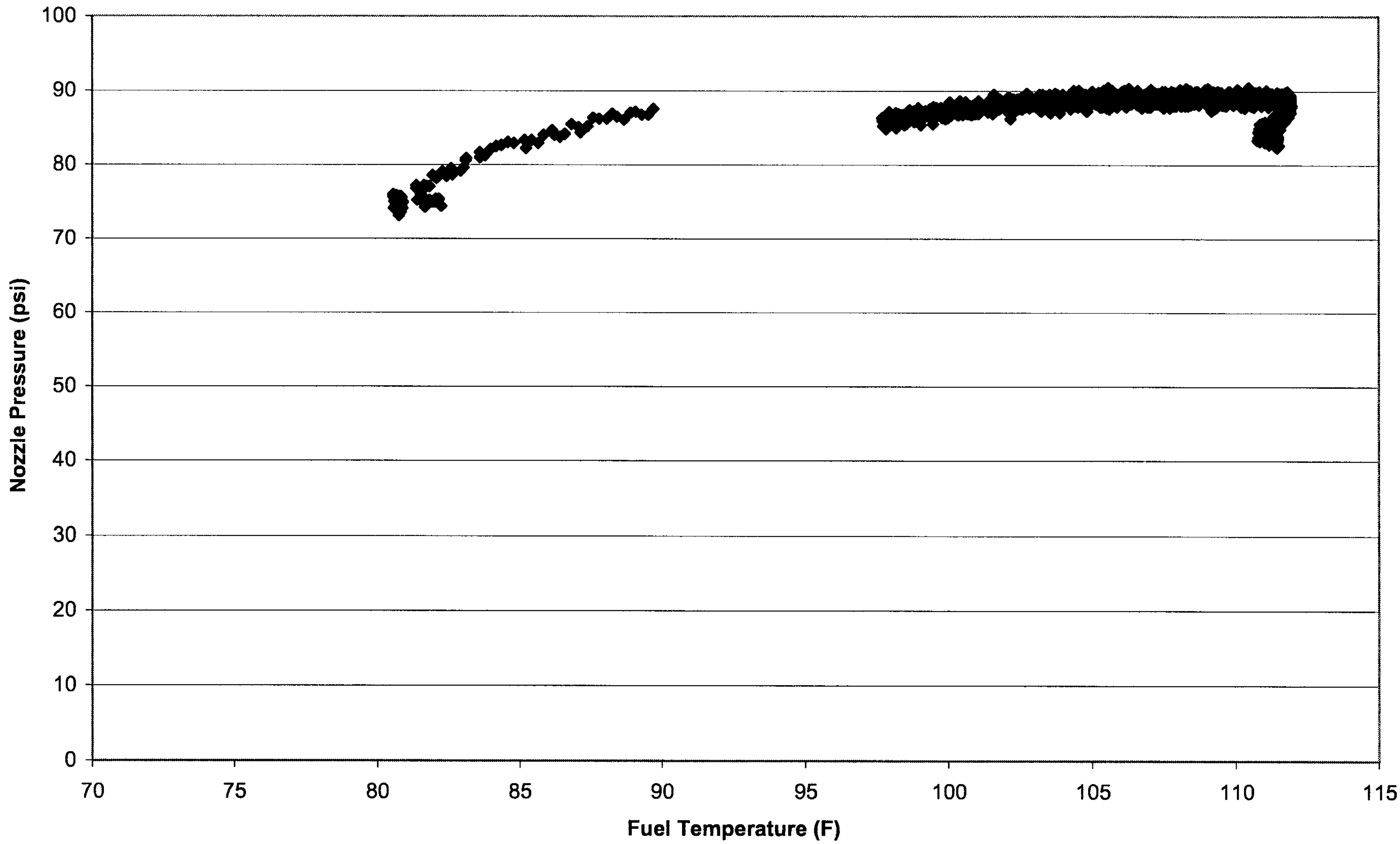
Nozzle Pressure versus Temperature NC-D1

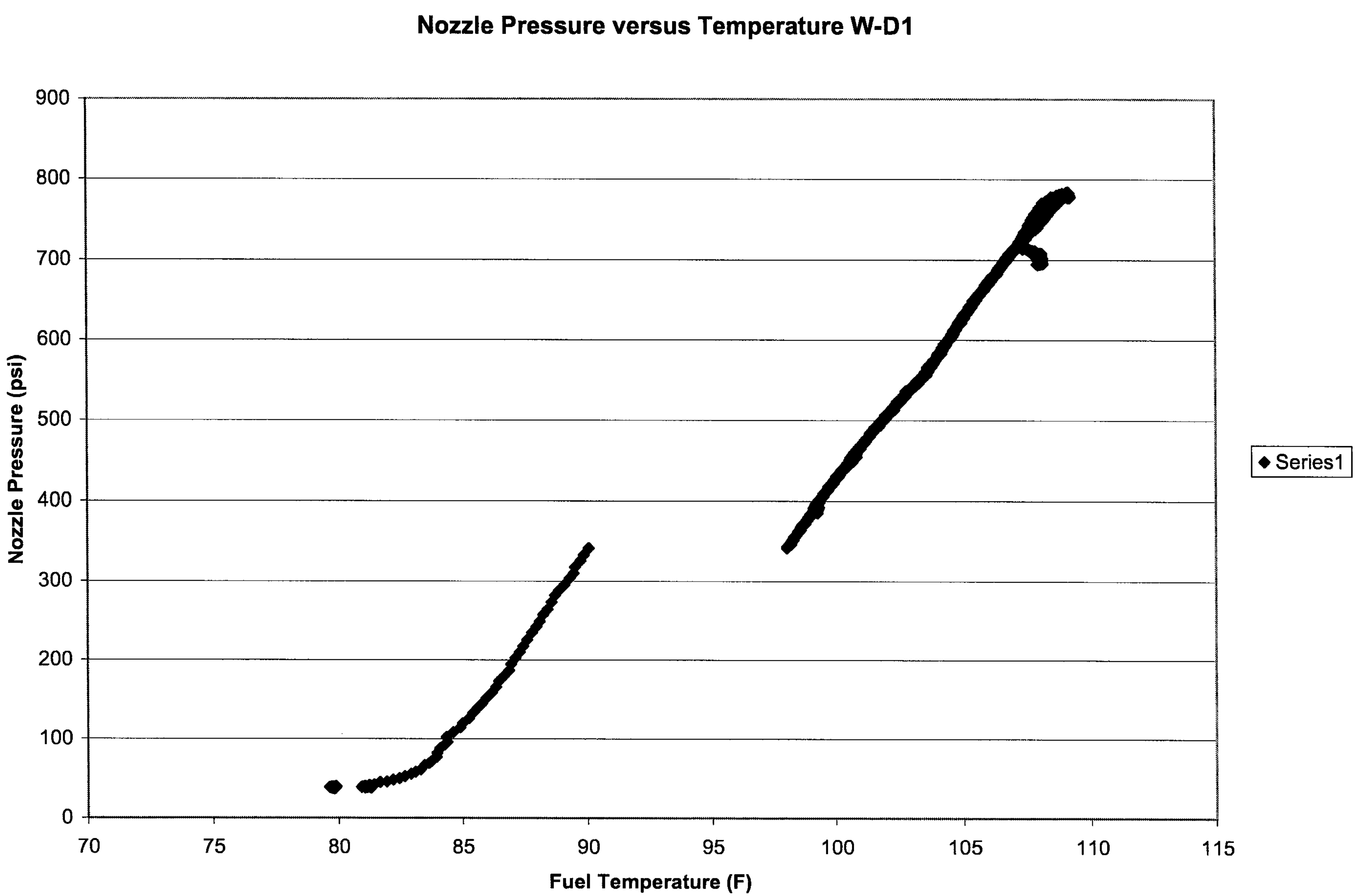


Nozzle Pressure versus Temperature NC-D1-R

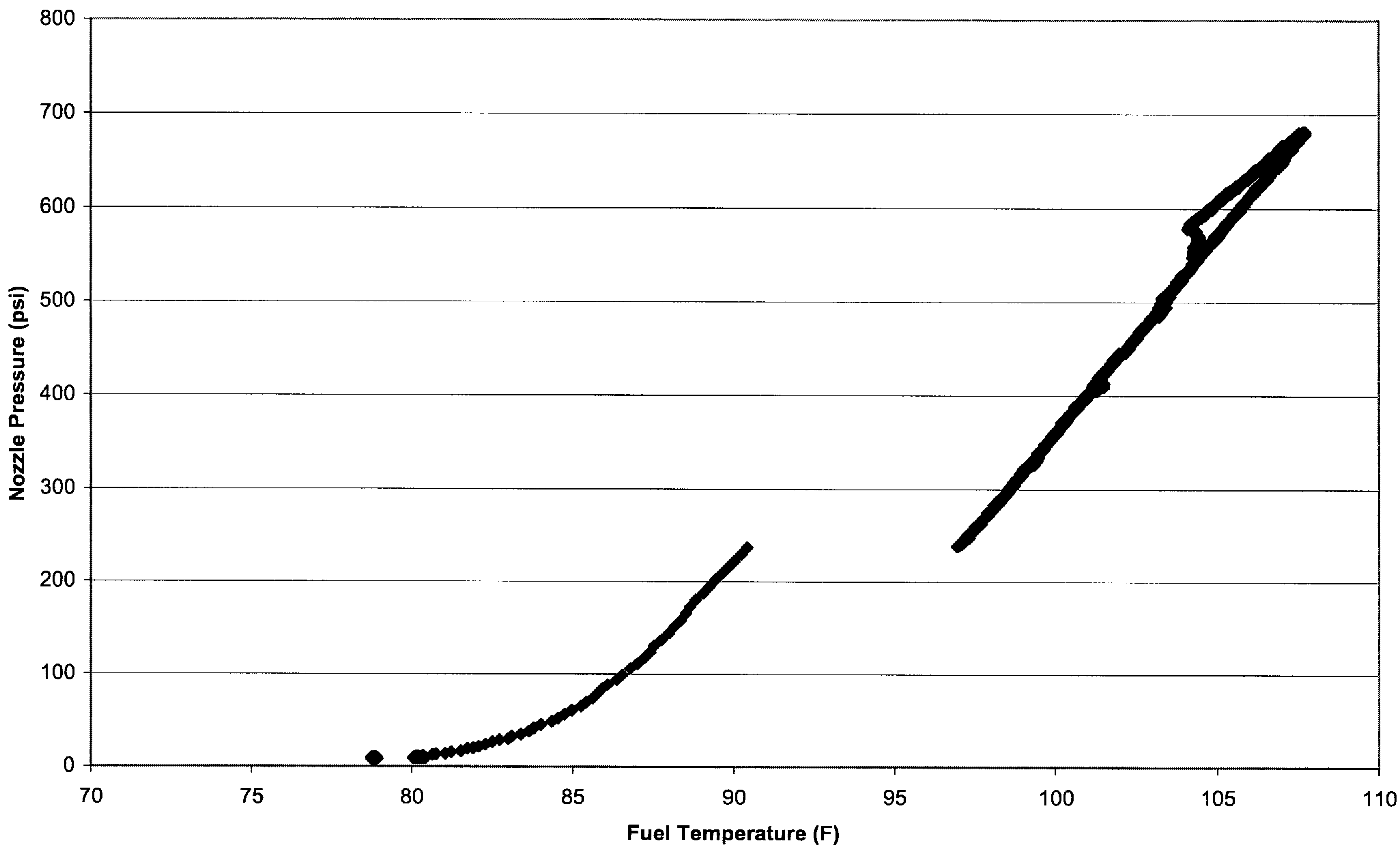


Nozzle Pressure versus Temperature NC-D1-H

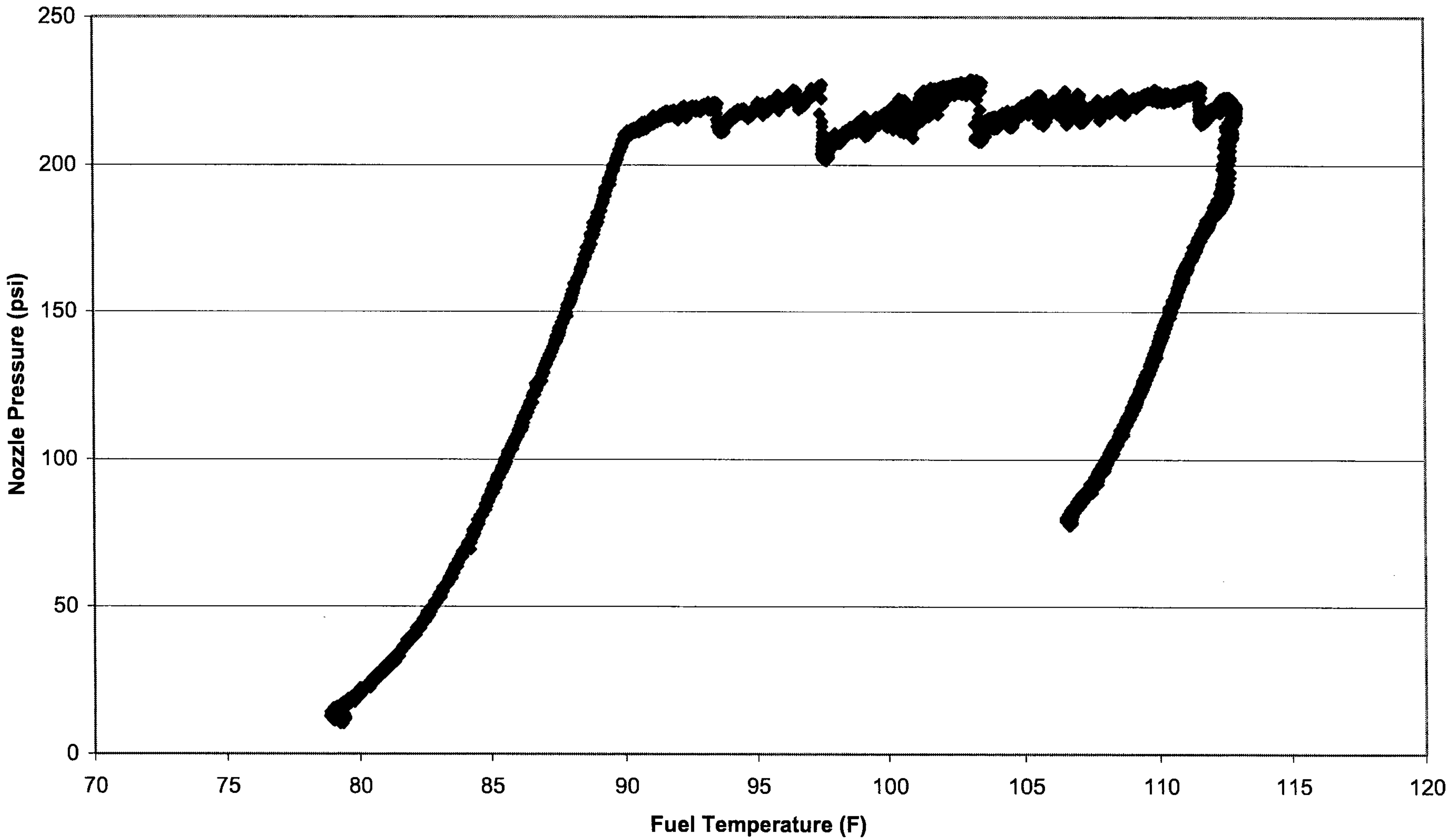



Nozzle Pressure versus Temperature W-D1
Nozzle Pressure (psi)
900
800
700
600
500
400
300
200
100
0
70
75
80
85
90
95
100
105
110
115
Fuel Temperature (F)
Series1

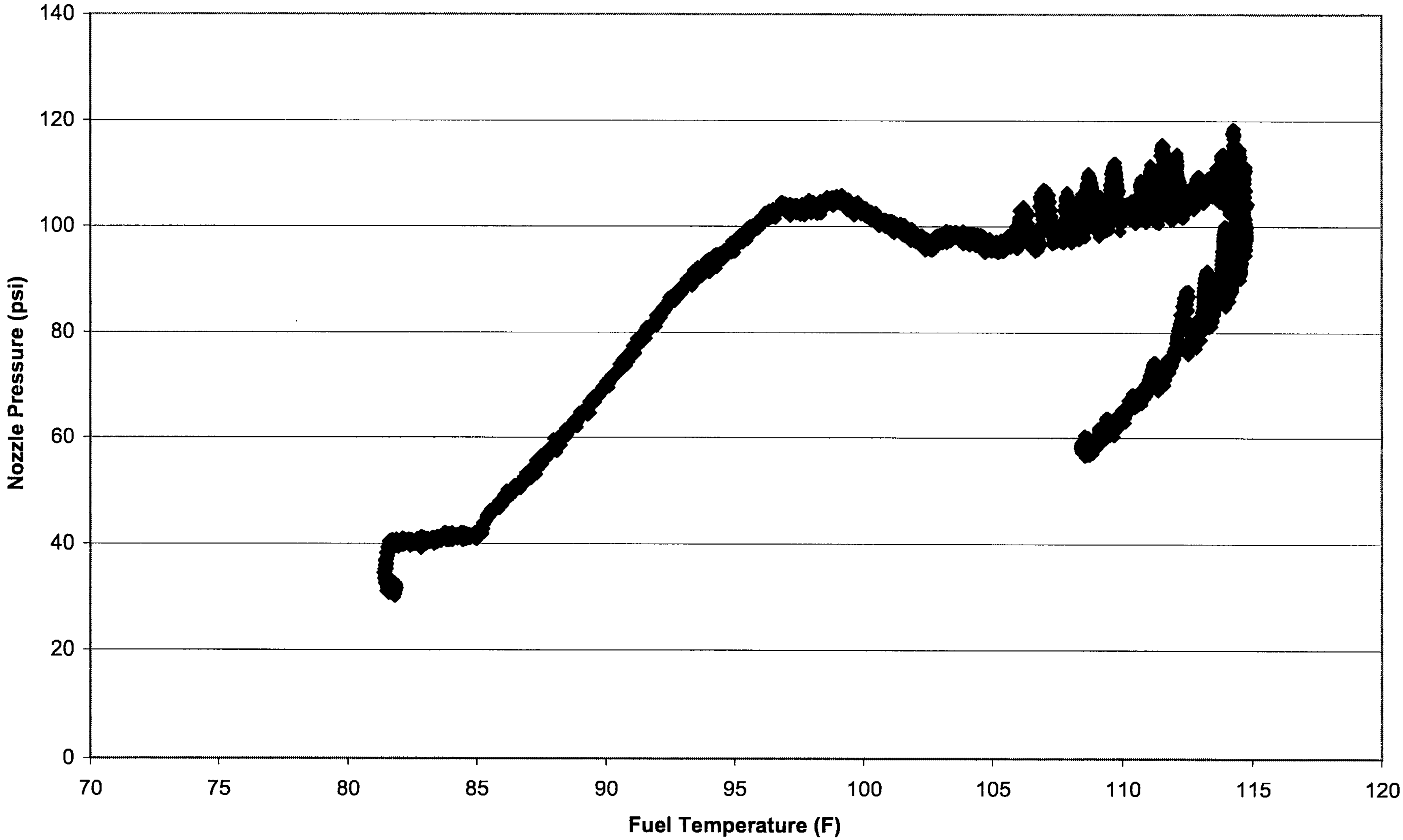
Nozzle Pressure versus Temperature CCR

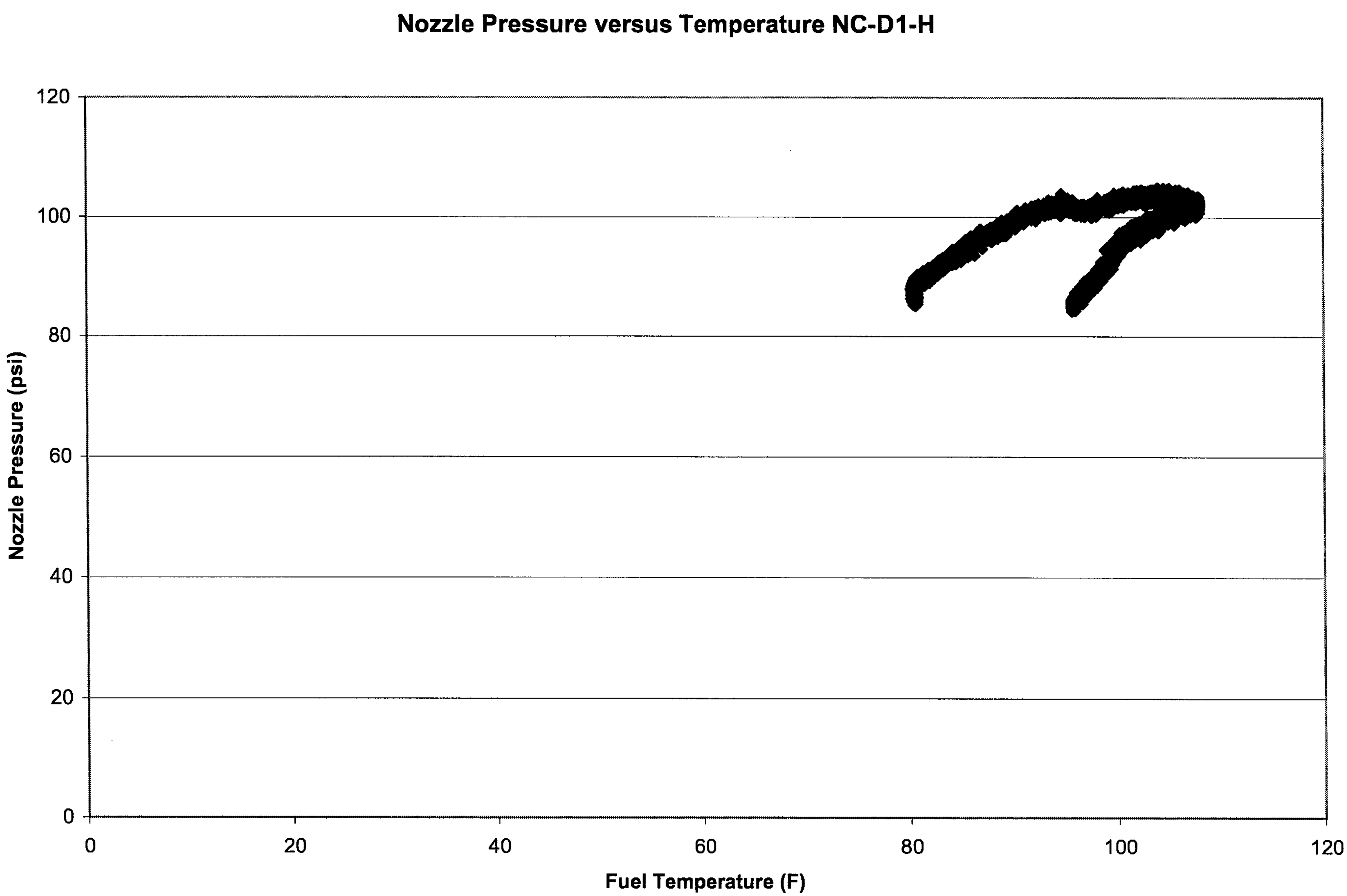


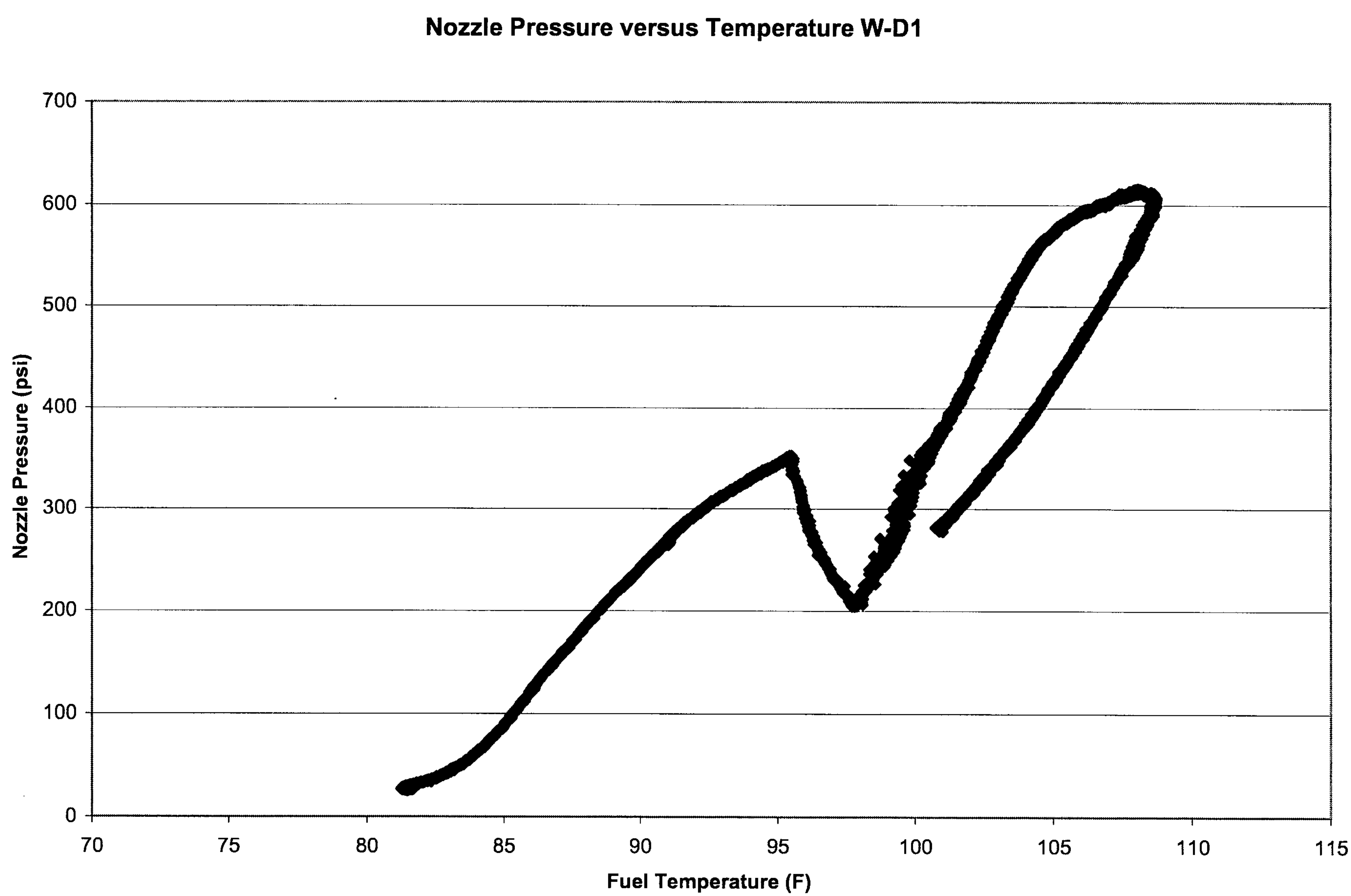
Nozzle Pressure versus Temperature NC-D1



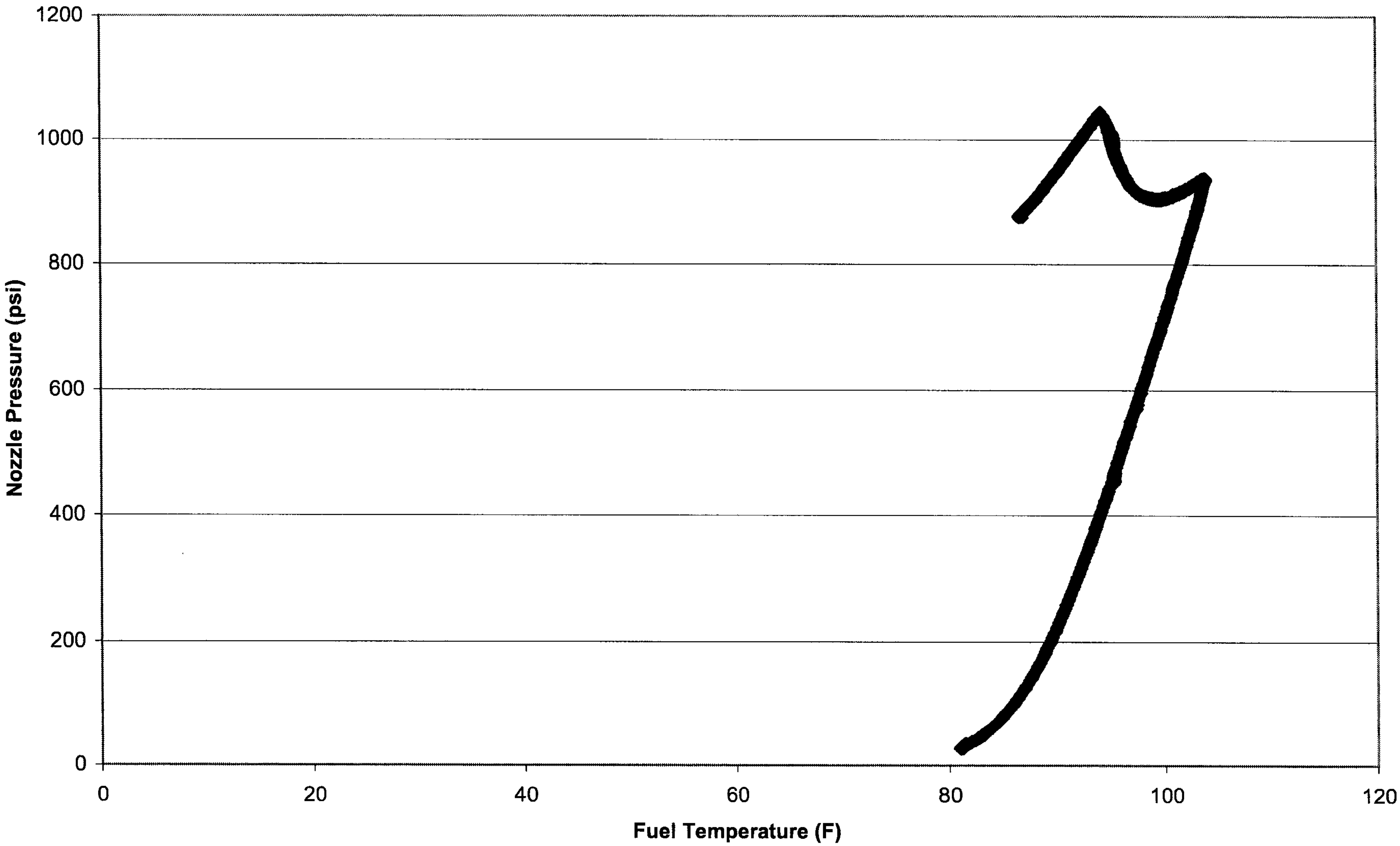
Nozzle Pressure versus Temperature NC-D1_R



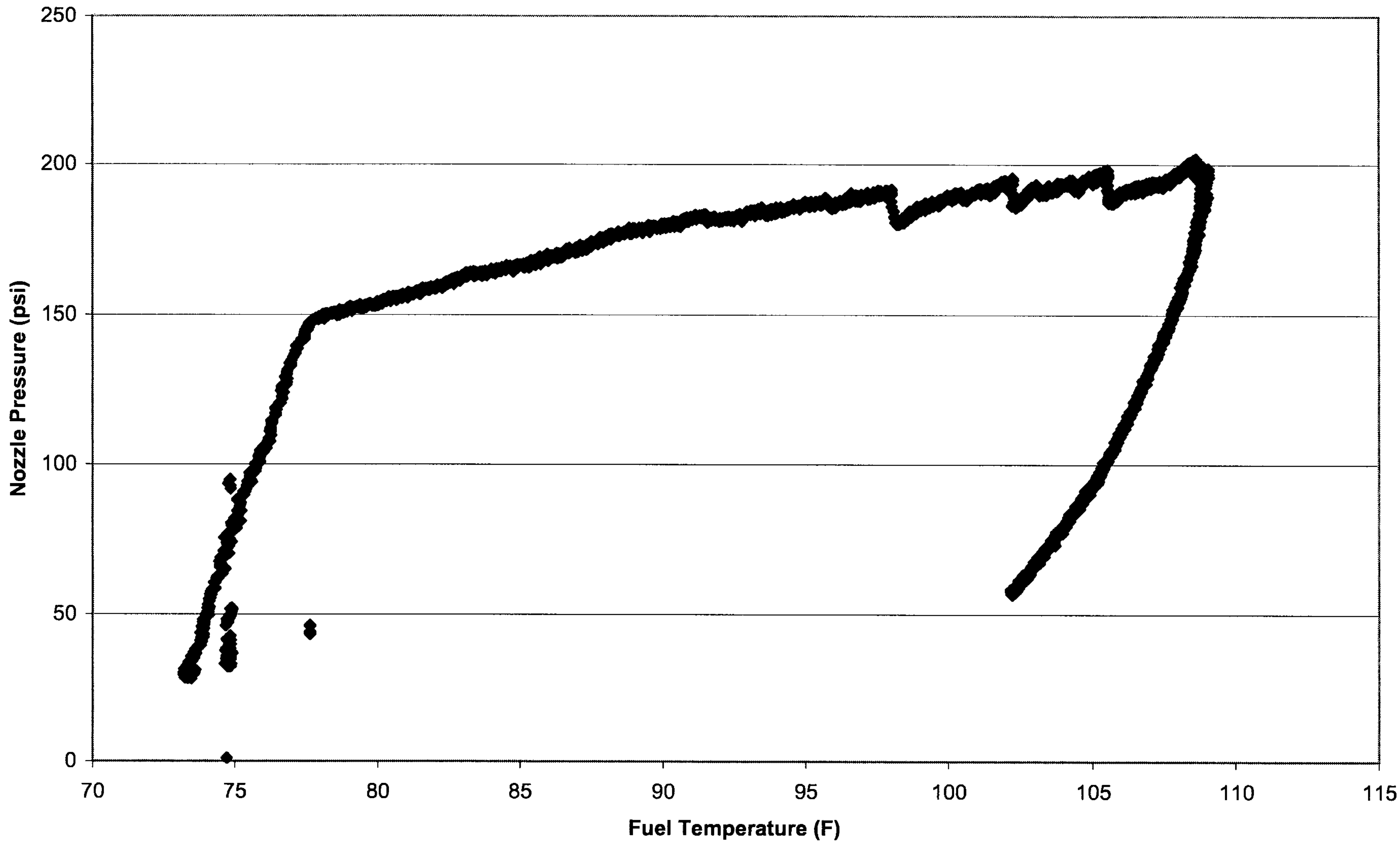

Nozzle Pressure versus Temperature NC-D1-H
Nozzle Pressure (psi)
120
100
80
60
40
20
0
0
20
40
60
80
100
120
Fuel Temperature (F)

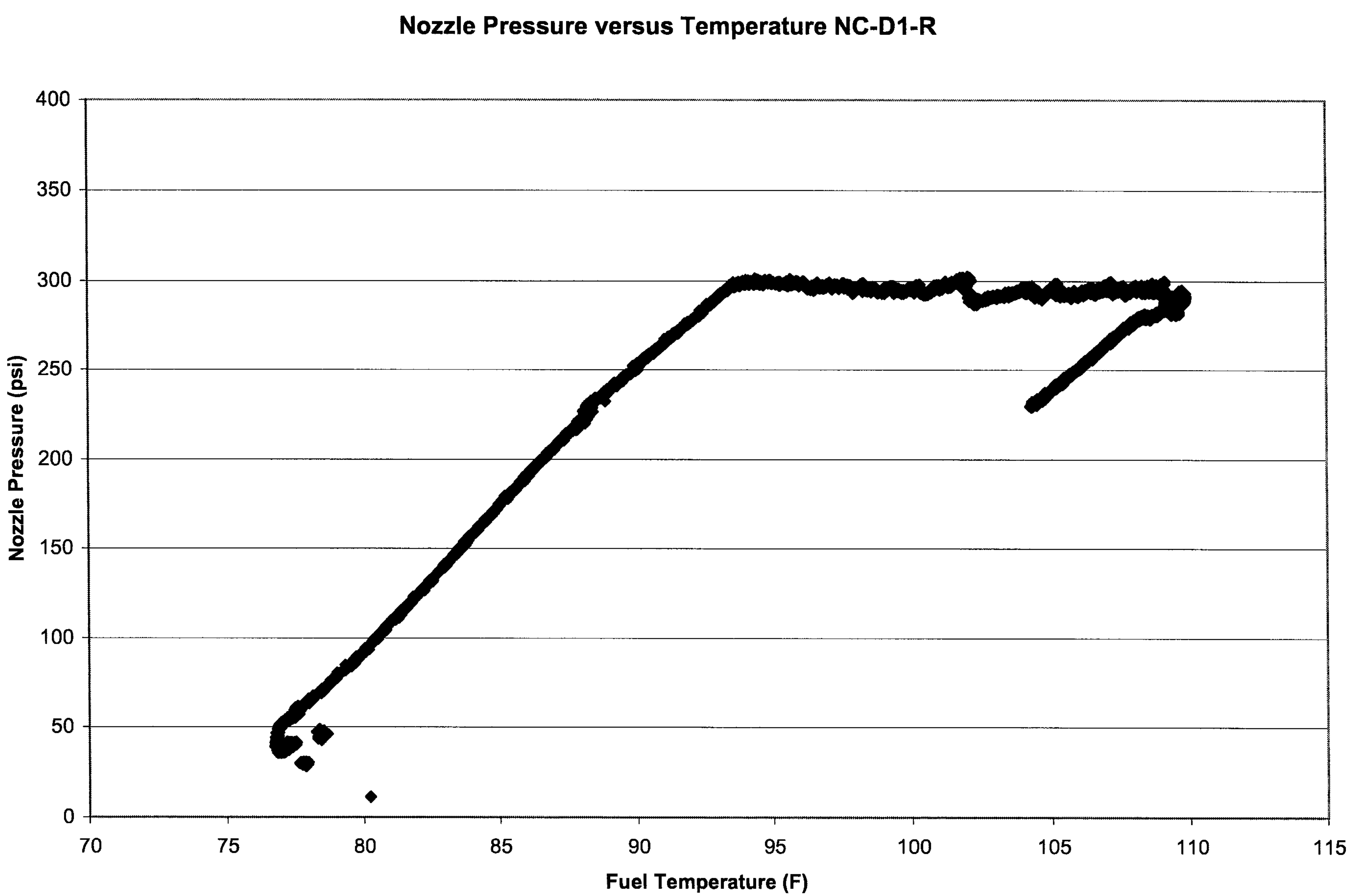

Nozzle Pressure versus Temperature W-D1
700
600
500
400
300
200
100
0
Nozzle Pressure (psi)
70
75
80
85
90
95
100
105
110
115
Fuel Temperature (F)

Nozzle Pressure versus Temperature CCR



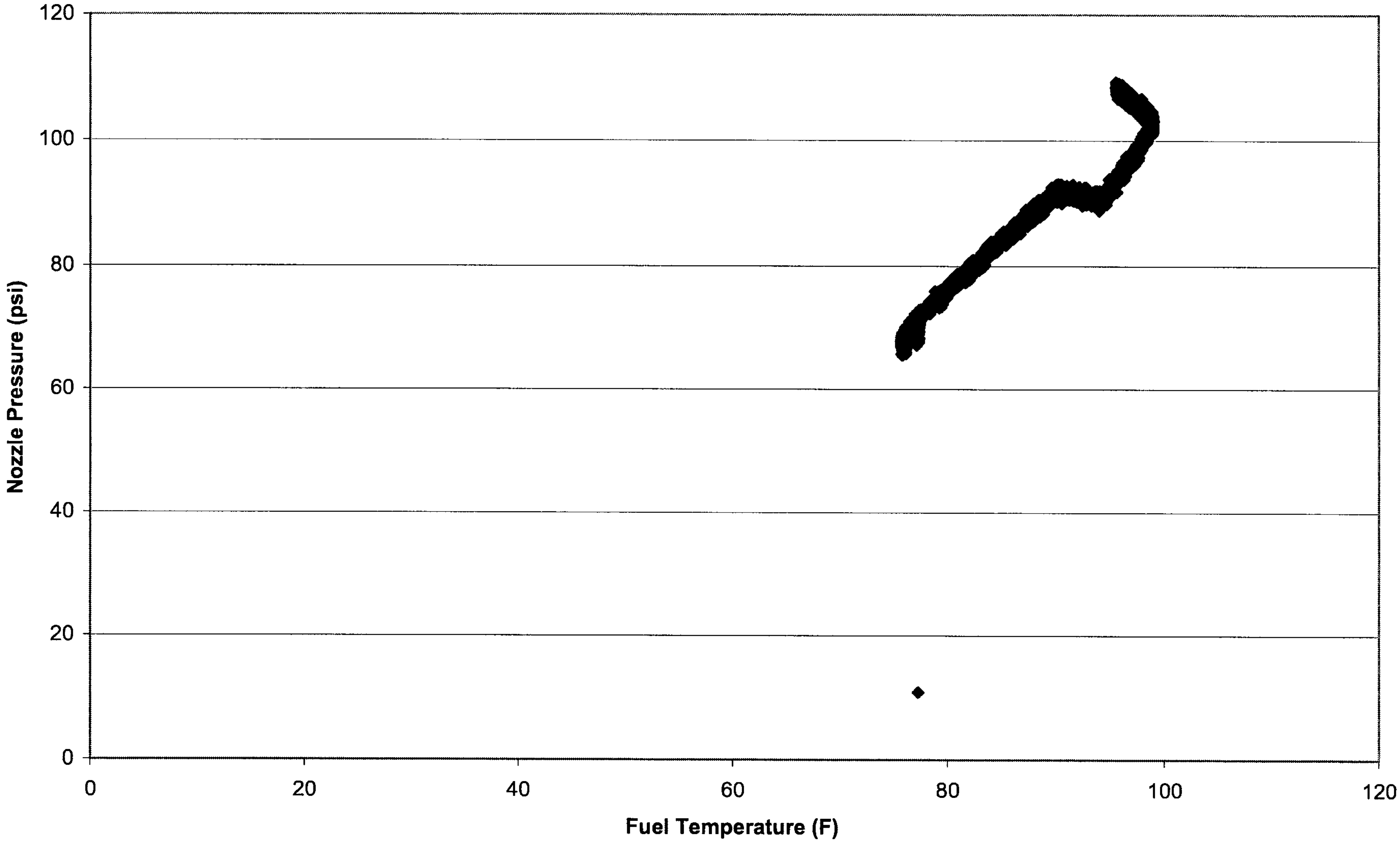
Nozzle Pressure versus Temperature NC-D1



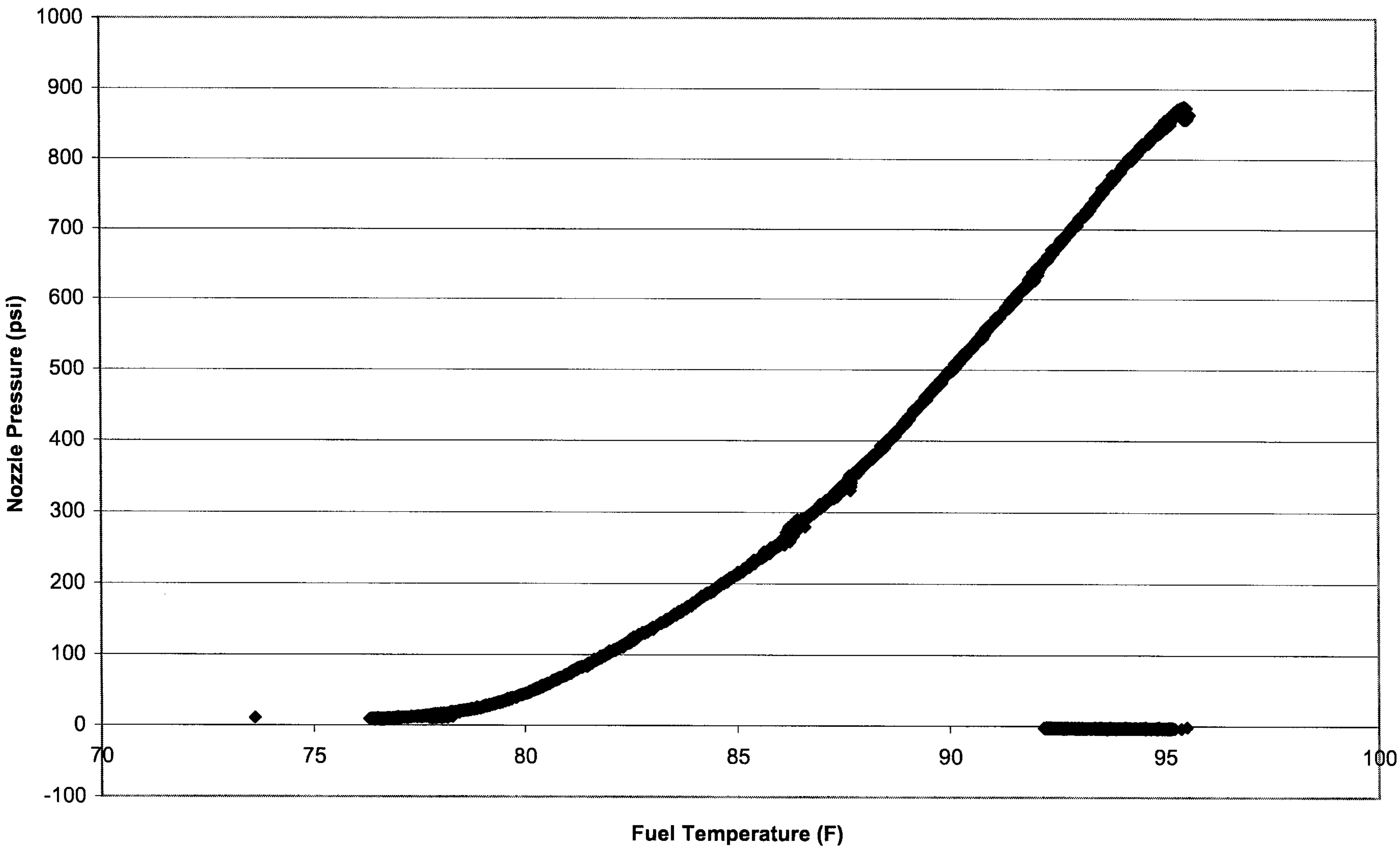


Nozzle Pressure versus Temperature NC-D1-R
Nozzle Pressure (psi)
400
350
300
250
200
150
100
50
0
70
75
80
85
90
95
100
105
110
115
Fuel Temperature (F)

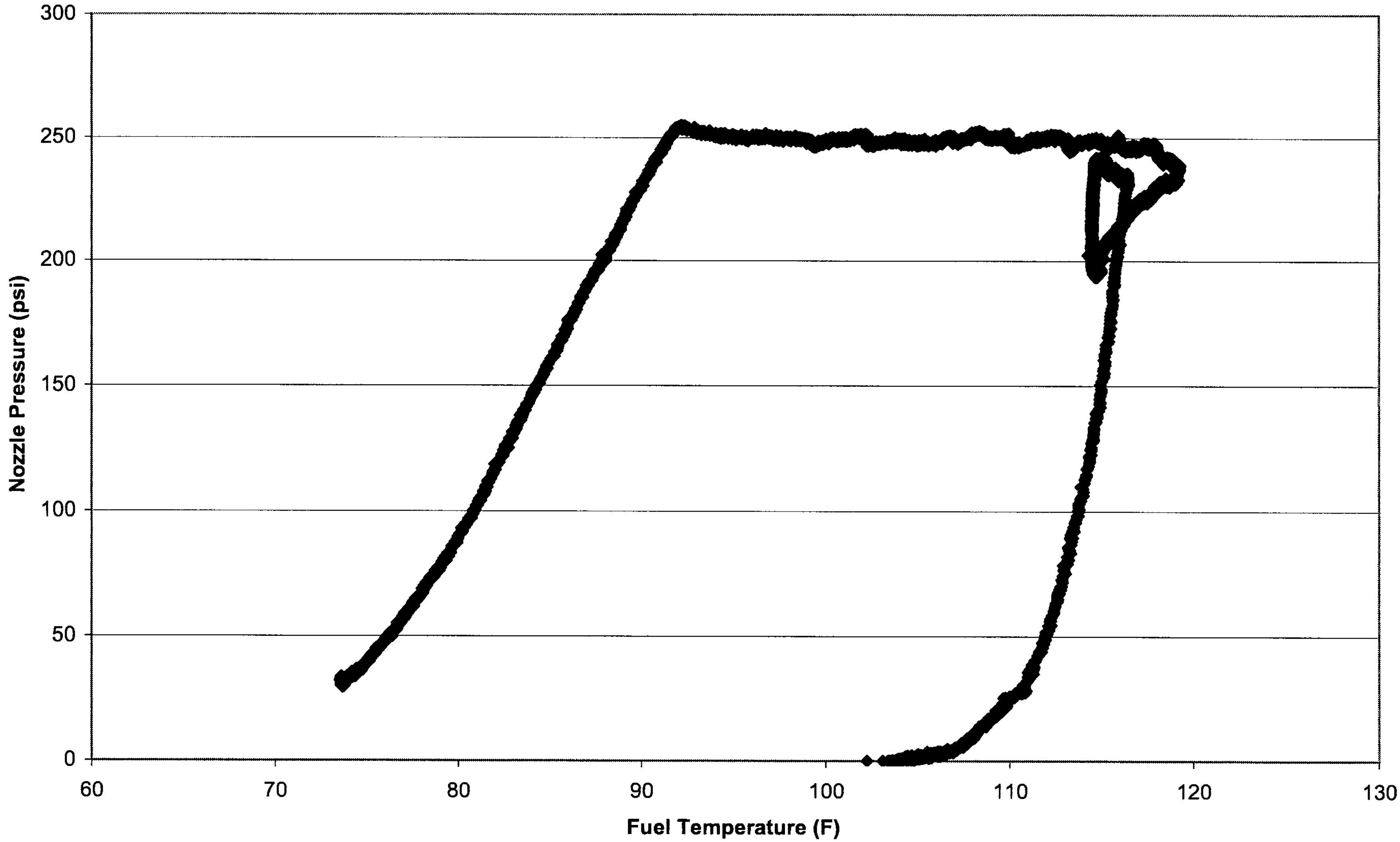
Nozzle Pressure versus Temperature NC-D1-H



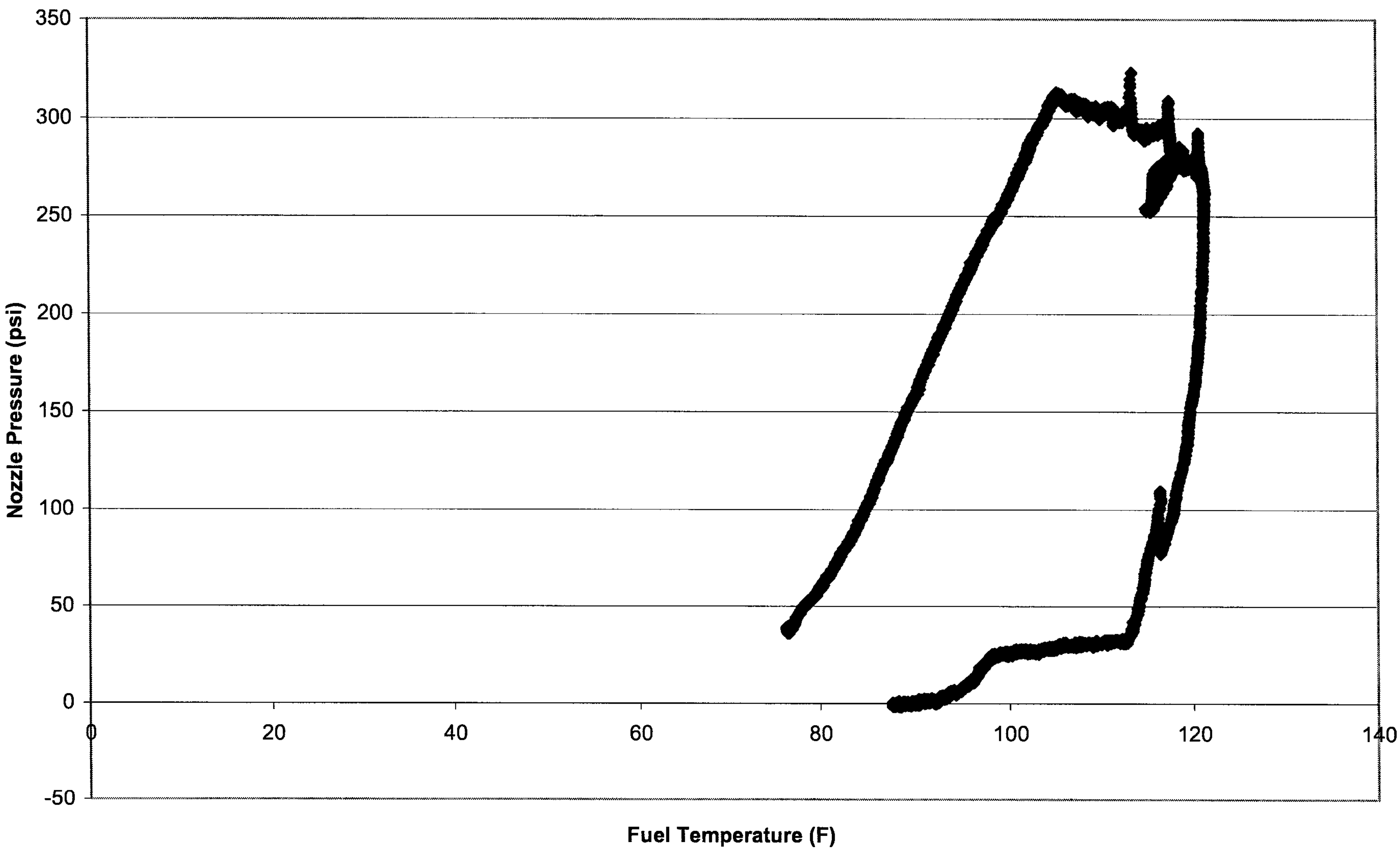
Nozzle Pressure versus Temperature W-D1



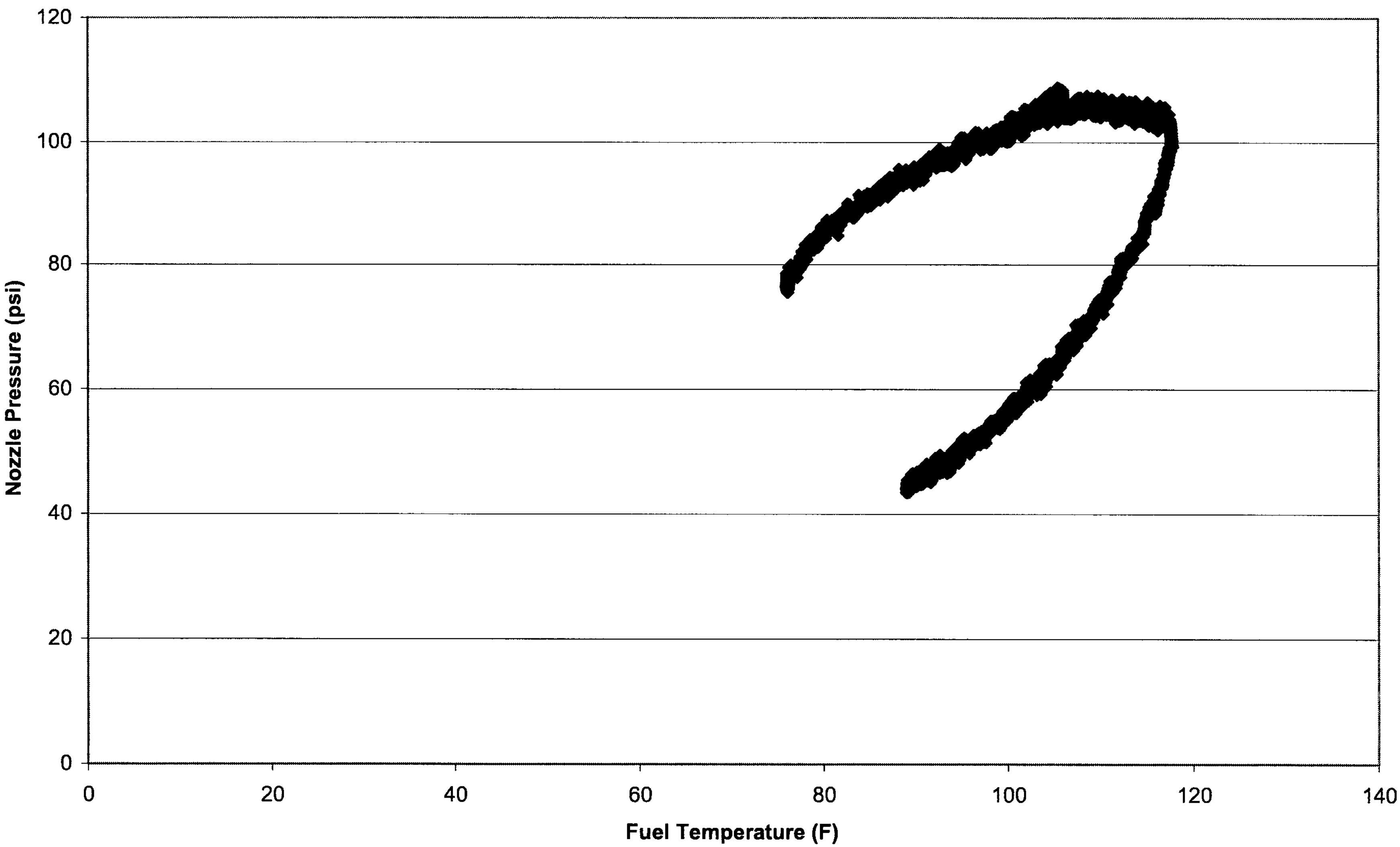
Nozzle Pressure versus Temperature NC-D1



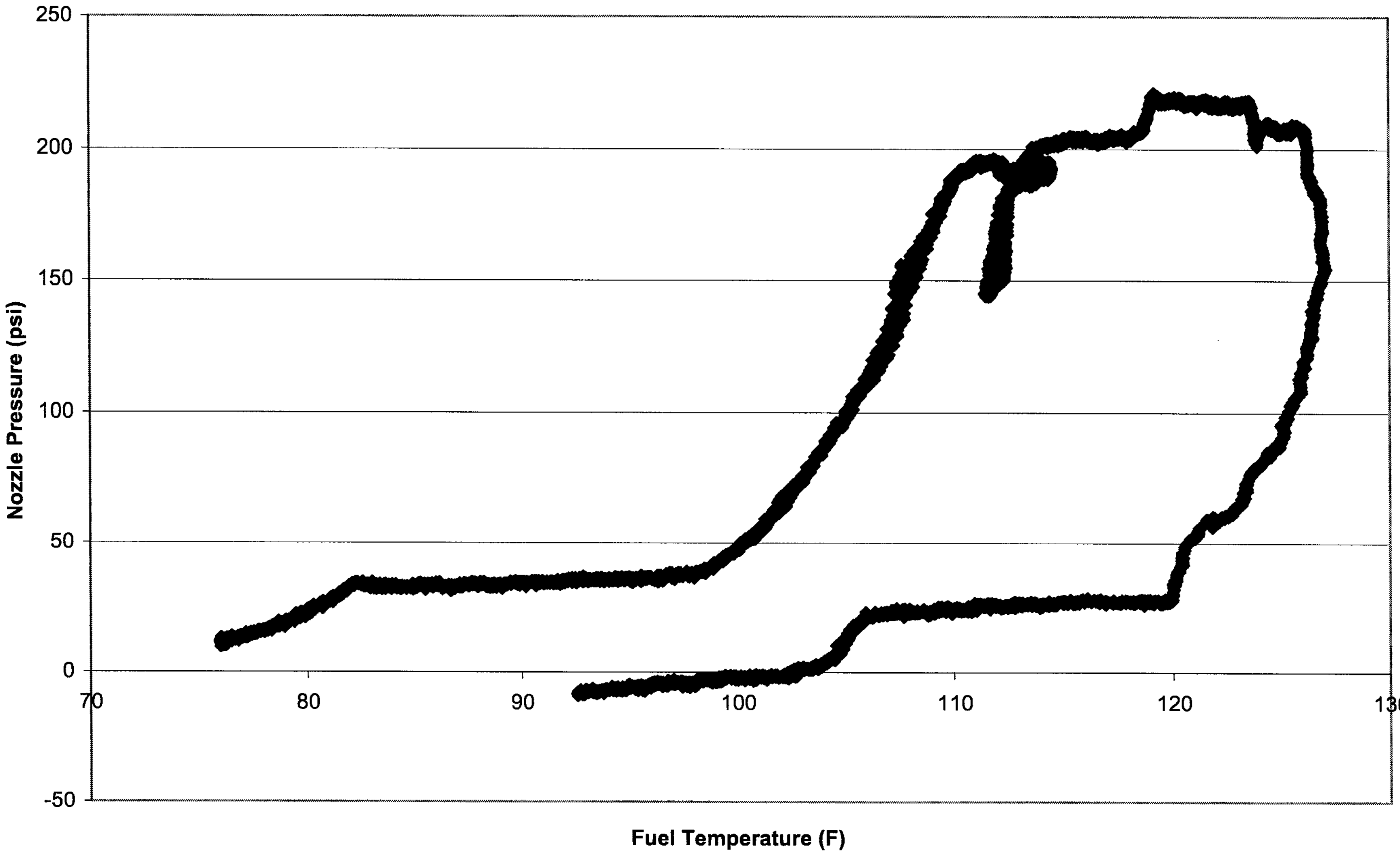
Nozzle Temperature versus Temperature NC-D1-R

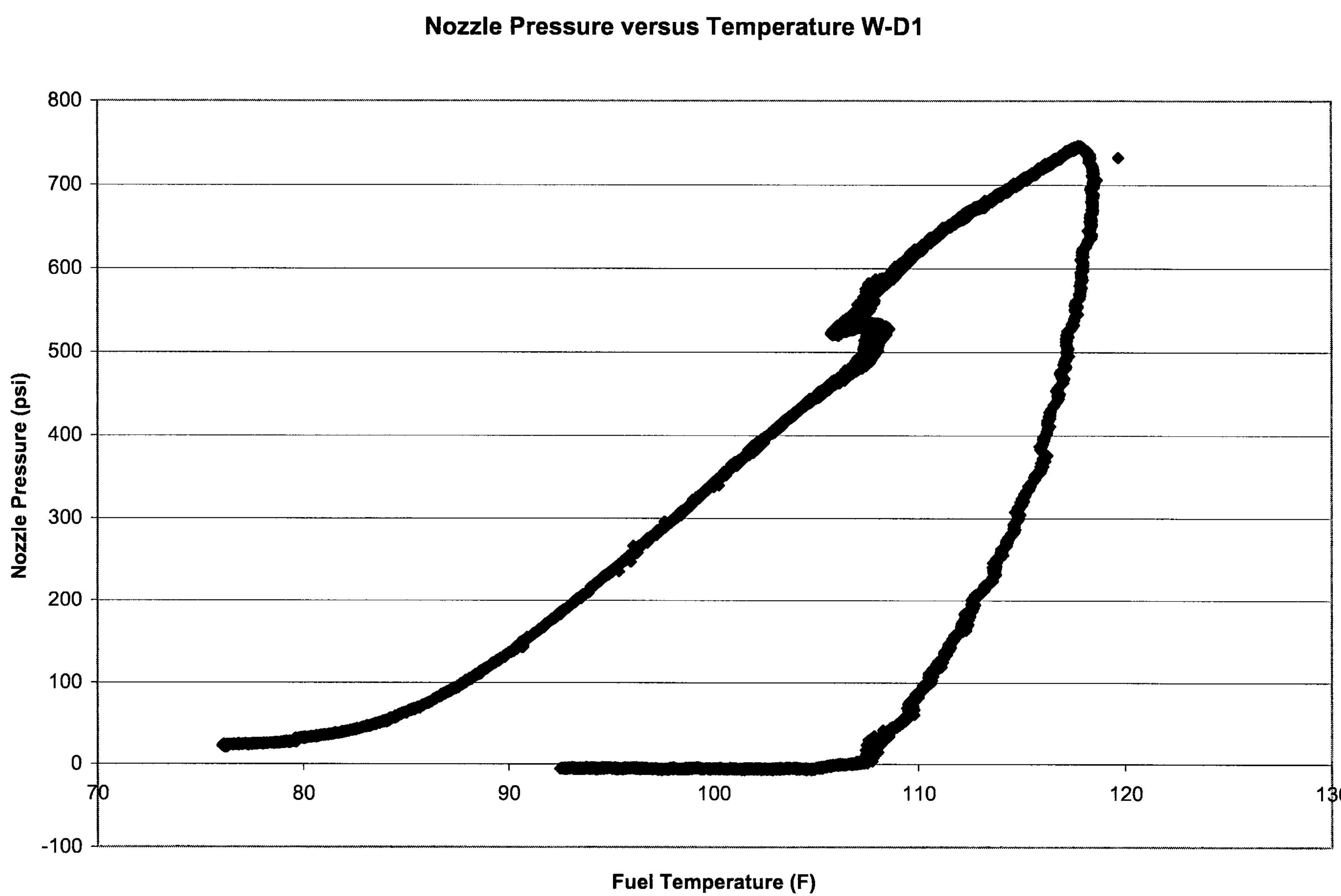


Nozzle Pressure versus Temperature NC-D1-H

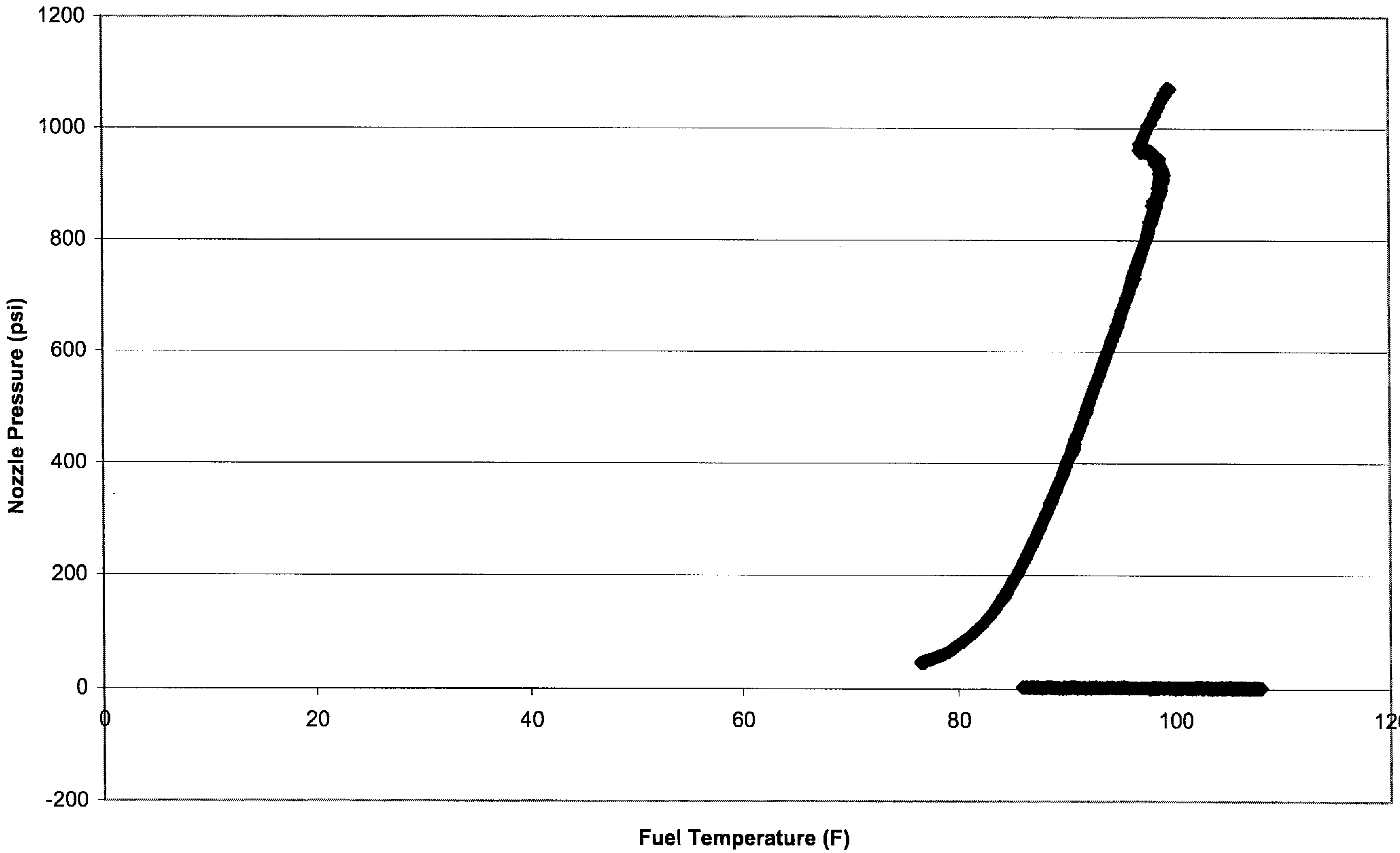


Nozzle Pressure versus Temperature NC-D1-R

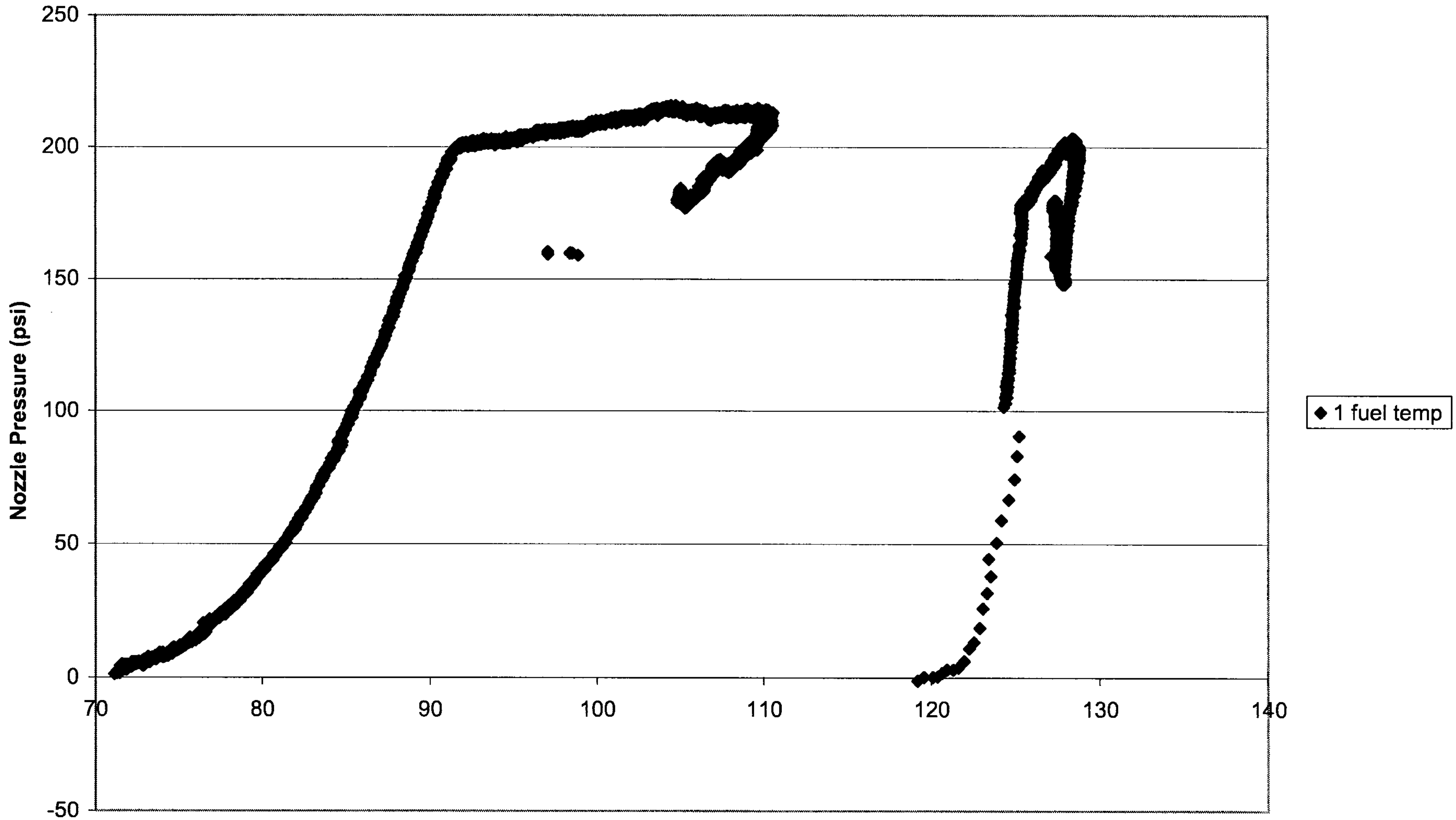



Nozzle Pressure versus Temperature W-D1
Nozzle Pressure (psi)
800
700
600
500
400
300
200
100
0
-100
70
80
90
100
110
120
130
Fuel Temperature (F)

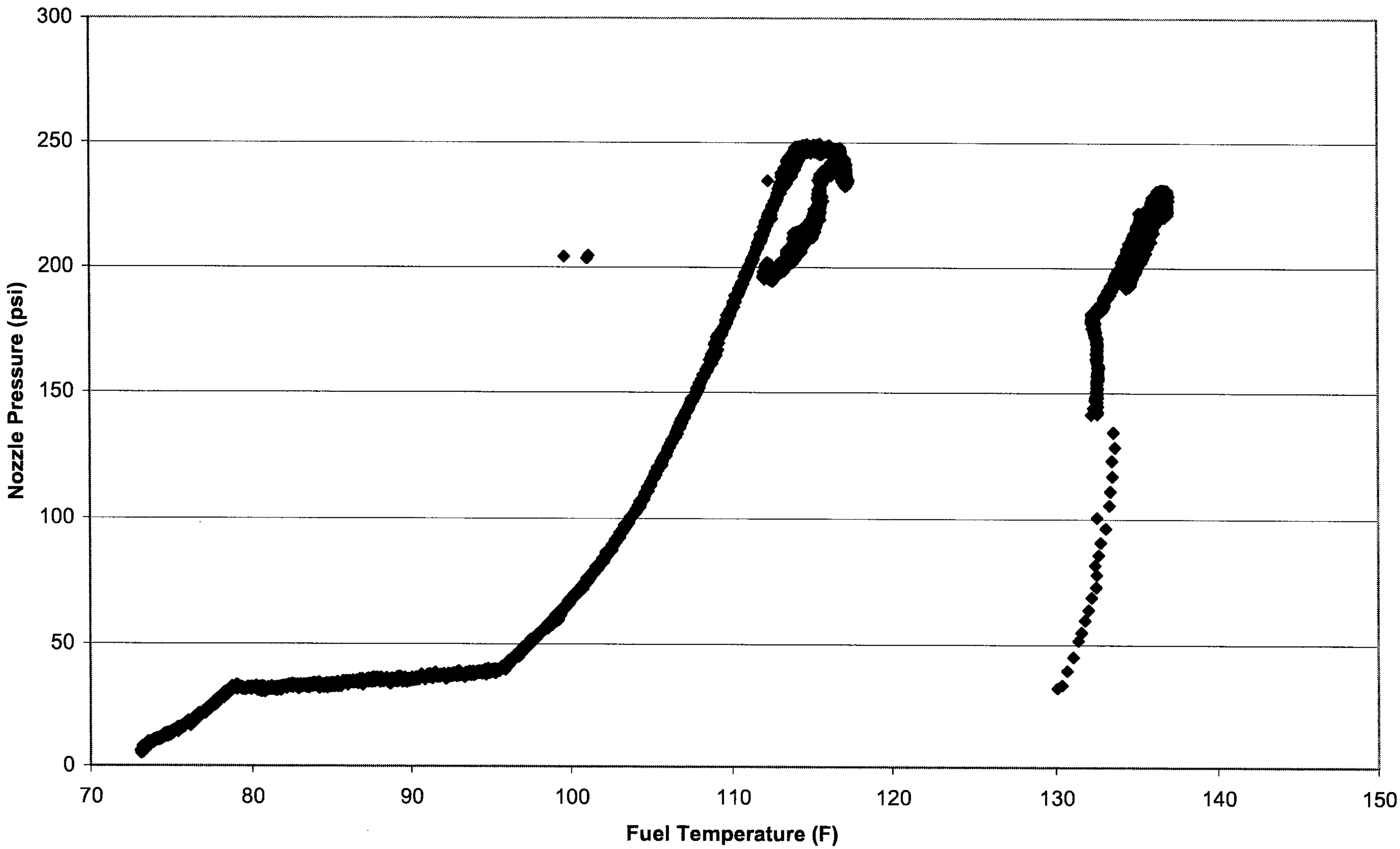
Nozzle Pressure versus Temperature CCR



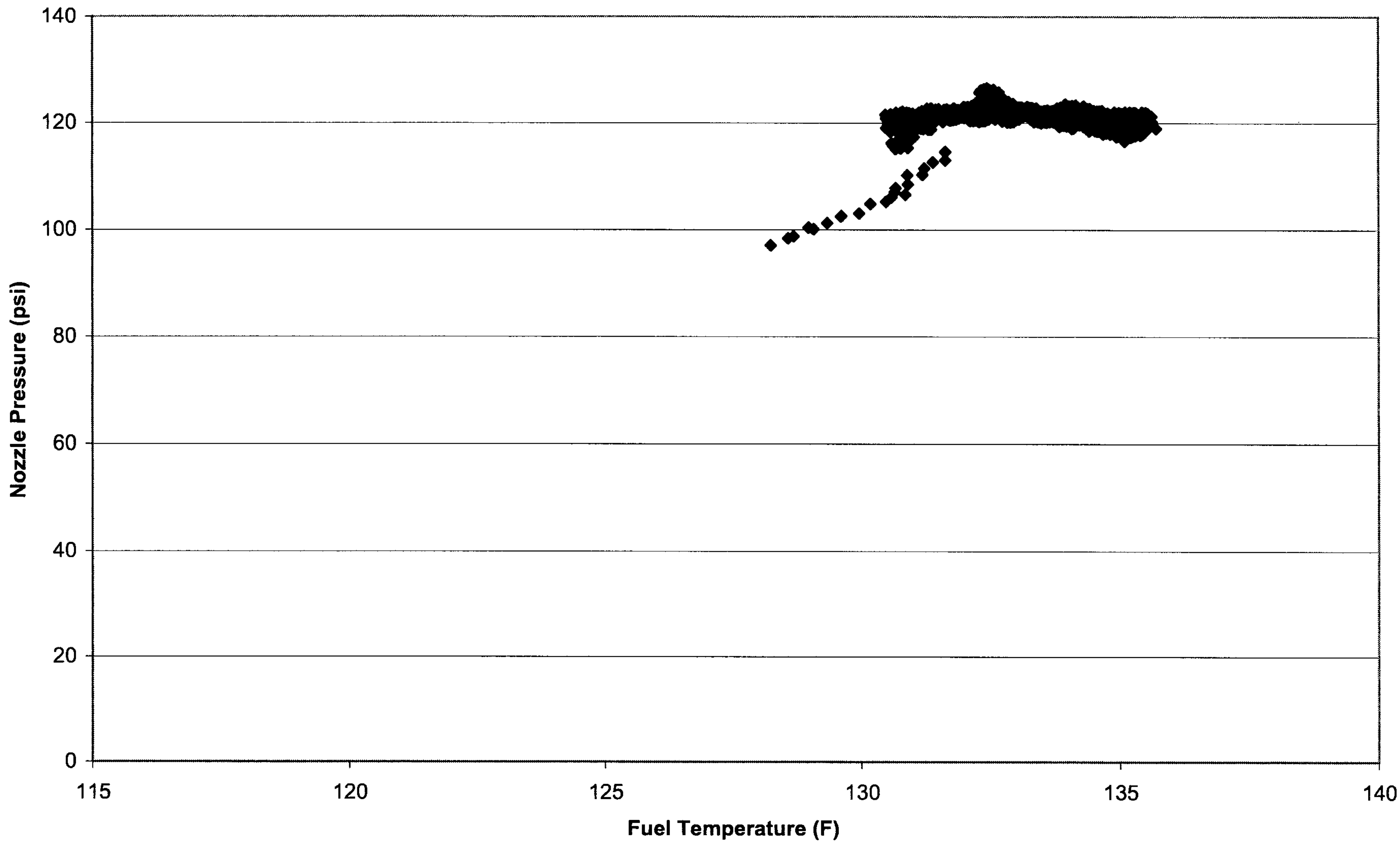
Nozzle Pressure versus Temperature NC-D1



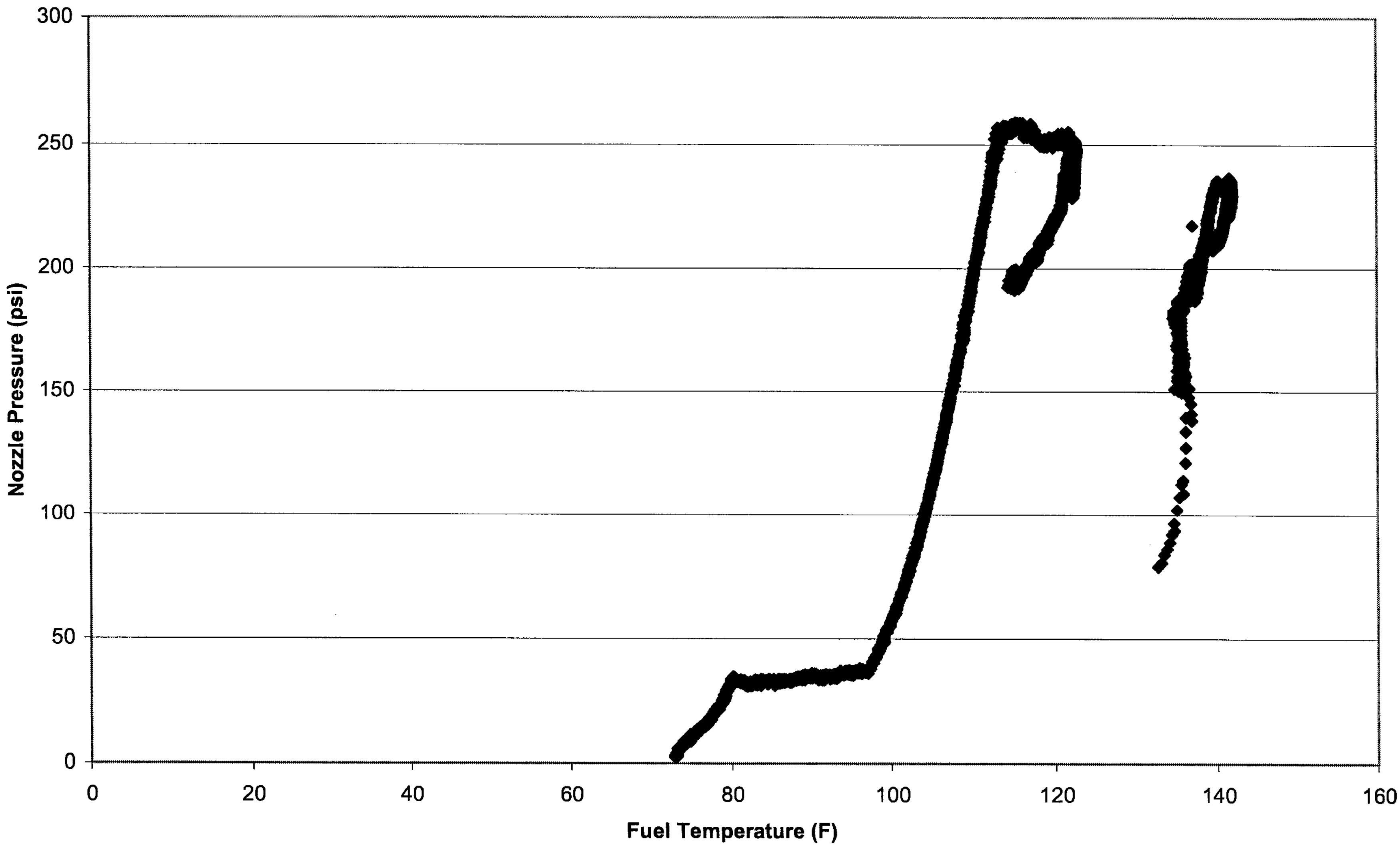
Nozzle Pressure versus Temperature NC-D1-R



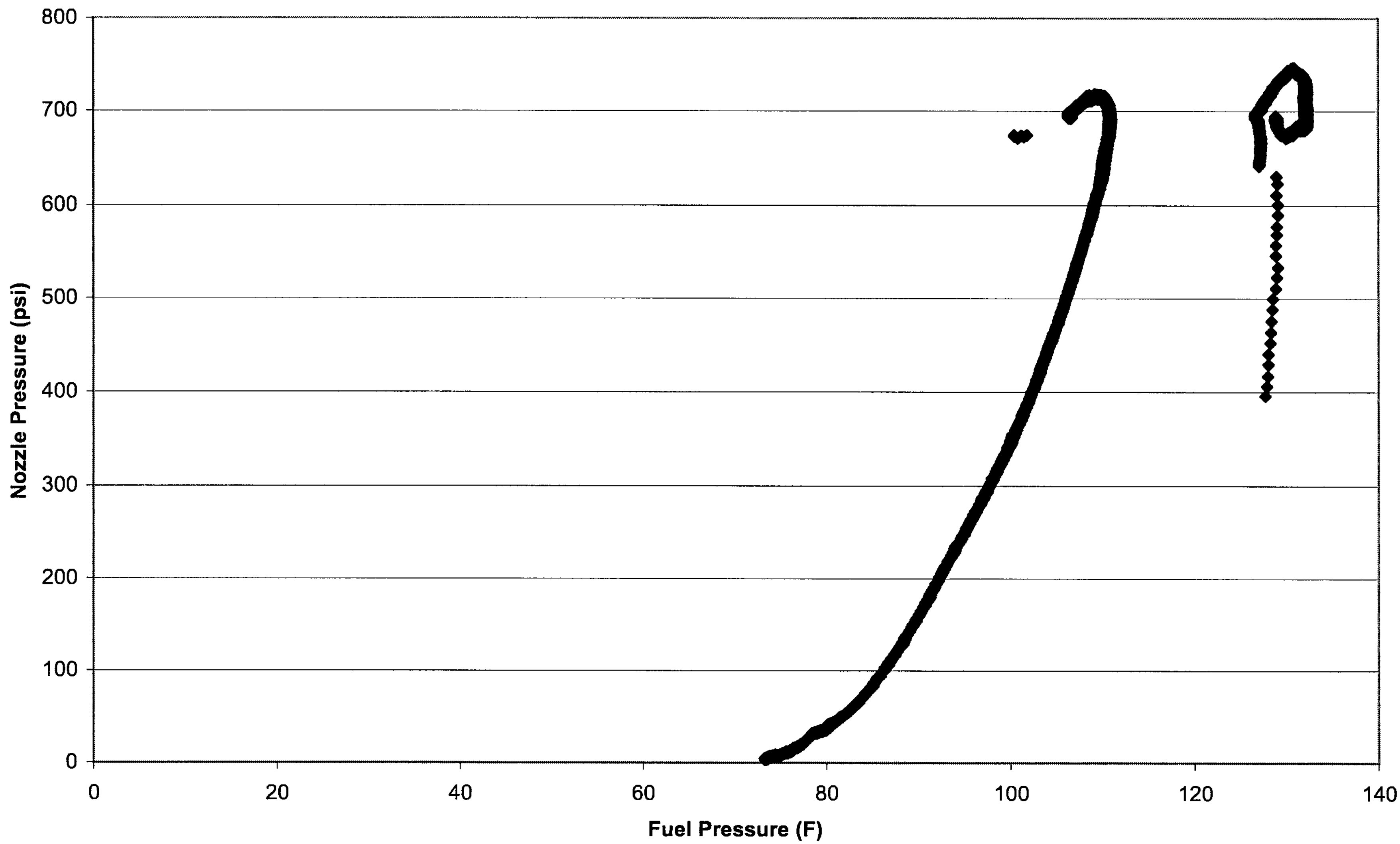
Nozzle Pressure versus Temperature NC-D1-H



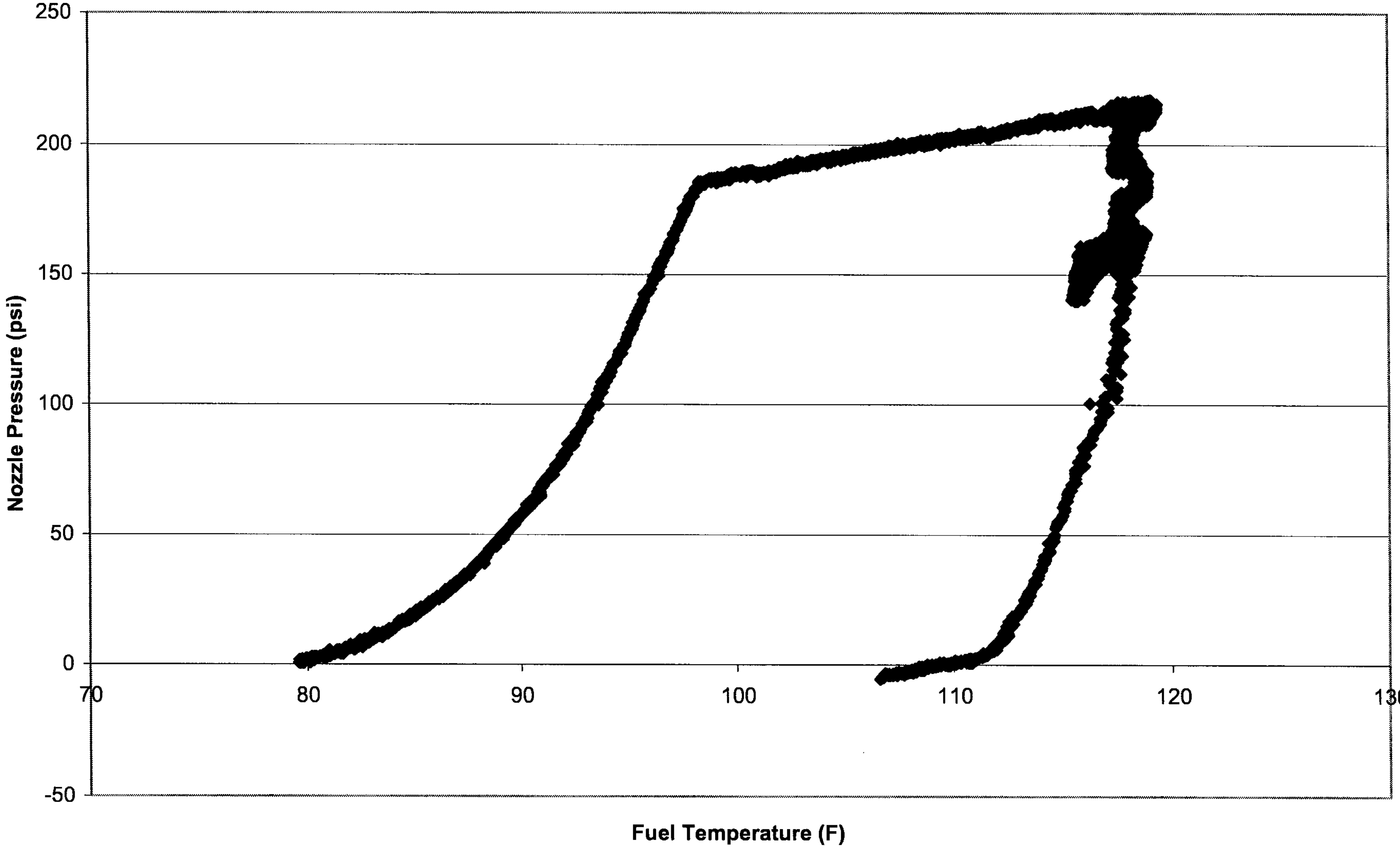
Nozzle Pressure versus Temperature NC-D1-R



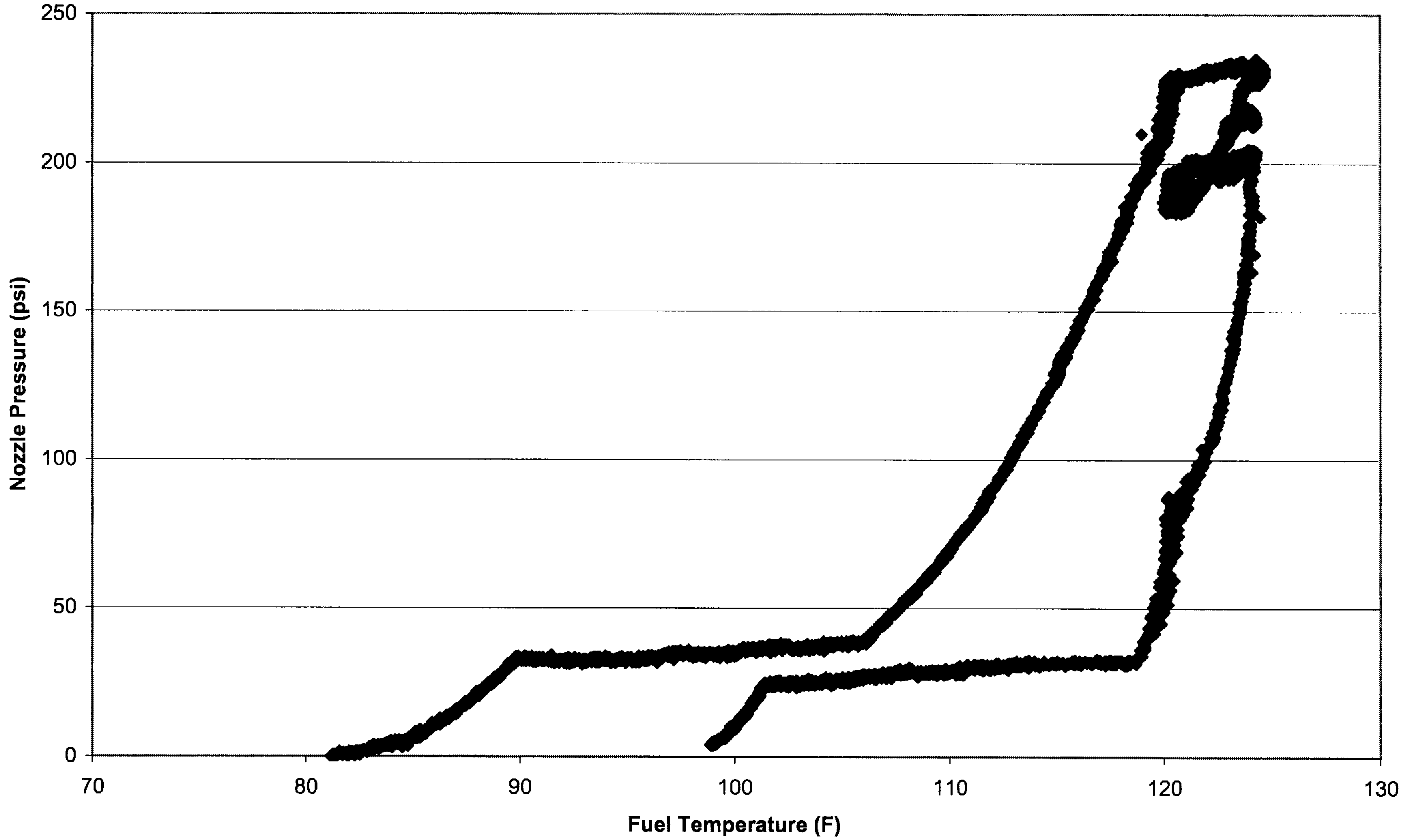
Nozzle Pressure versus Temperature W-D1

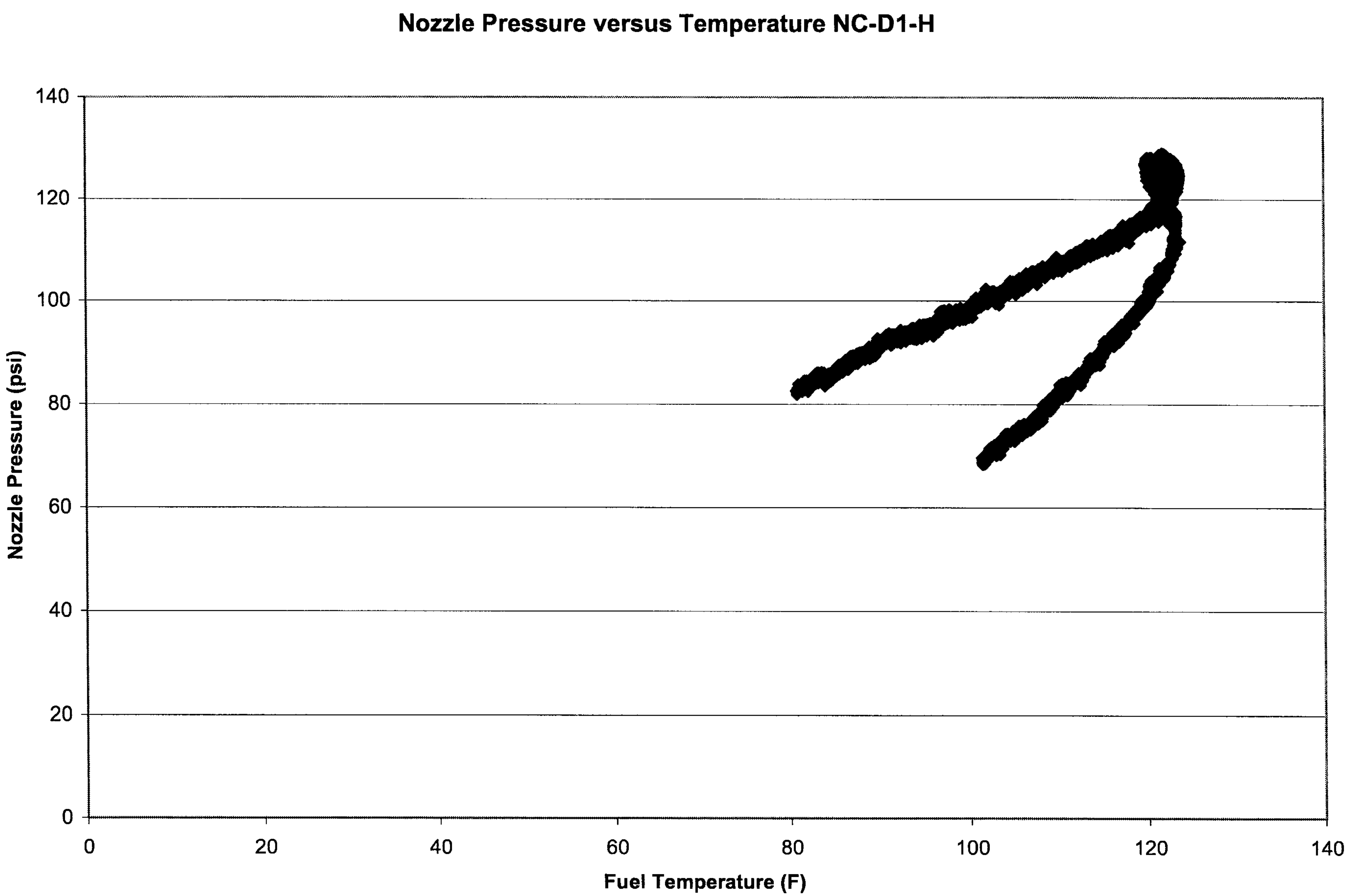


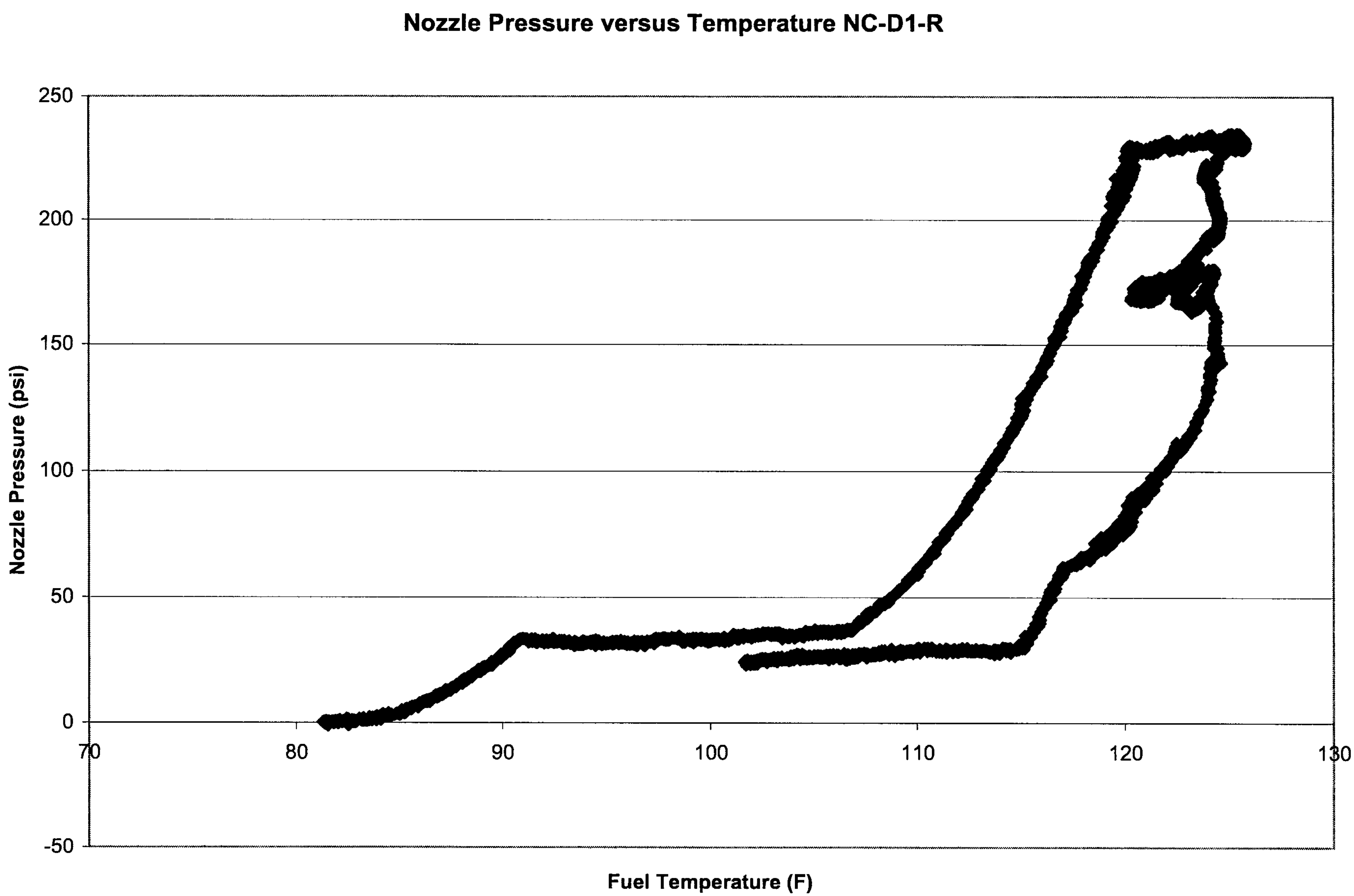
Nozzle Pressure versus Fuul Temperature NC-D1



Pressure versus Temperature NC-D1-R

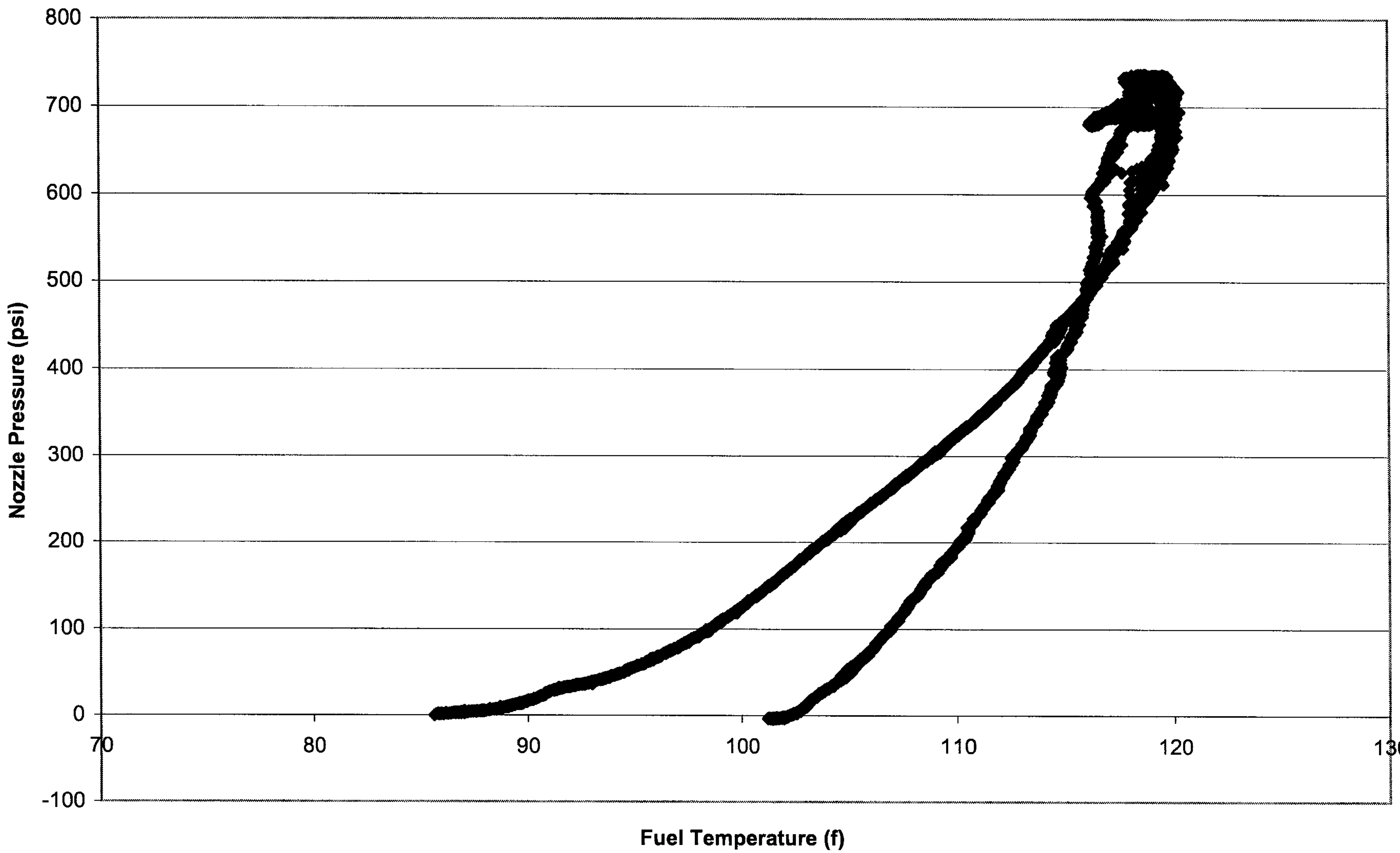



Nozzle Pressure versus Temperature NC-D1-H
Nozzle Pressure (psi)
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Fuel Temperature (F)

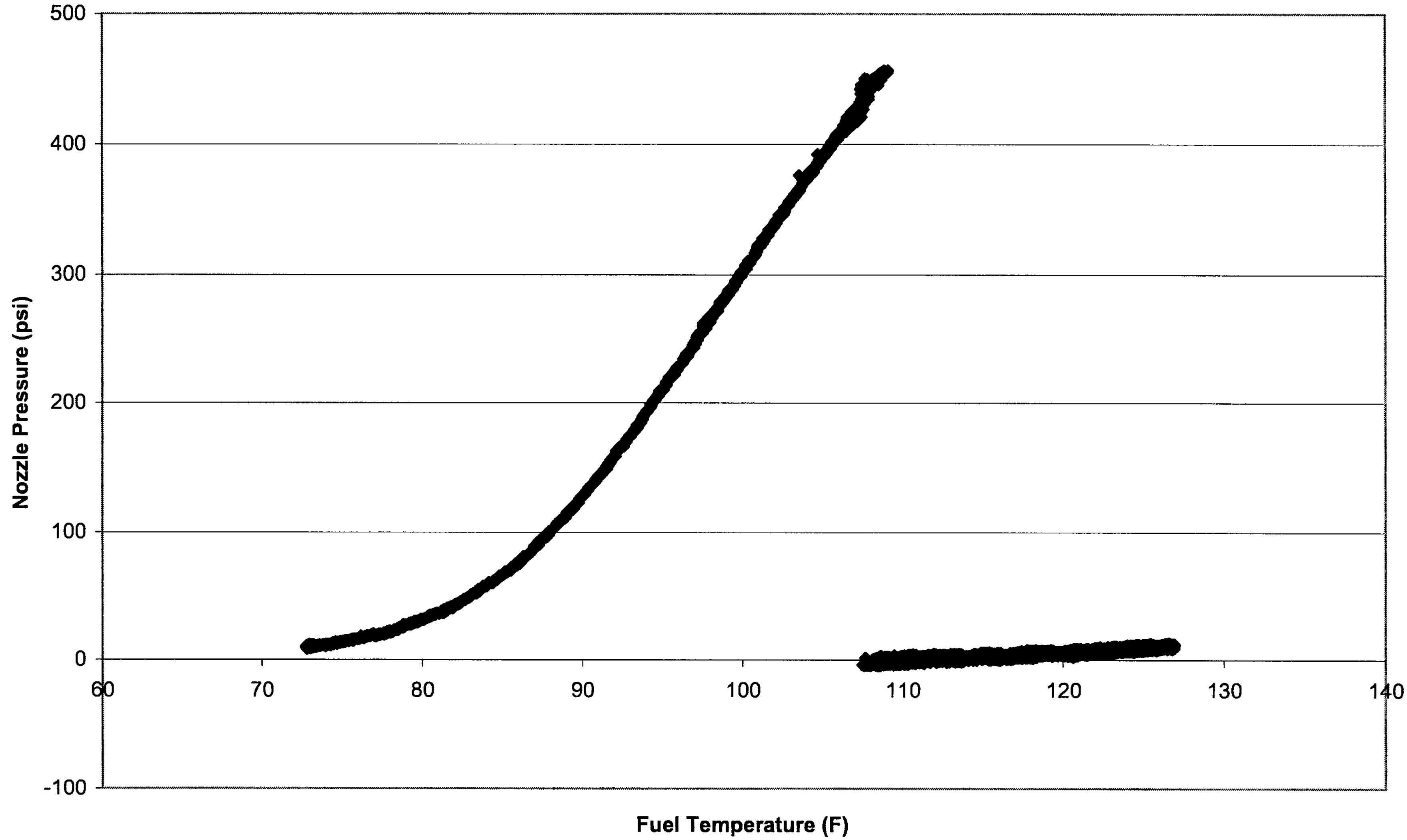


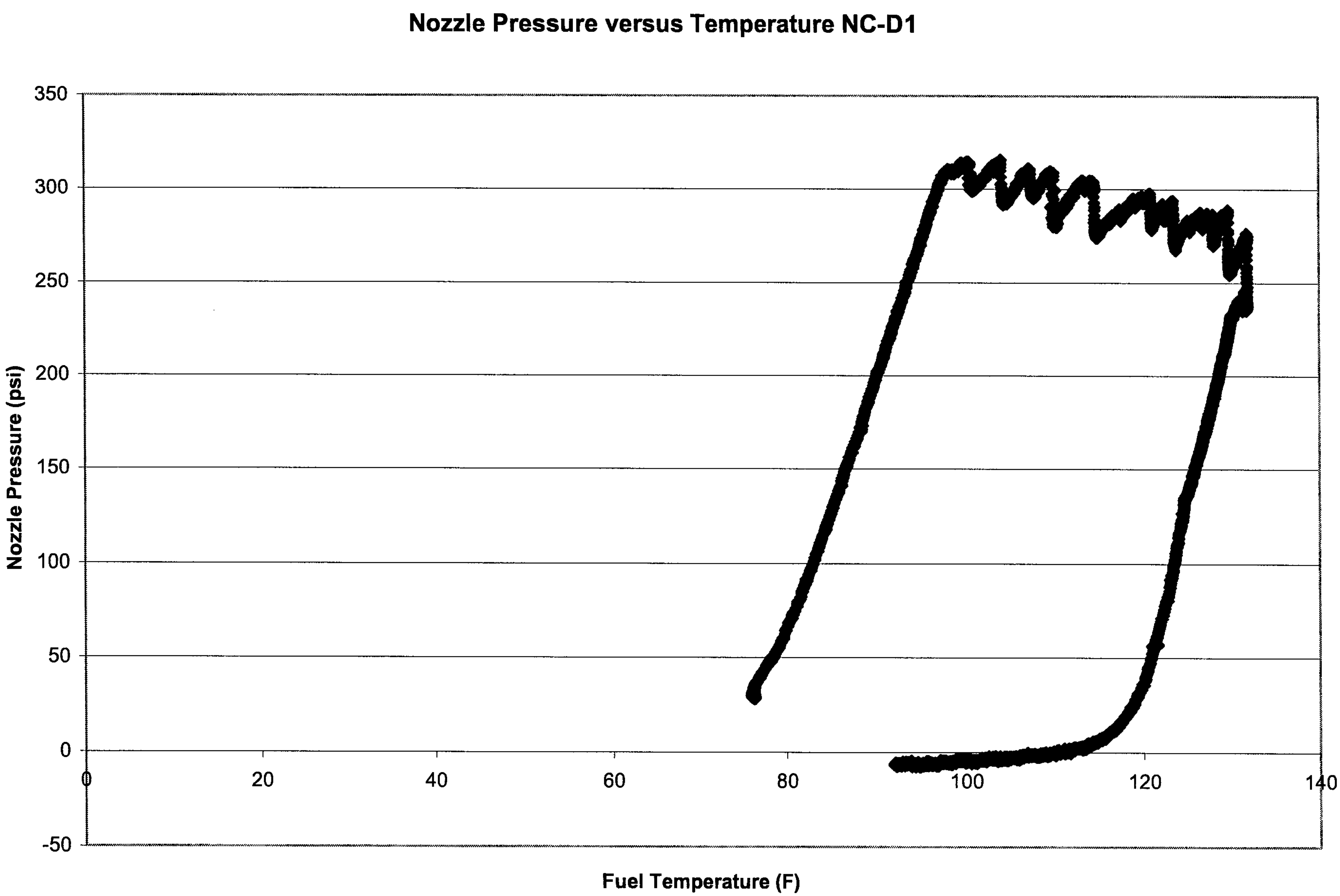
Nozzle Pressure versus Temperature NC-D1-R
250
200
150
100
50
0
-50
Nozzle Pressure (psi)
70
80
90
100
110
120
130
Fuel Temperature (F)

Nozzle Pressure versus Temperature W-D1

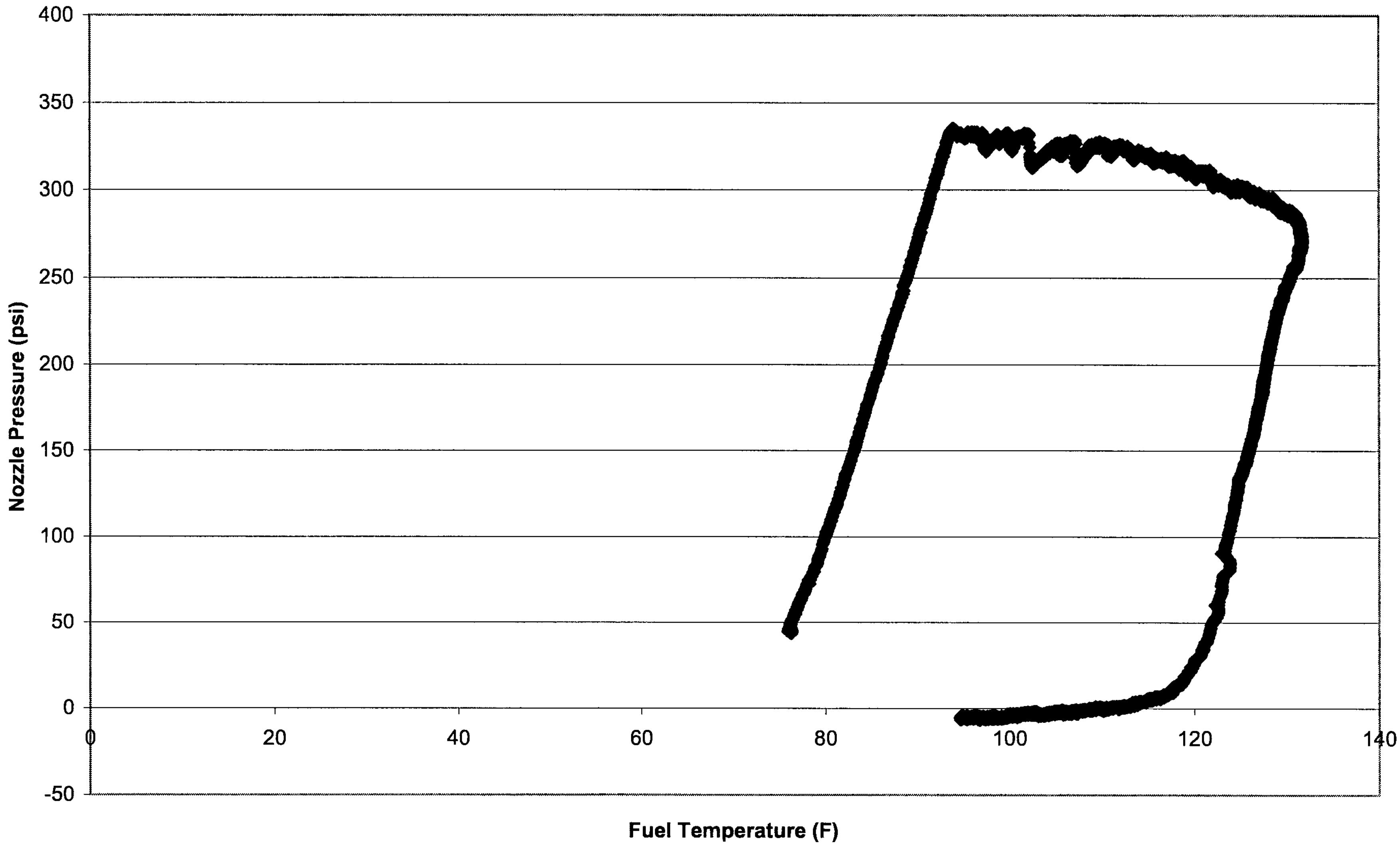


Nozzle Pressure versus Temperature OC-D1

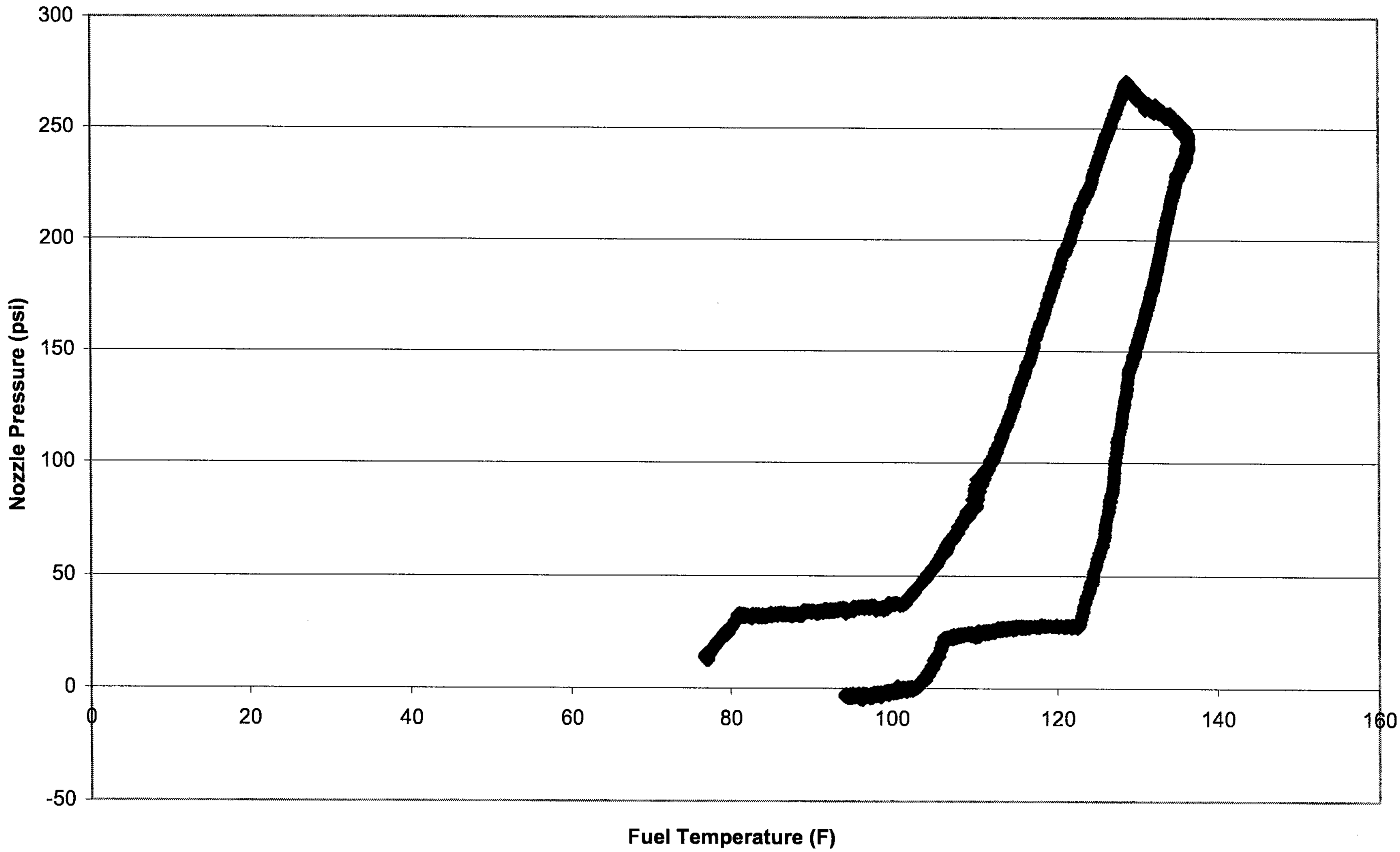



Nozzle Pressure versus Temperature NC-D1
350
300
250
200
150
100
50
0
-50
Nozzle Pressure (psi)
0
20
40
60
80
100
120
140
Fuel Temperature (F)

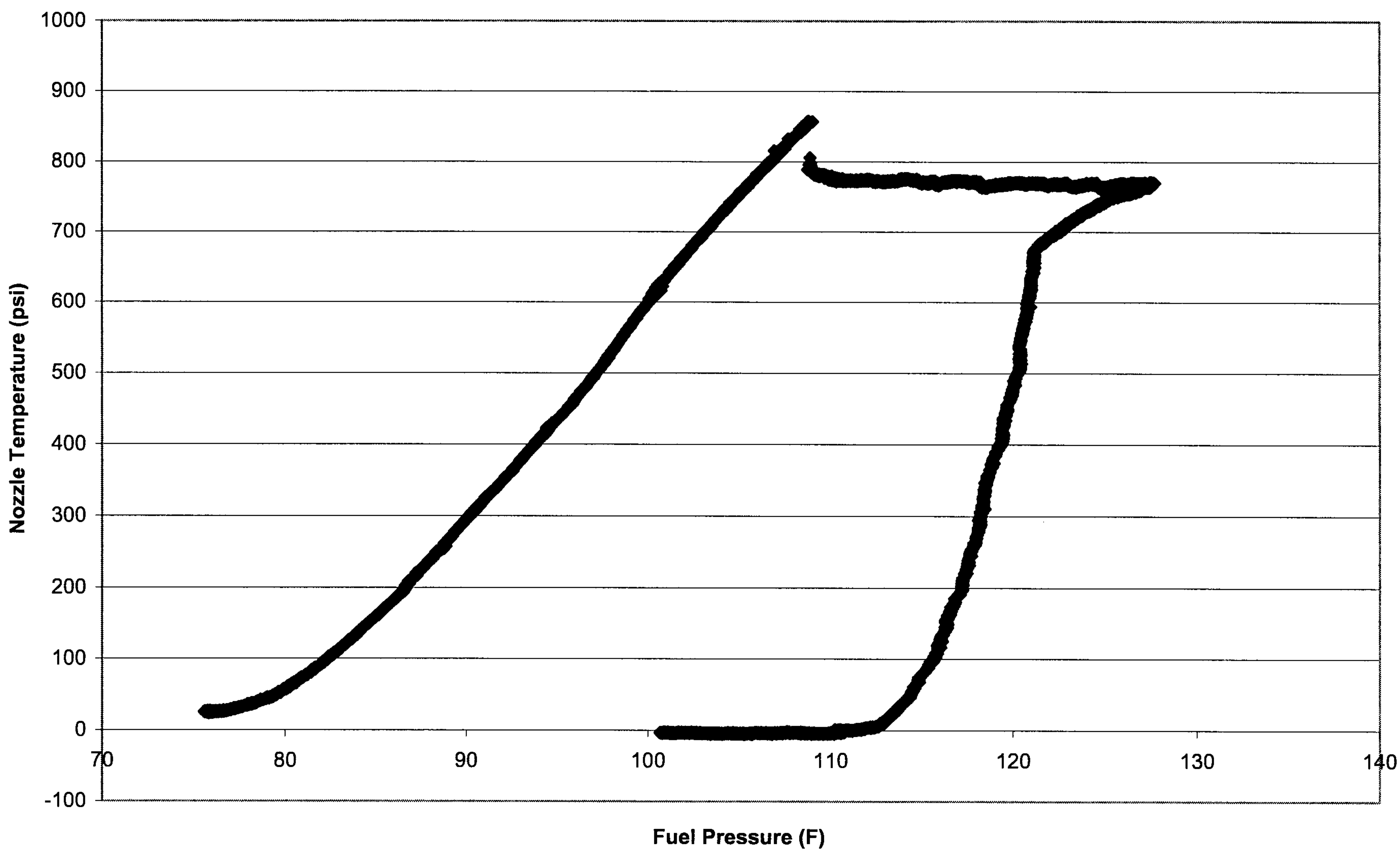
Nozzle Pressure versus Temperature NC-D1



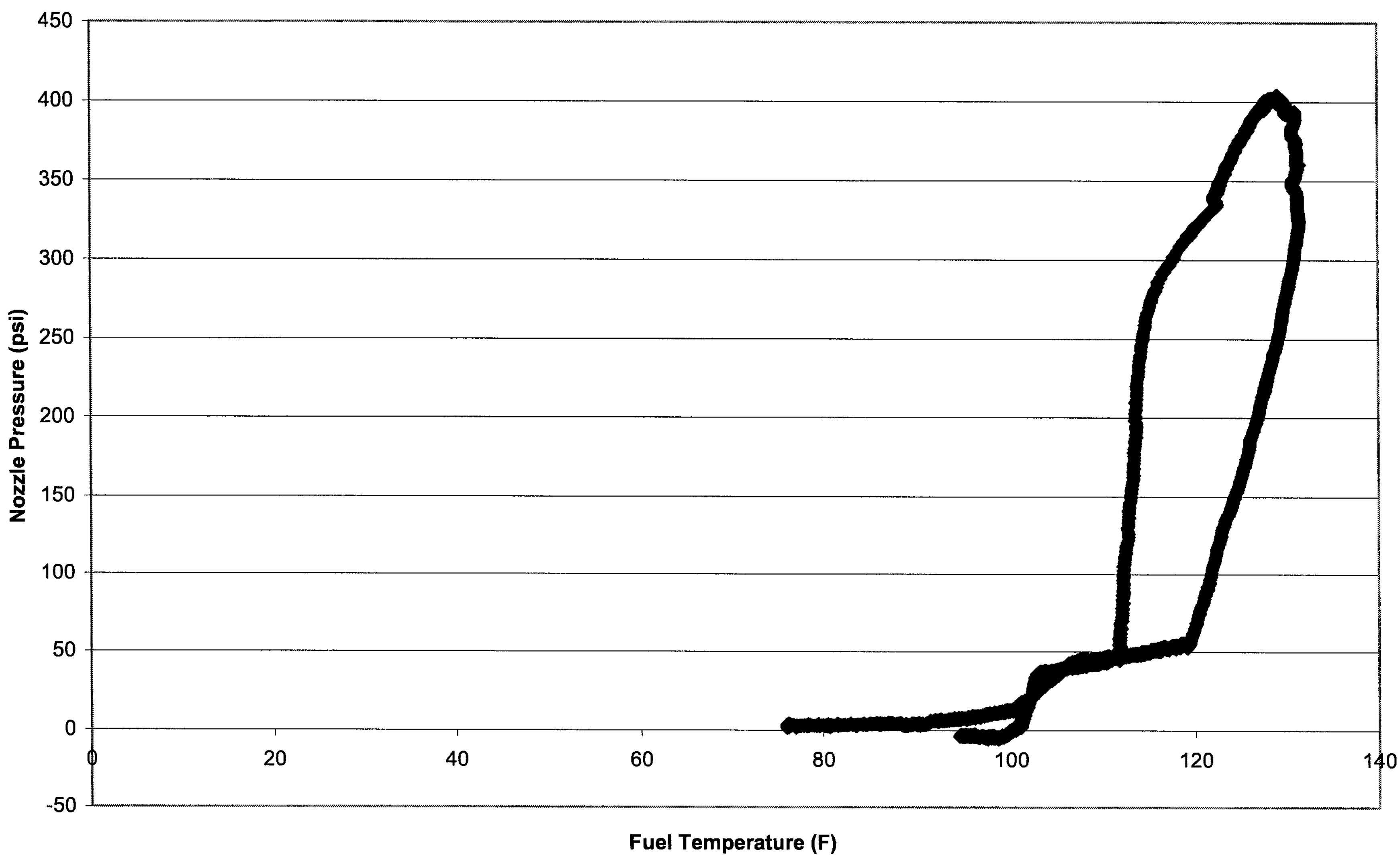
Nozzle Pressure versus Termperature NC-D1-R



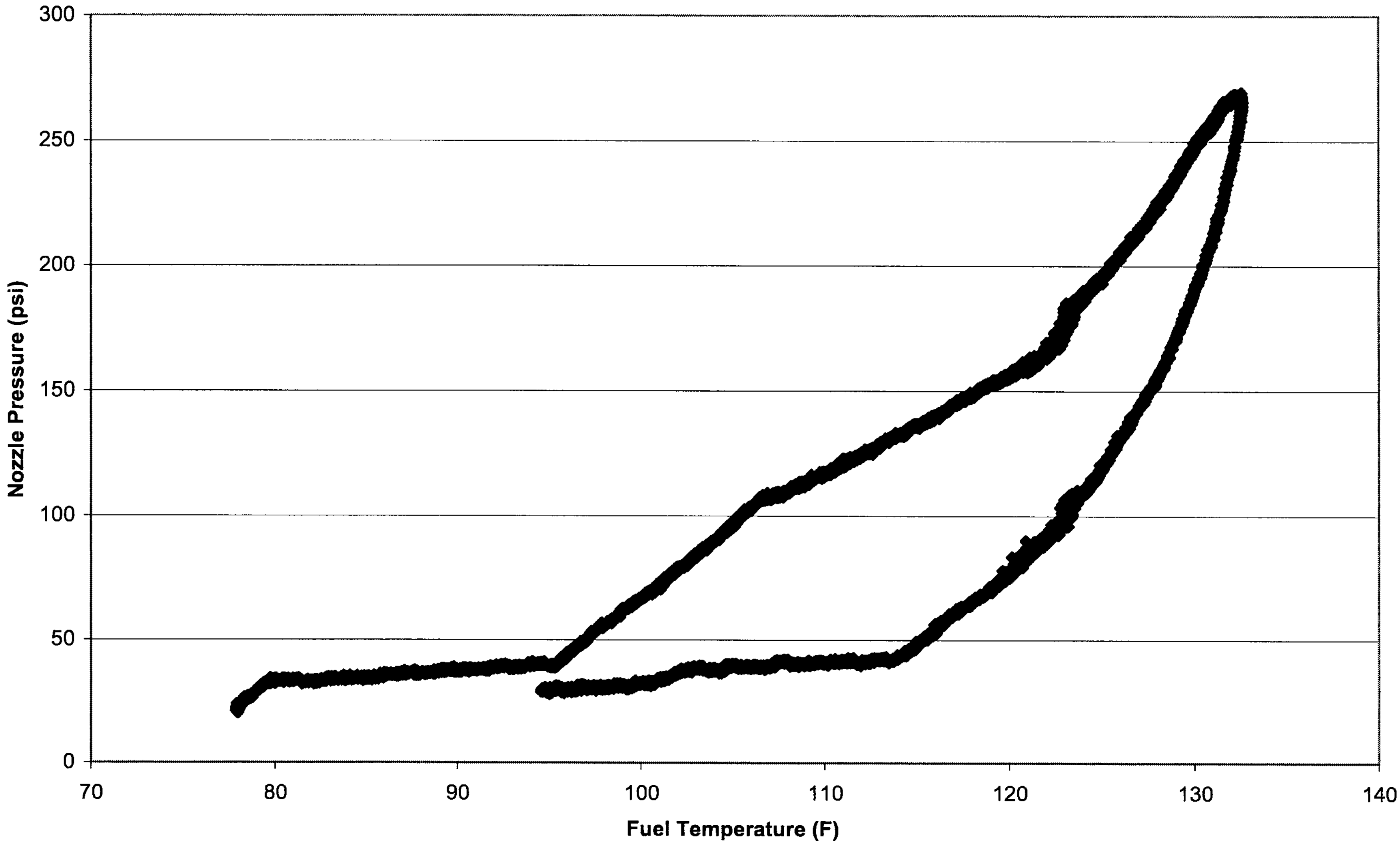
Nozzle Pressure versus Temperature W-D1



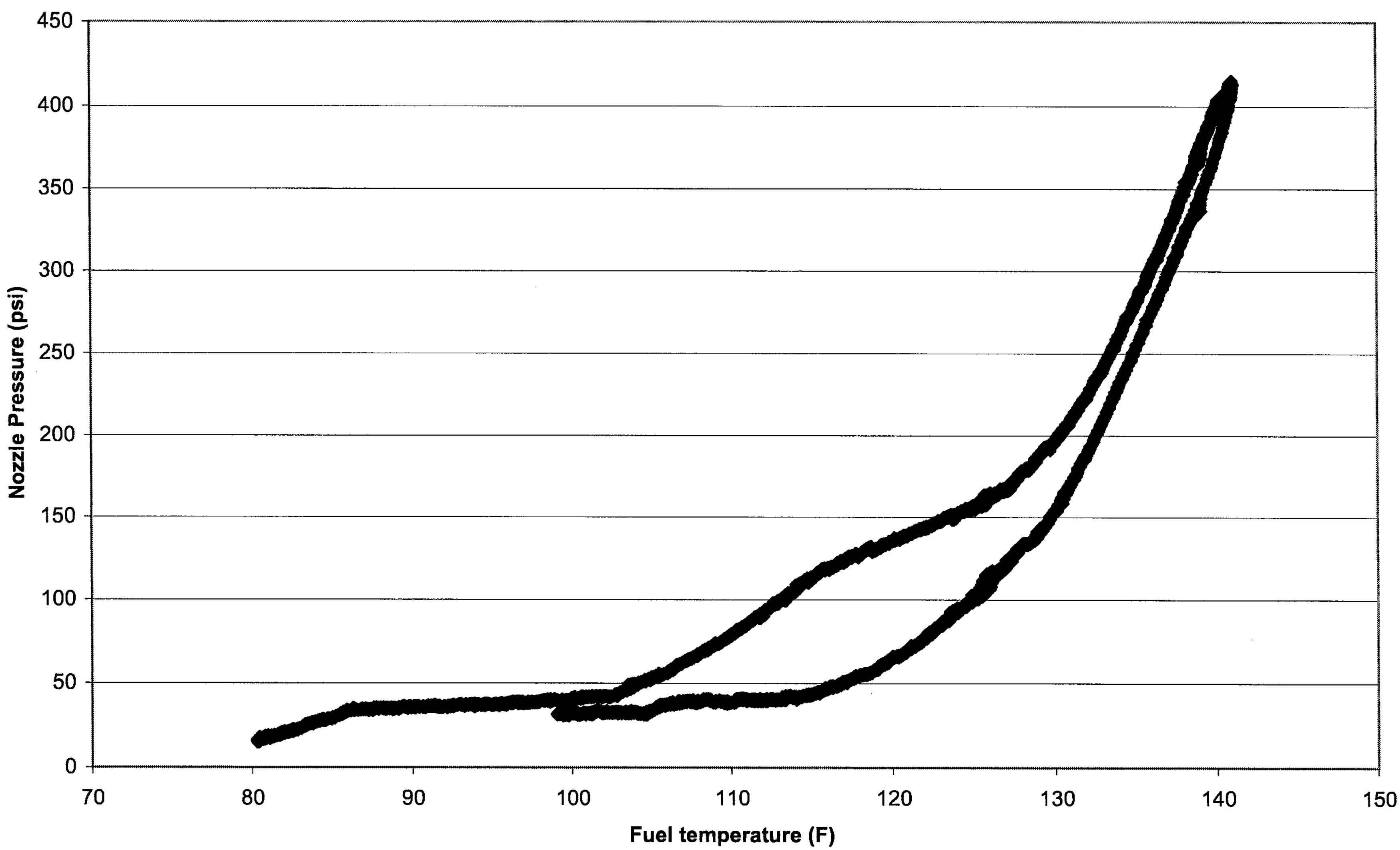
Nozzle Pressure versus Temperature W-D1-R



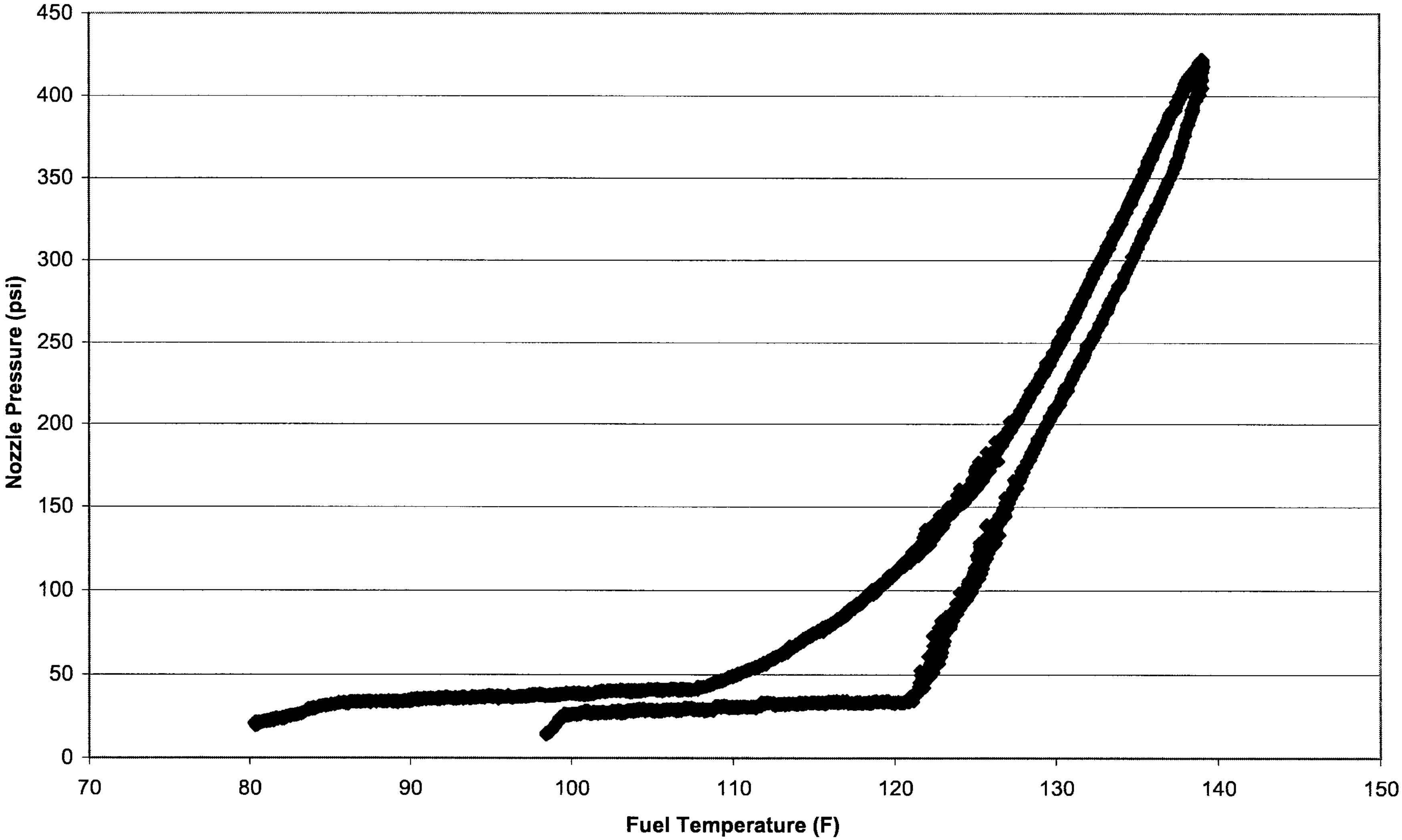
Nozzle Pressure versus Temperature NC-D1-R-NR



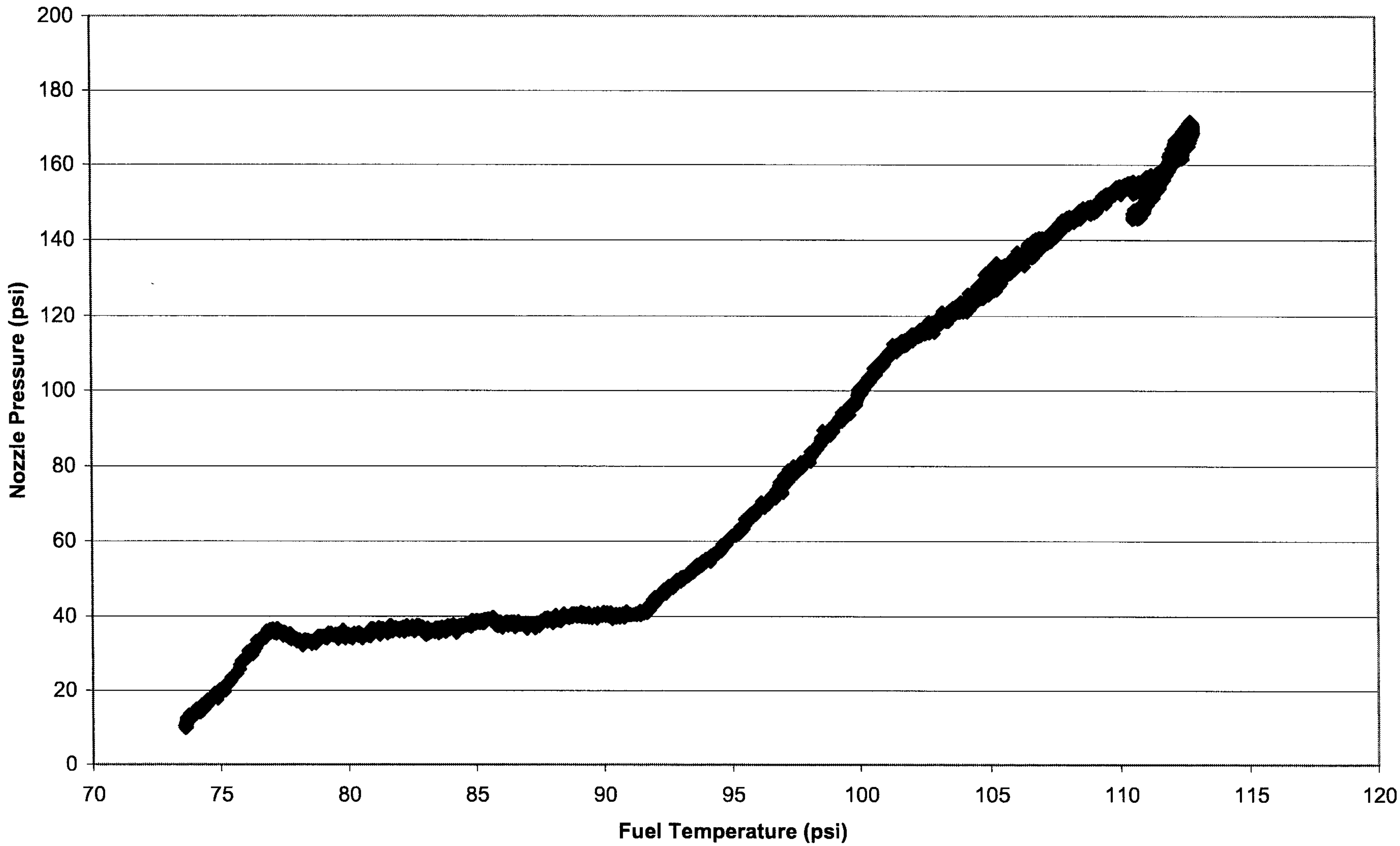
Nozzle Pressure versus Temperature OC-D1-R-NR



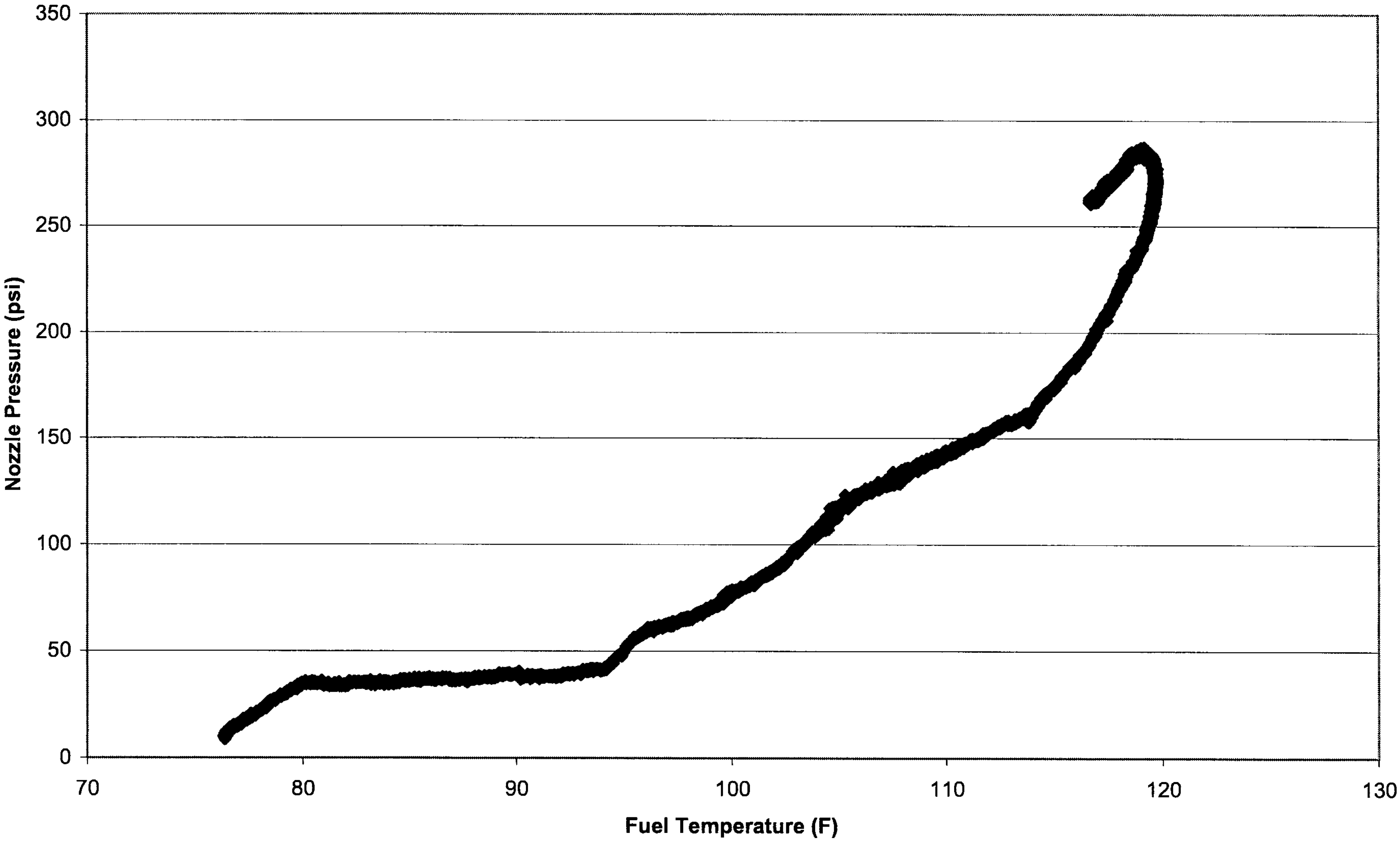
Nozzle Pressure versus Temperature OC-D1-R



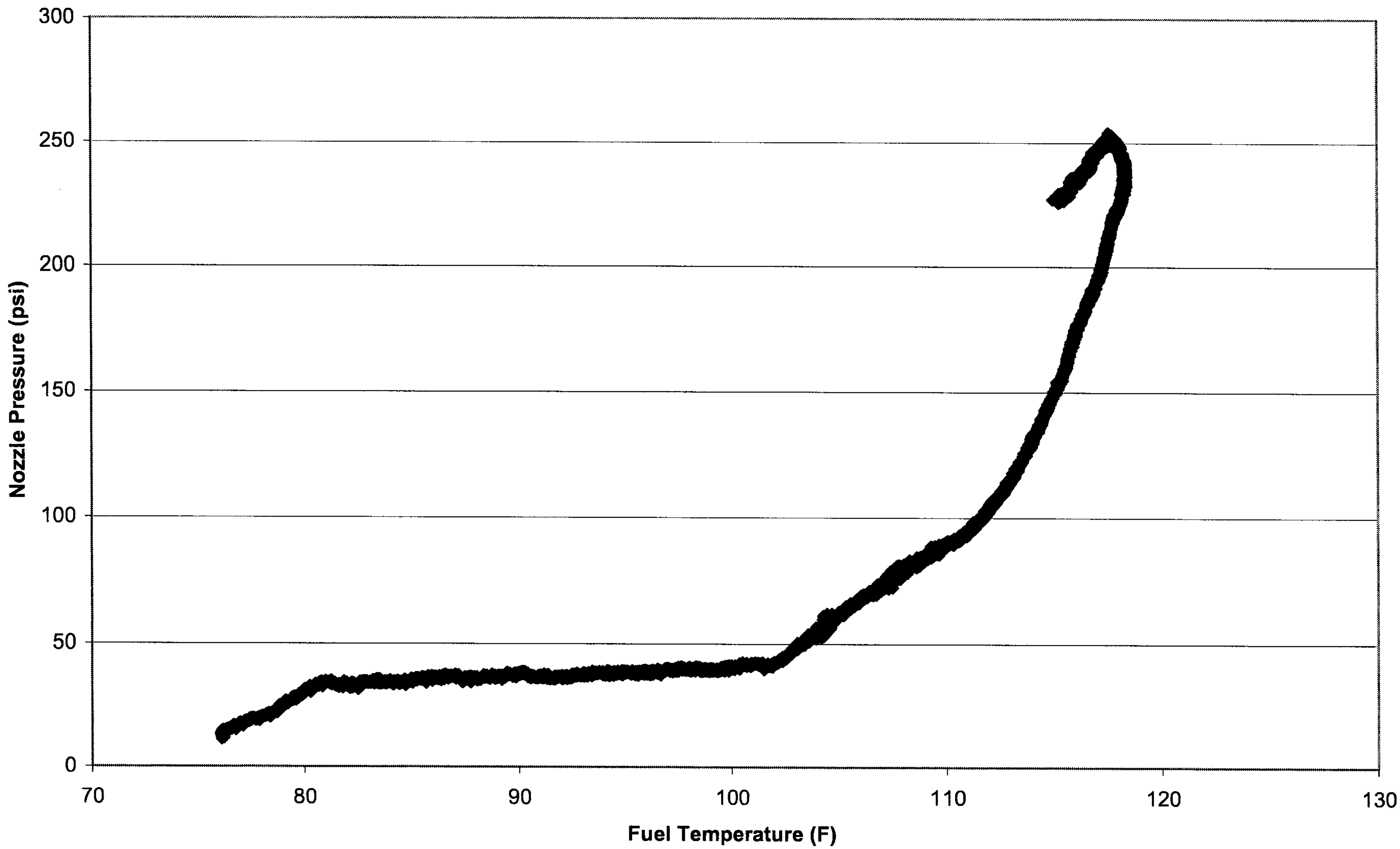
Nozzle Pressure versus Temperature NC-D1-R-NR



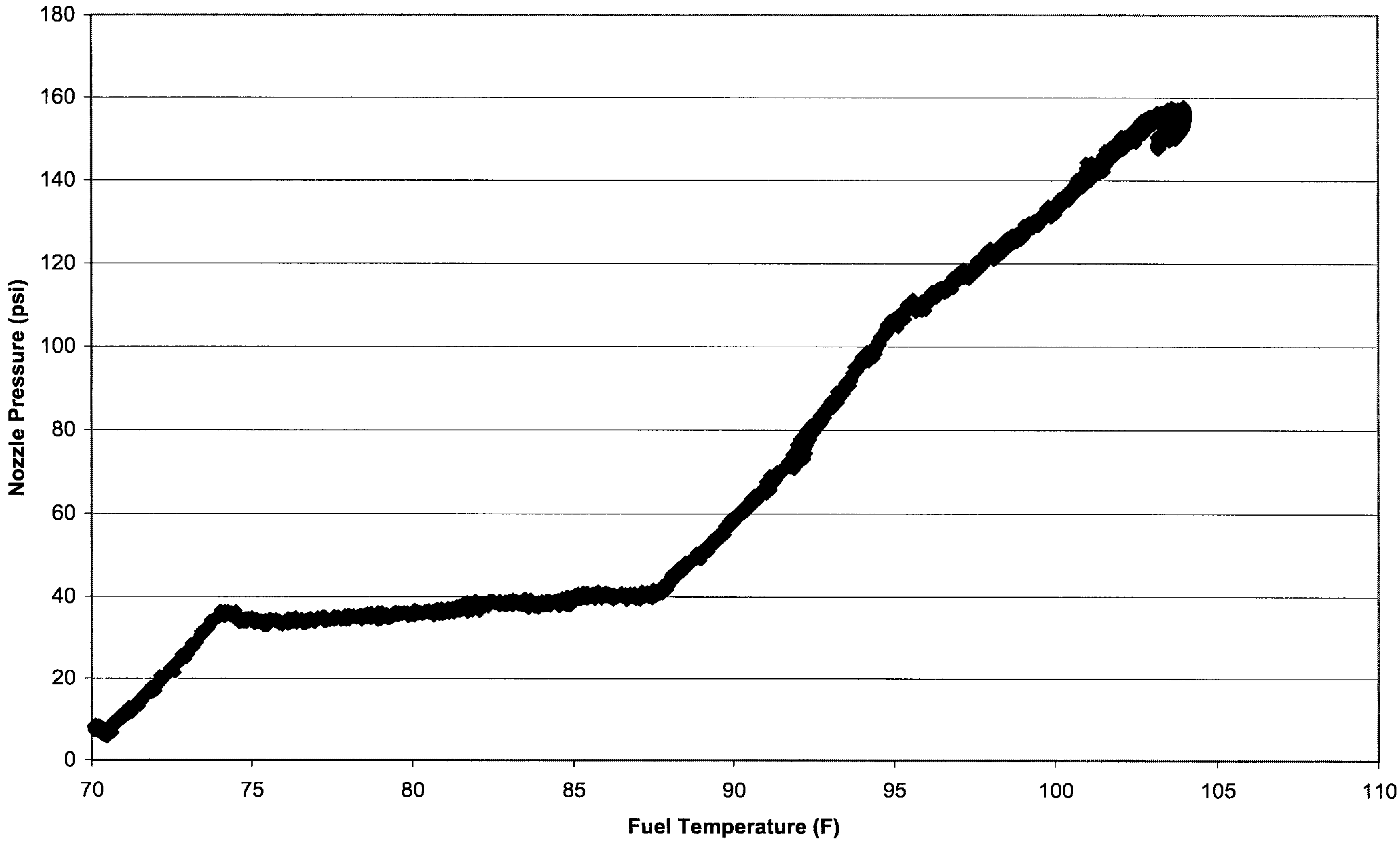
Nozzle Pressure versus Temperature OC-D1-R-NR



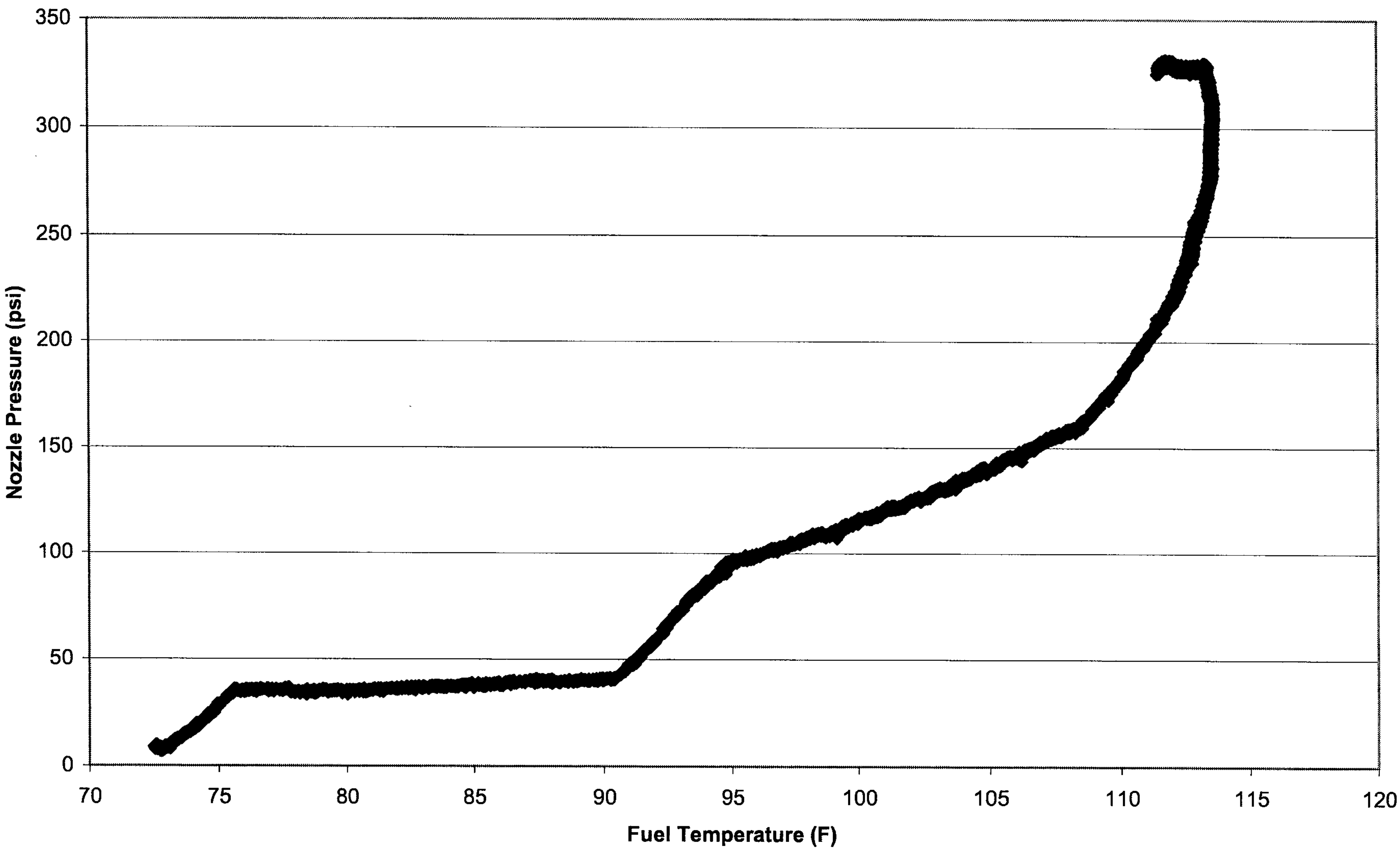
Nozzle Pressure versus Temperature OC-D1-R



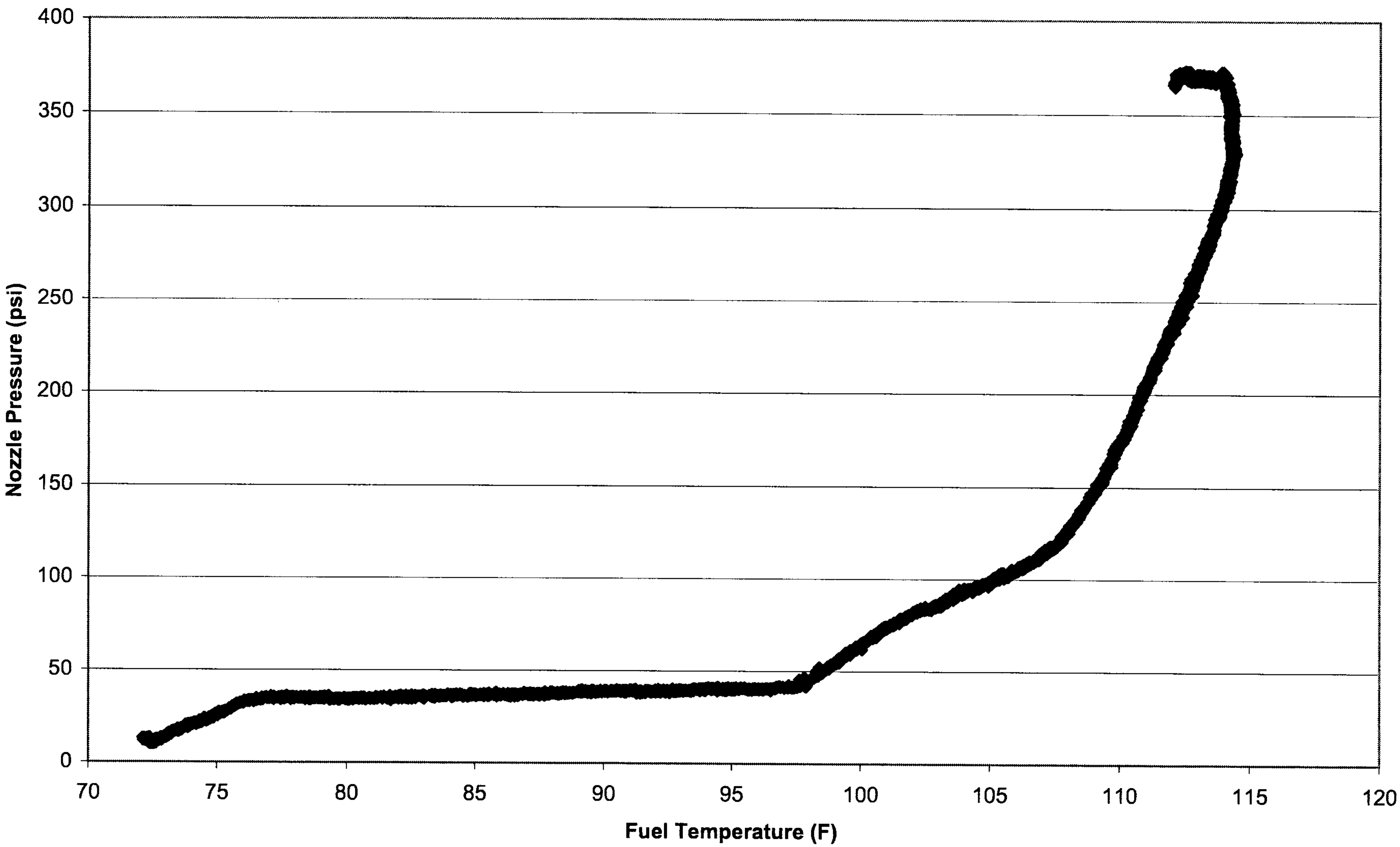
Nozzle Pressure versus Temperature NC-D1-R-NR



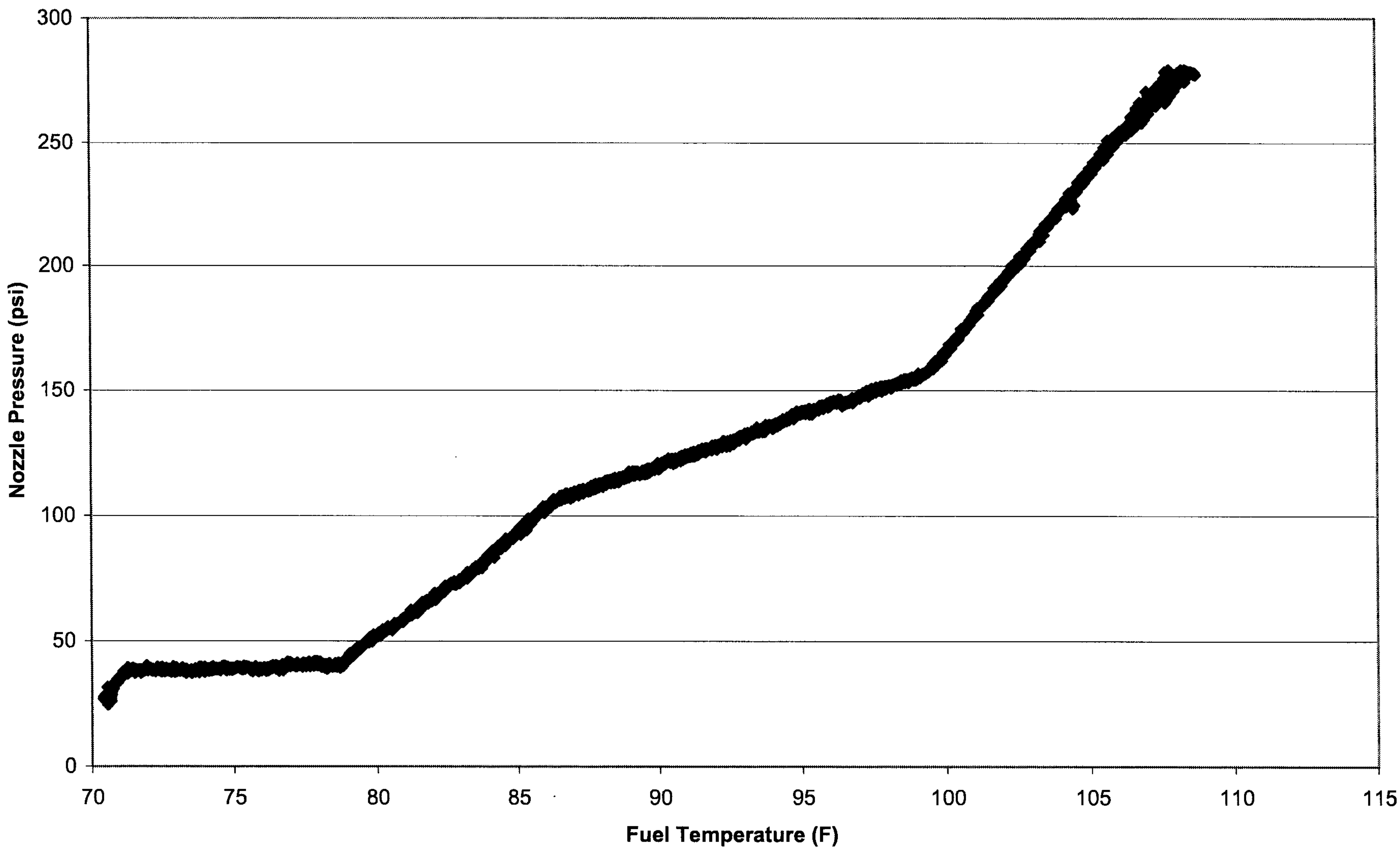
Nozzle Pressure versus Temperature OC-D1-R-NR



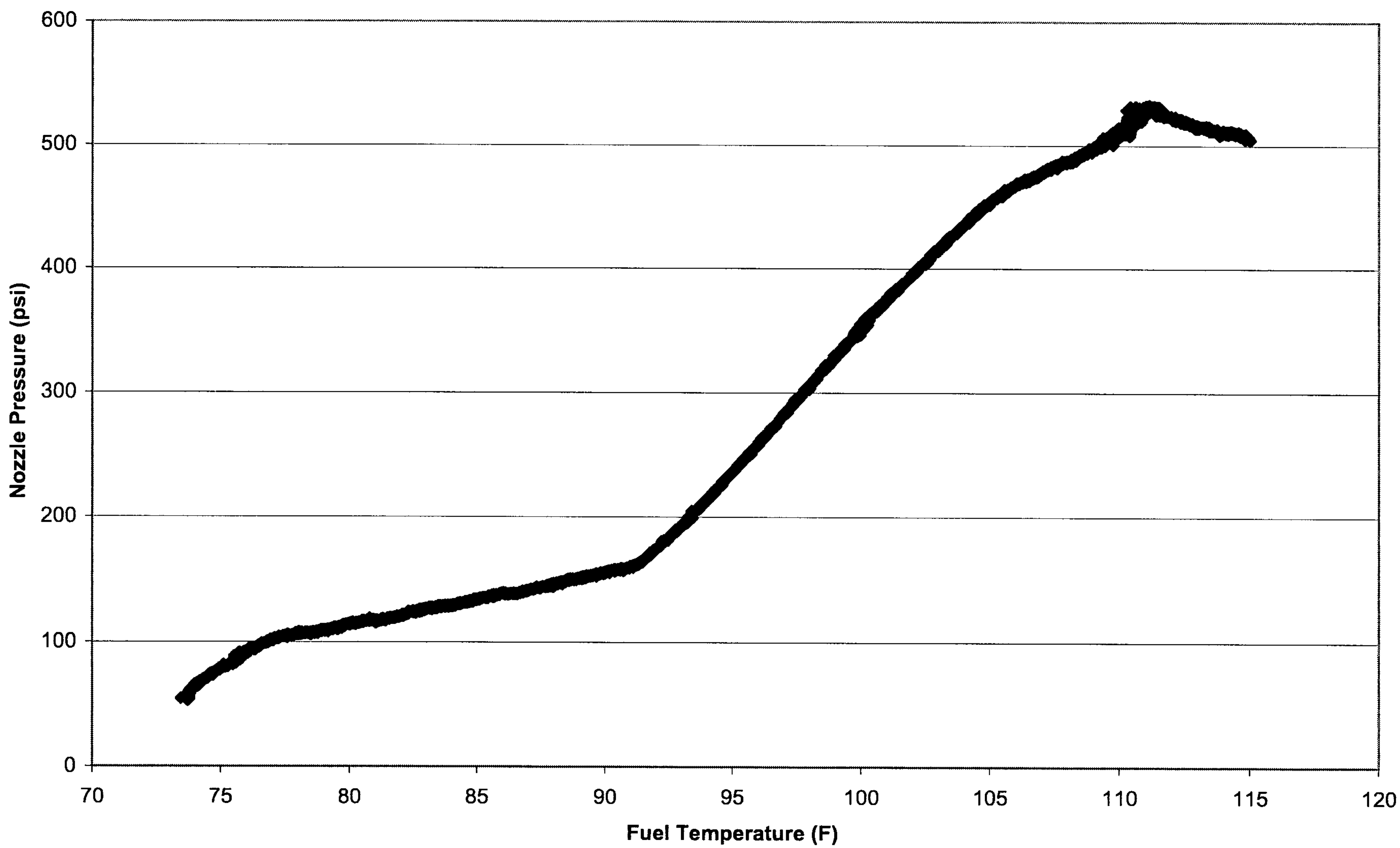
Nozzle Pressure versus Temperature OC-D1-R



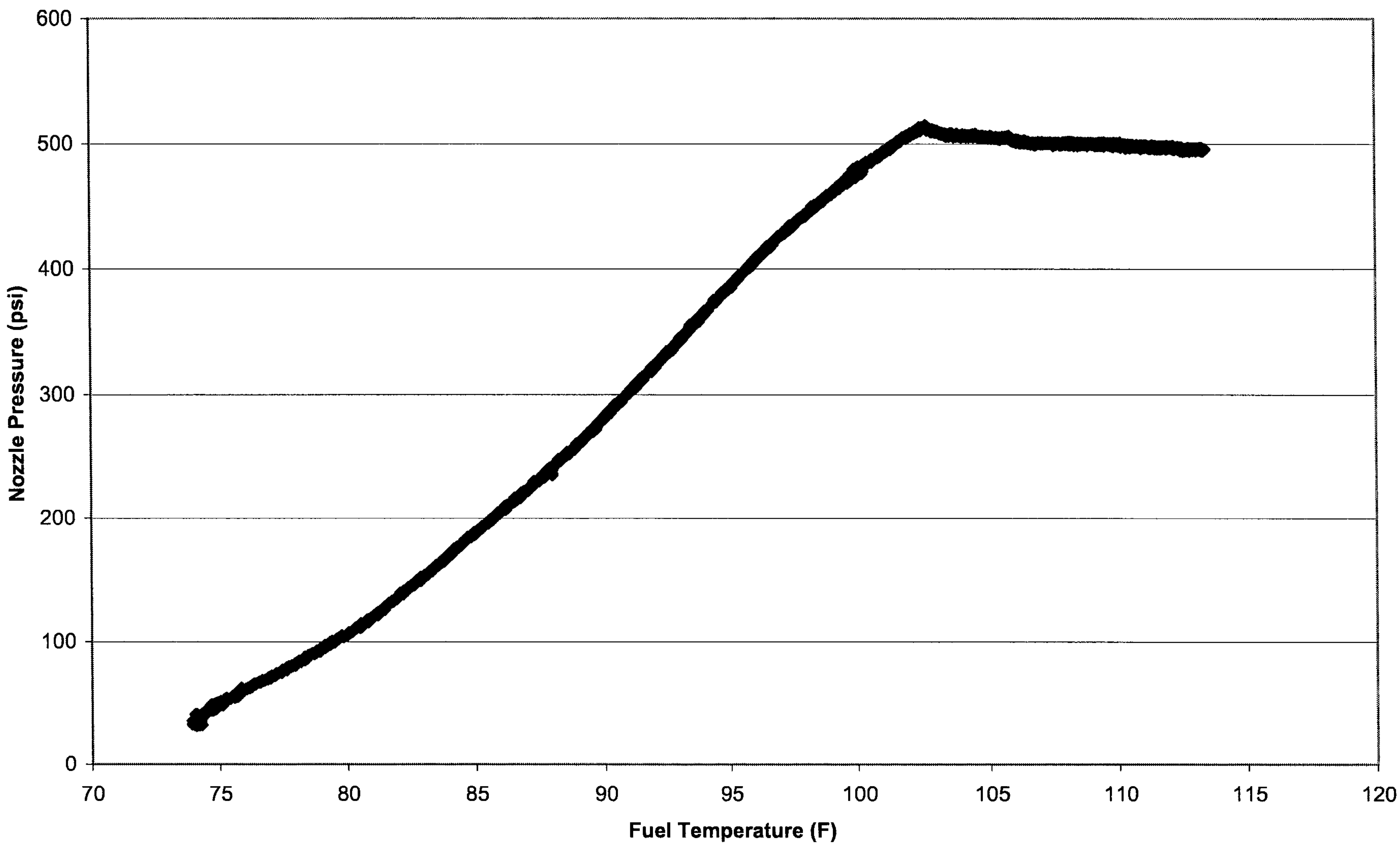
Nozzle Pressure versus Temperature NC-D1-R-NR

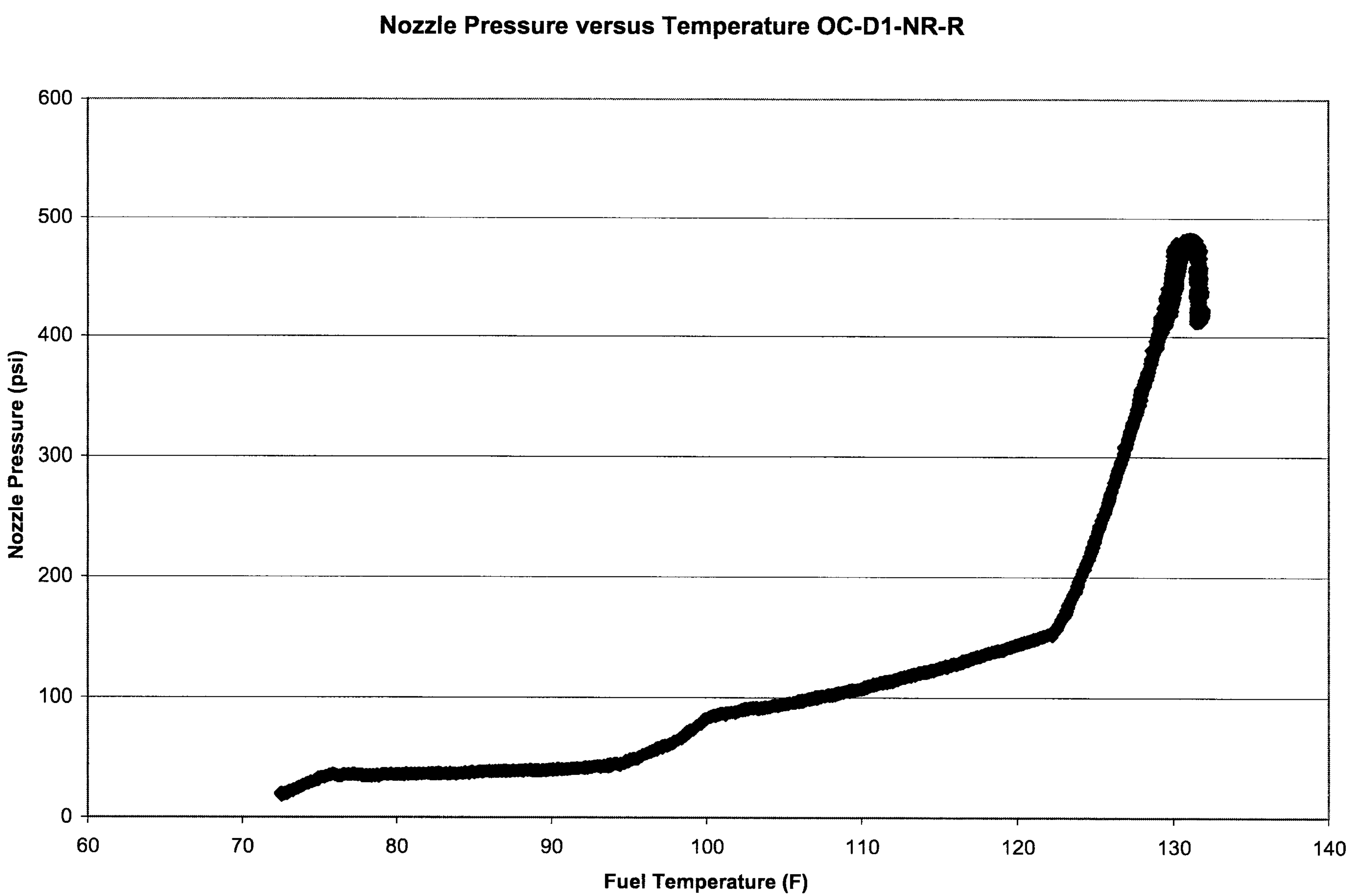


Nozzle Pressure versus Temperature OC-D1-R-NR



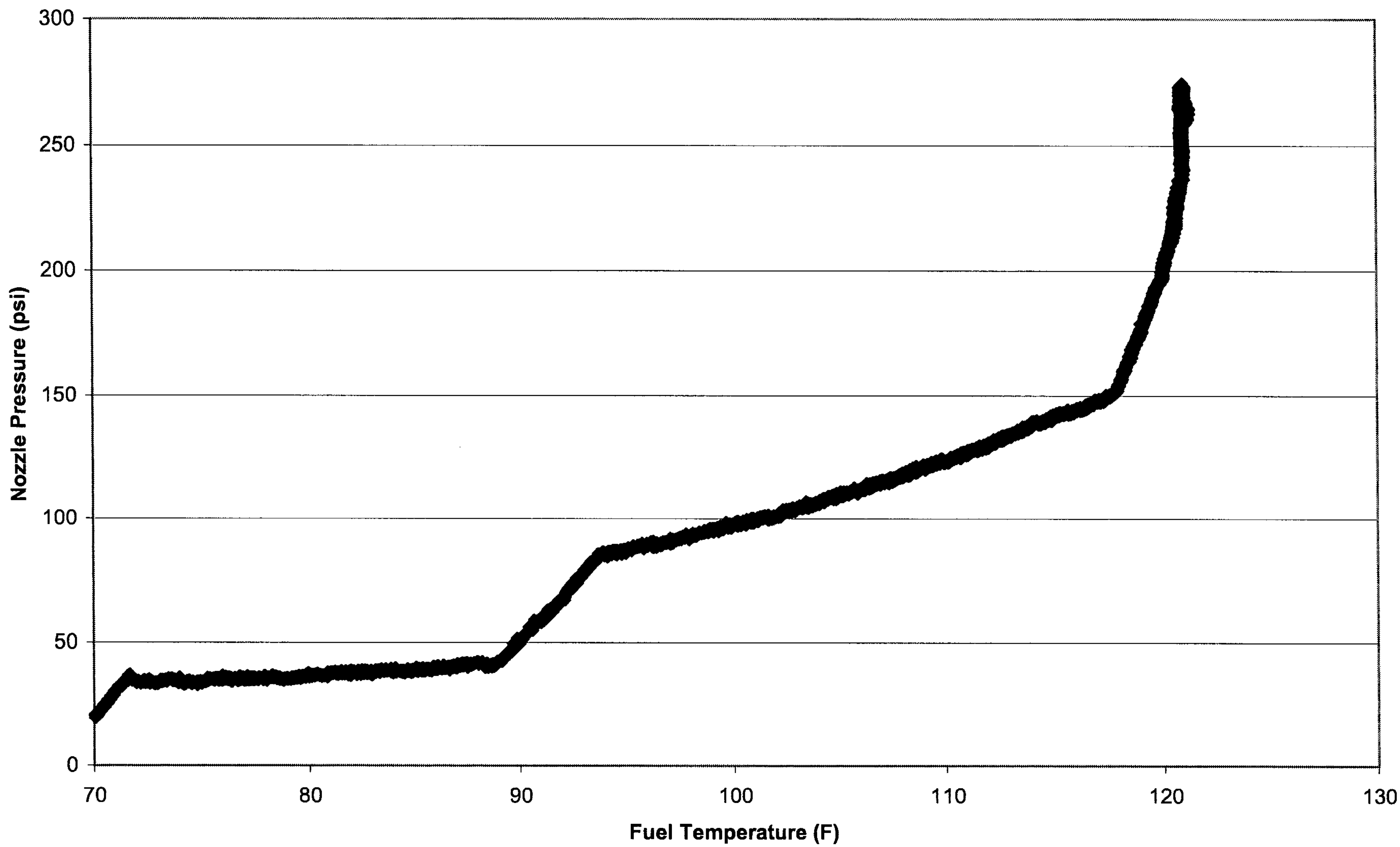
Nozzle Pressure versus Temperature OC-D1-R



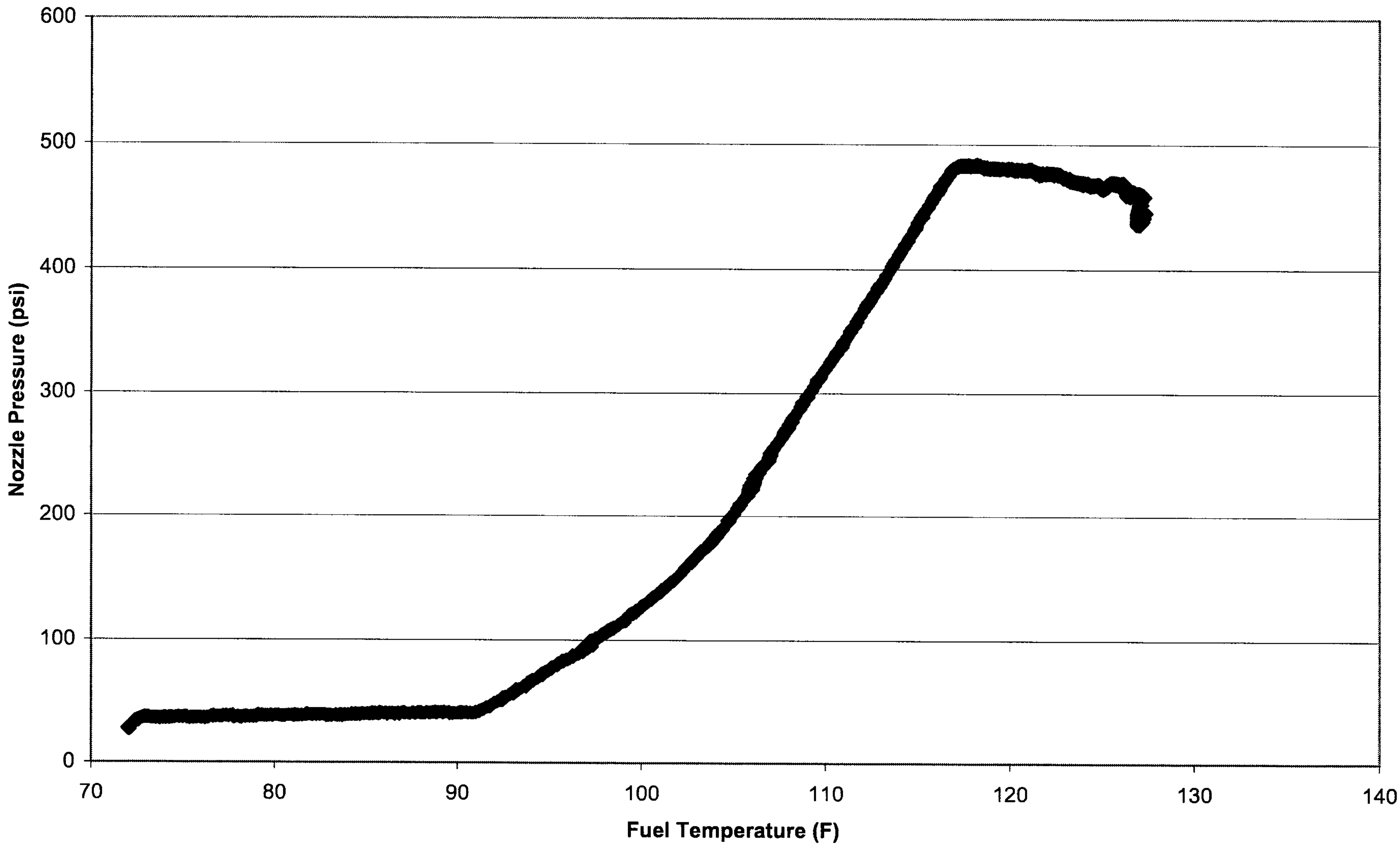


Nozzle Pressure versus Temperature OC-D1-NR-R
600
500
400
300
200
100
0
Nozzle Pressure (psi)
60
70
80
90
100
110
120
130
140
Fuel Temperature (F)

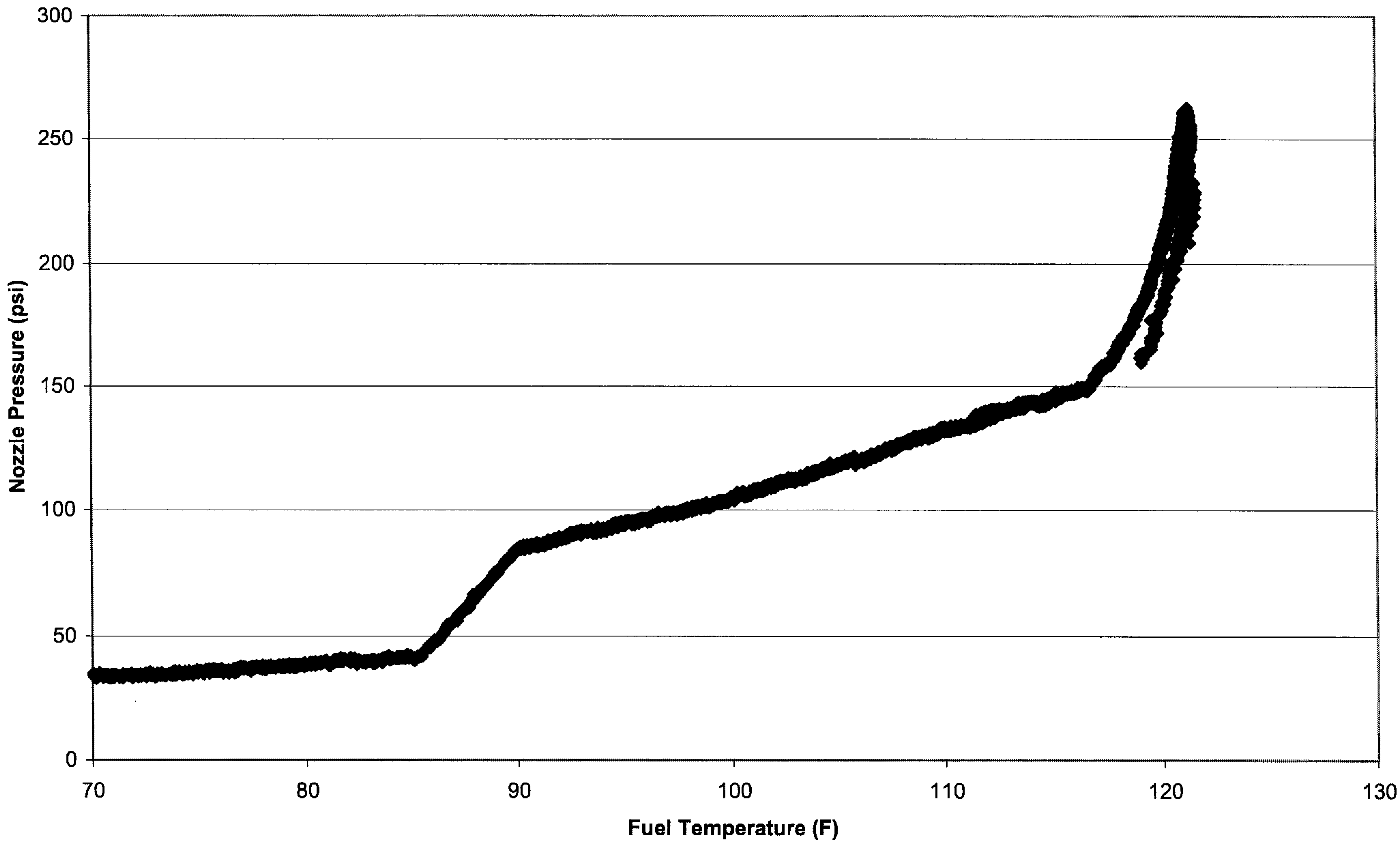
Nozzle Pressure versus Temperature NC-D1-NR-R



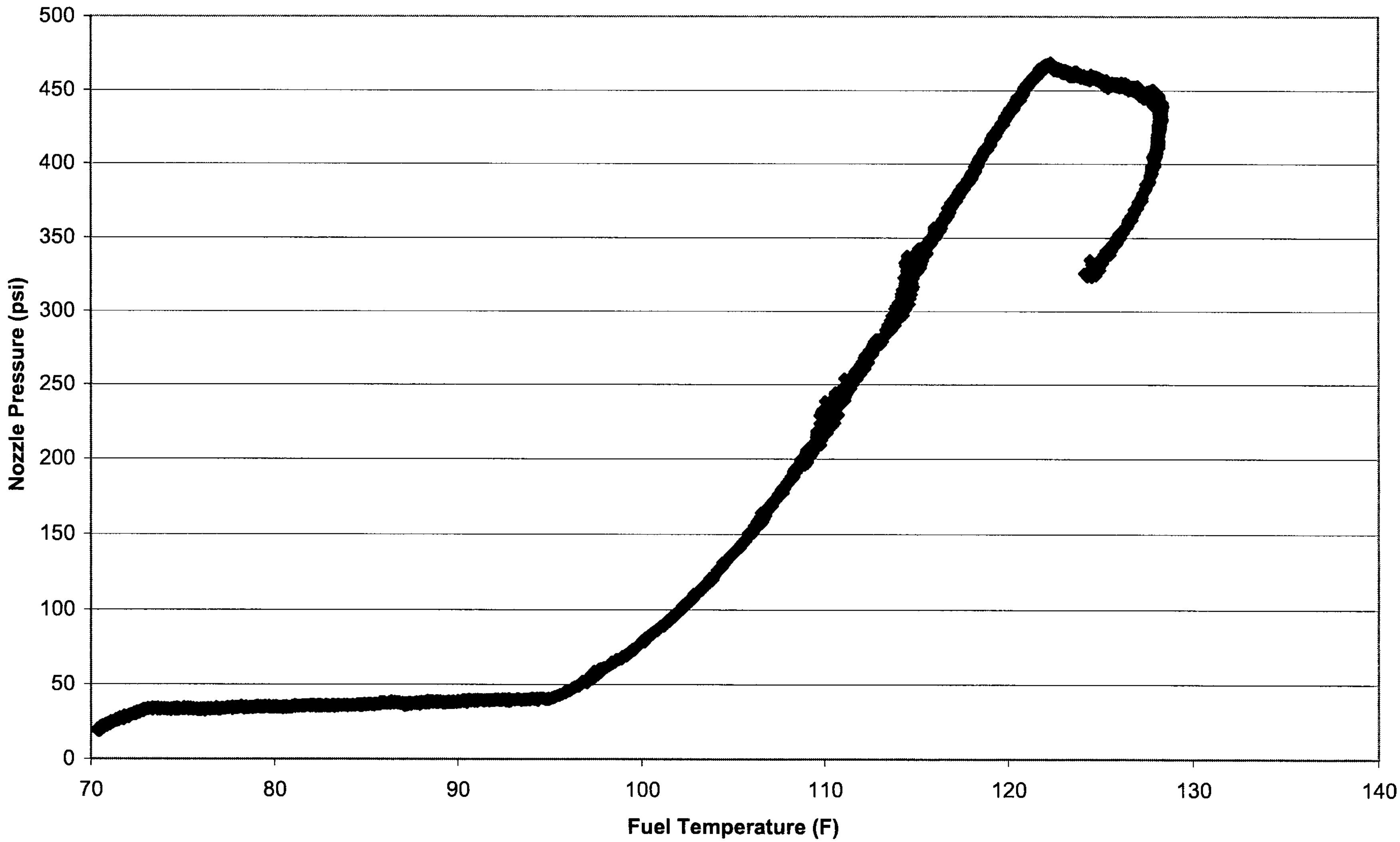
Nozzle Pressure versus Temperature OC-D1-R



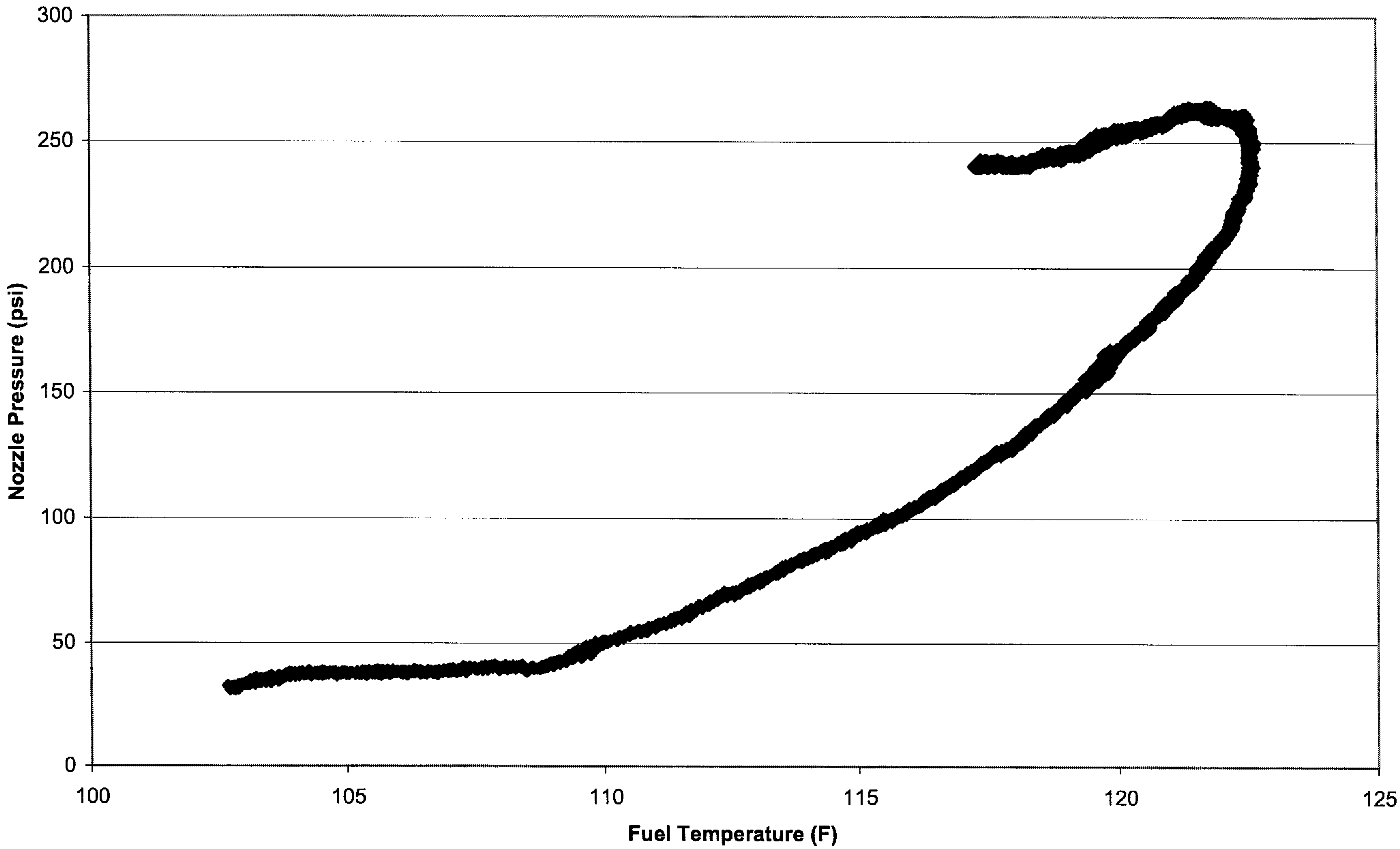
Nozzle Pressure versus Temperature NC-D1-NR-R



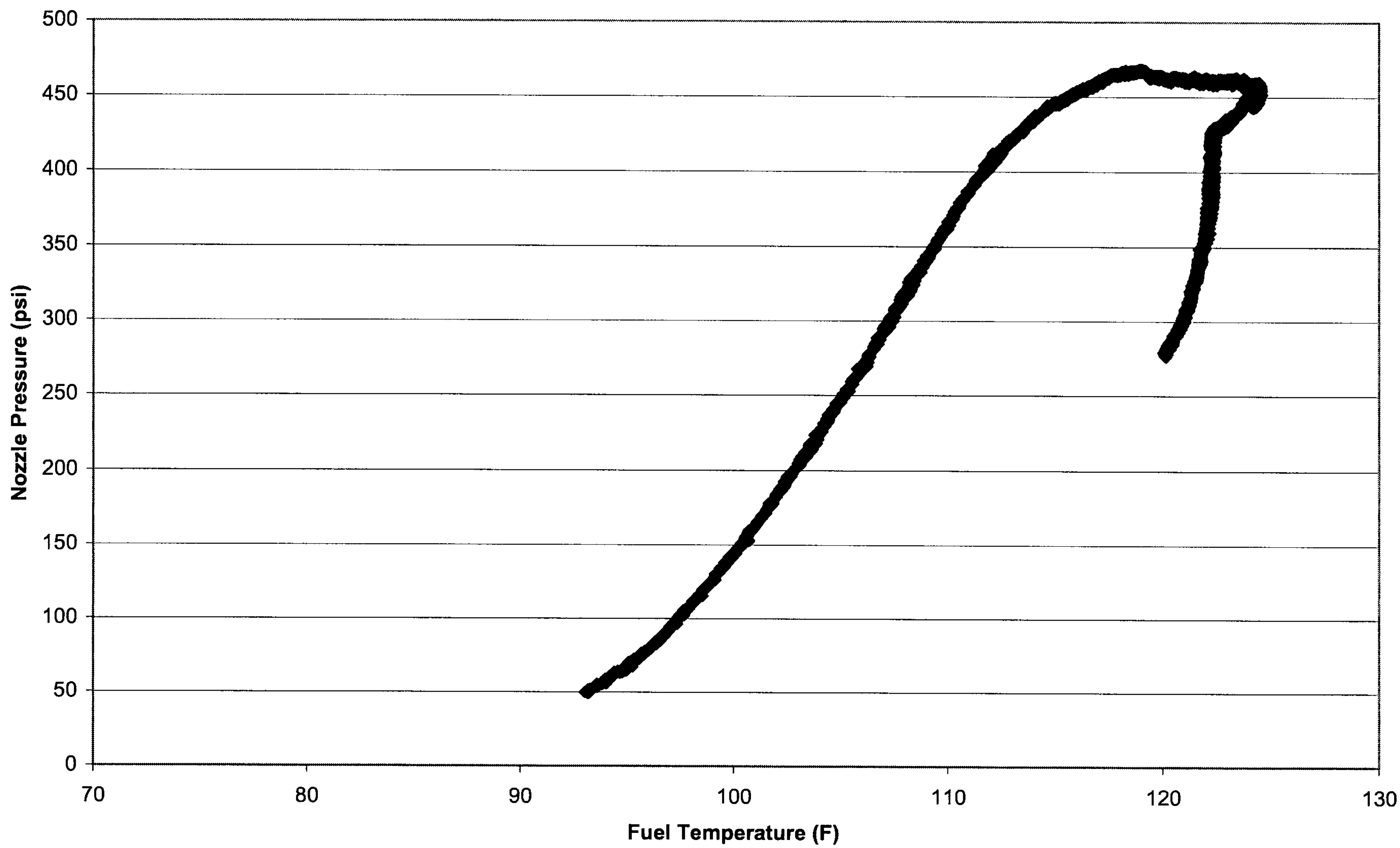
Nozzle Pressure versus Temperature OC-D1-R



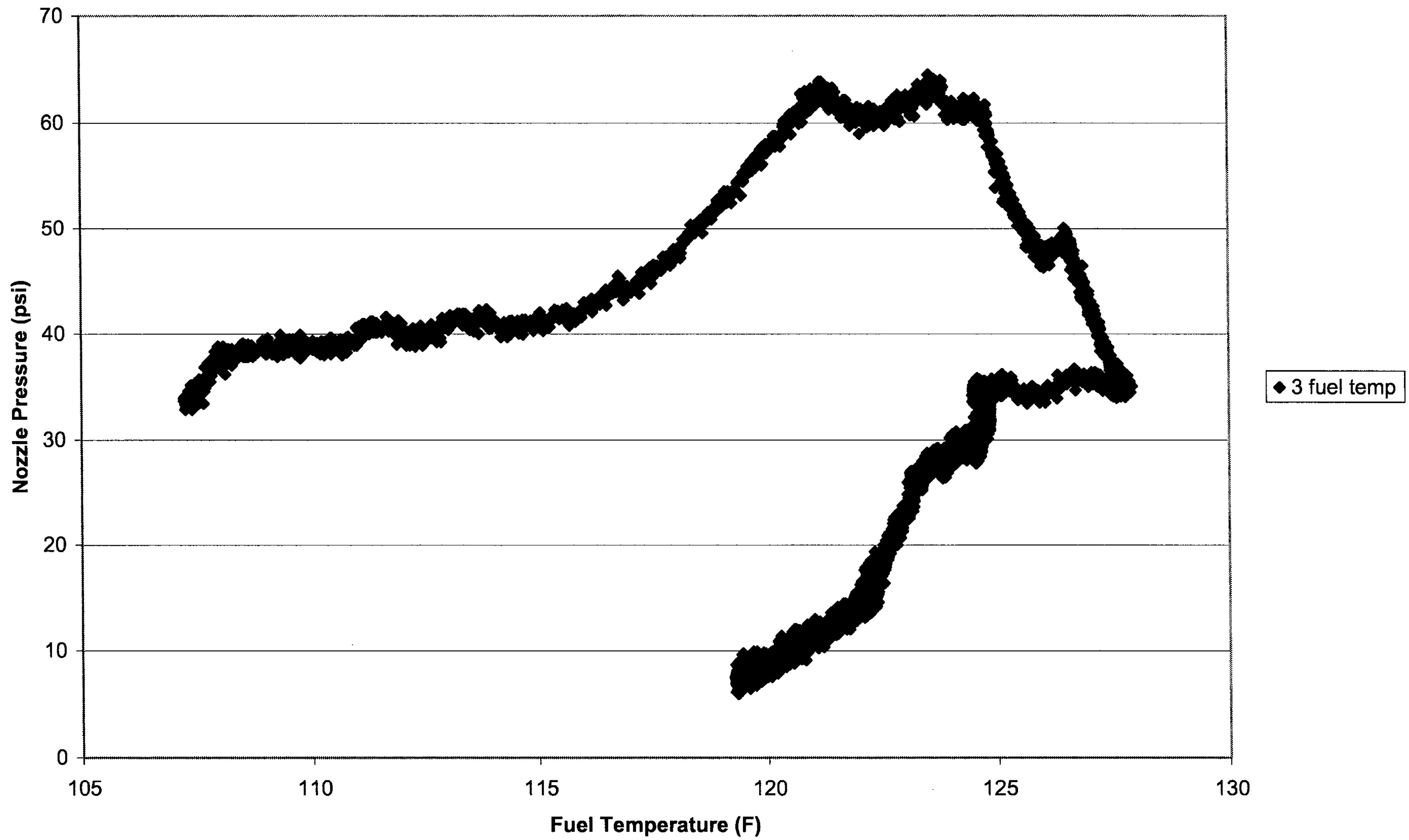
Nozzle Pressure versus Temperature OC-D1-NH-R



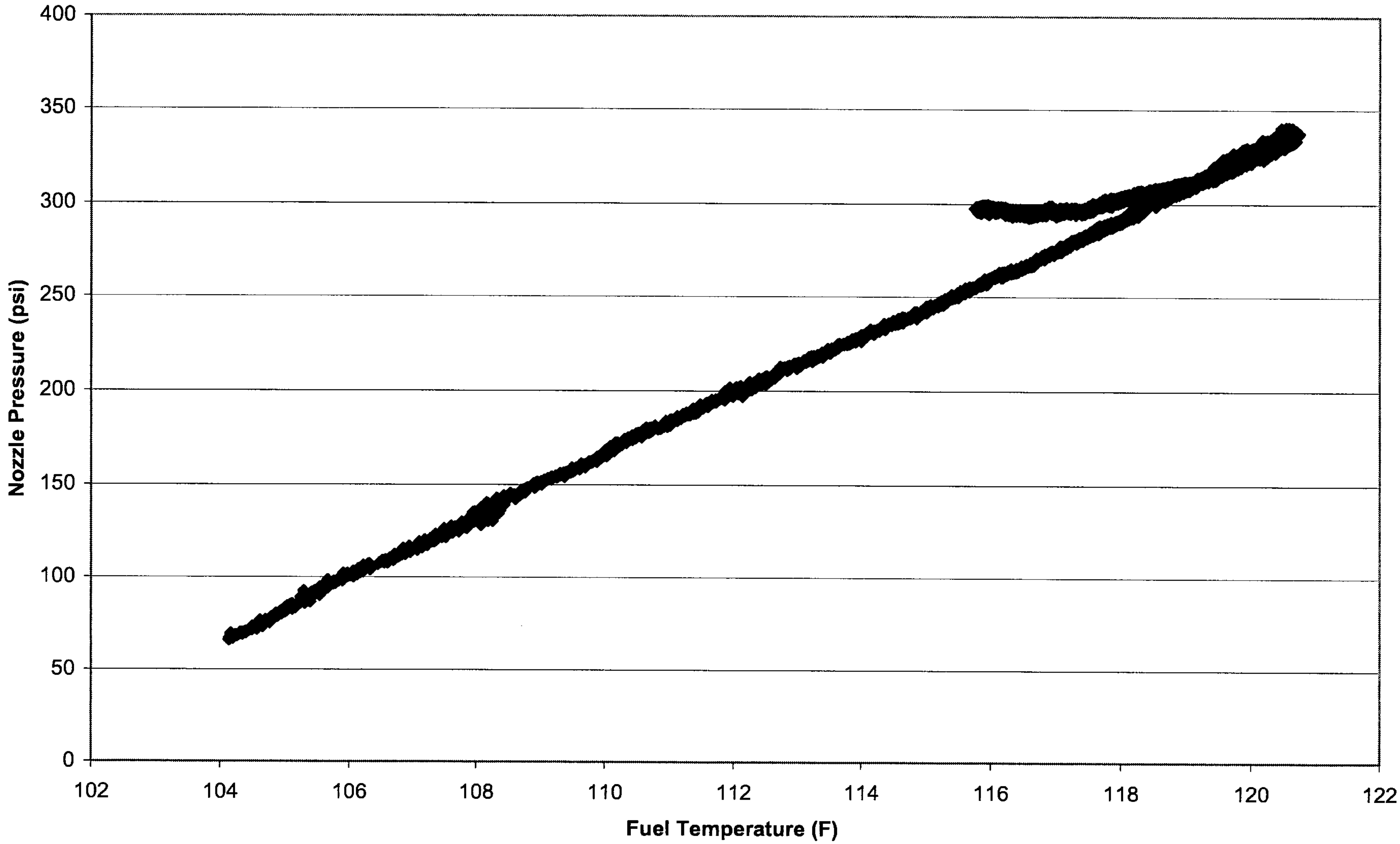
Nozzle Pressure versus Temperature

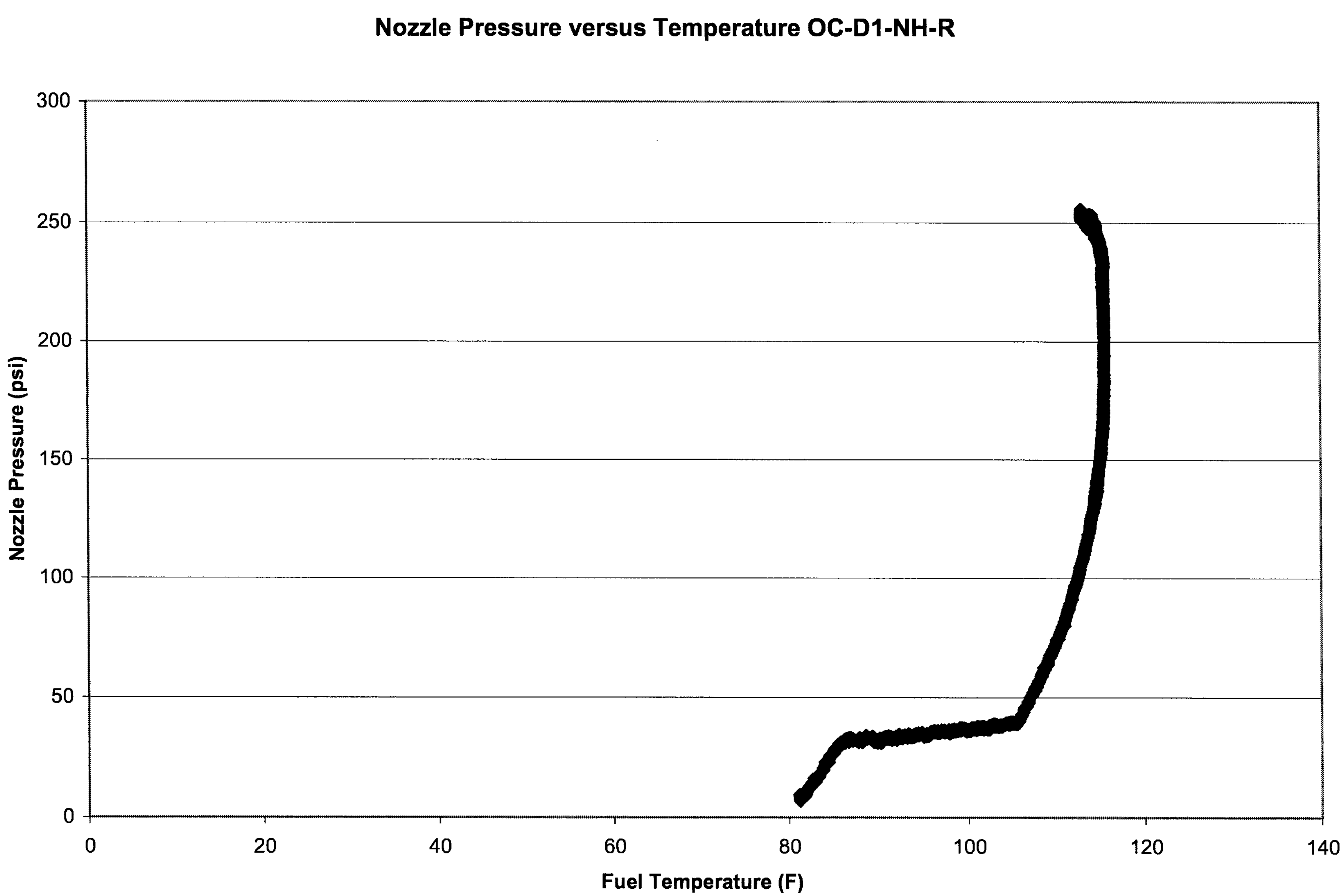


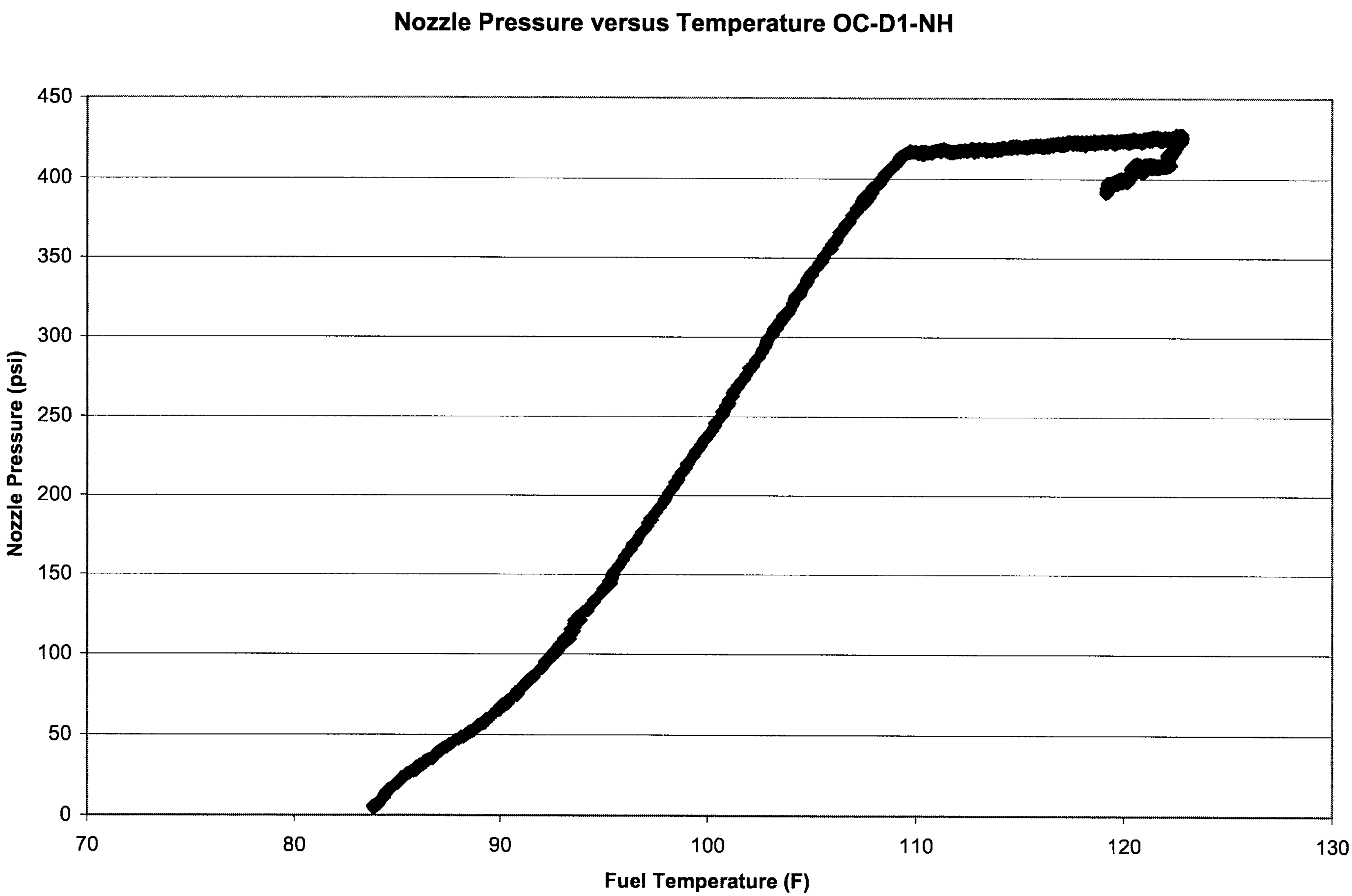
Nozzle Pressure versus Temperature OC-D1-NH-R



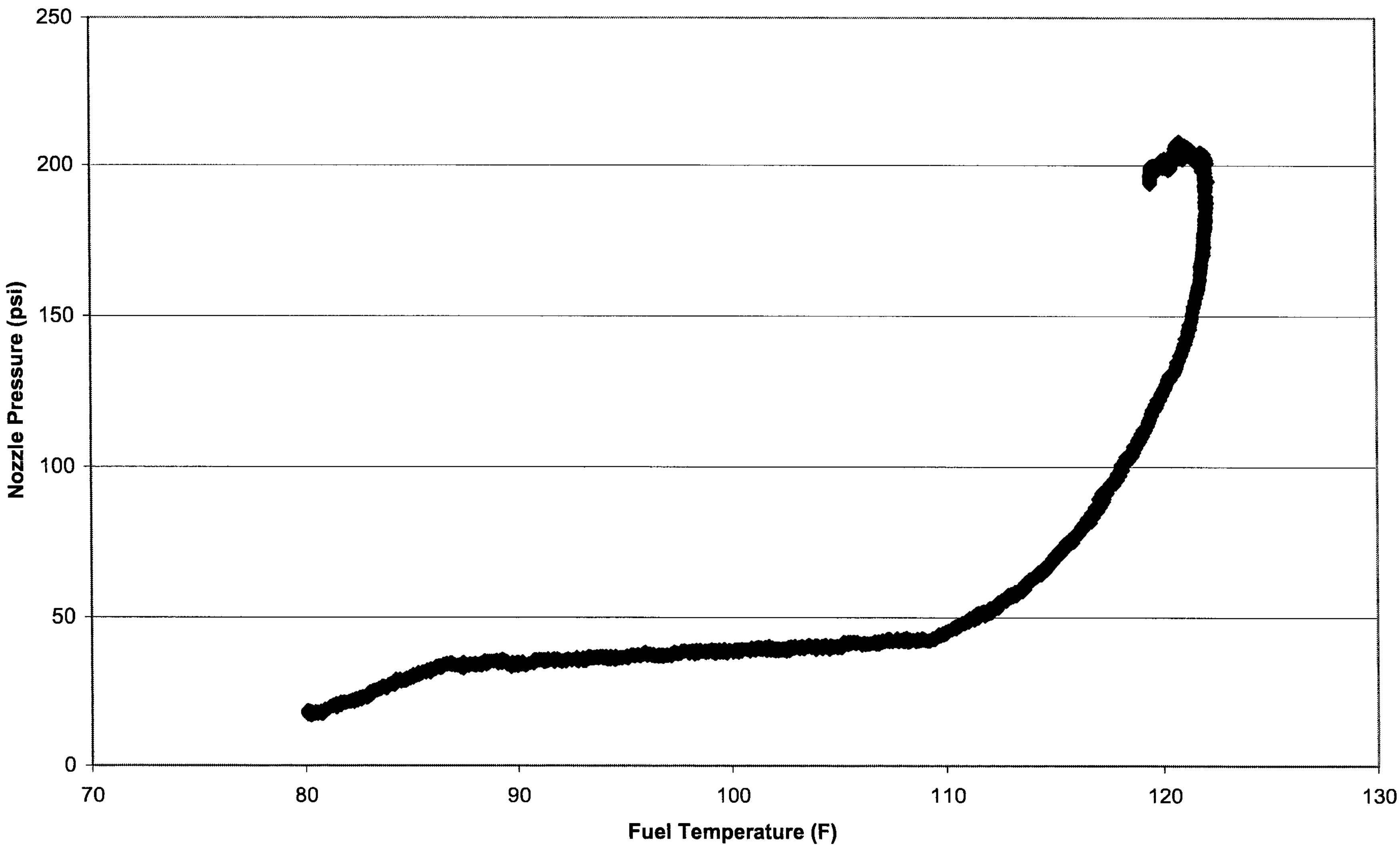
Nozzle Pressure versus Temperature OC-D1-NH



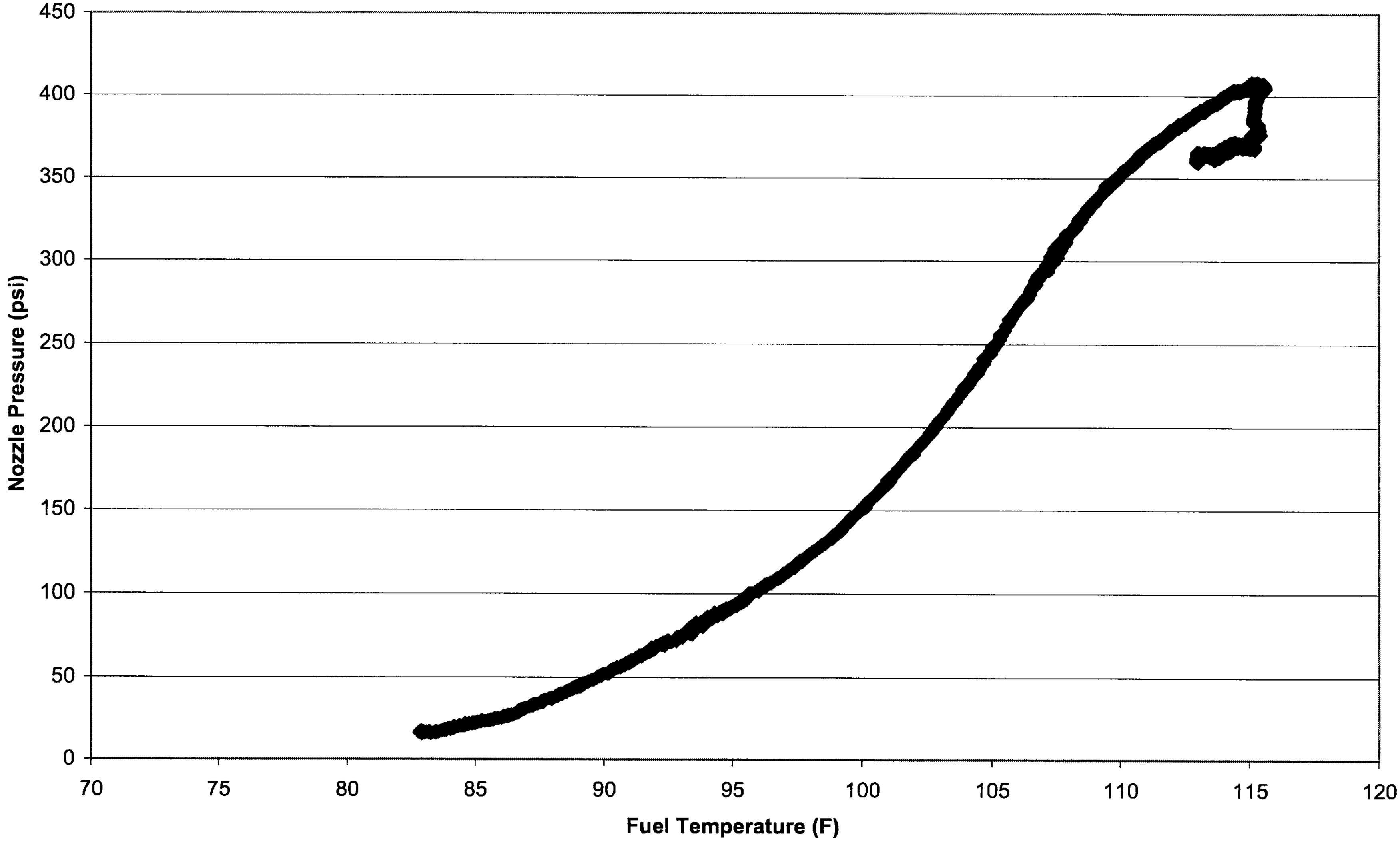

Nozzle Pressure versus Temperature OC-D1-NH-R
Nozzle Pressure (psi)
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Fuel Temperature (F)


Nozzle Pressure versus Temperature OC-D1-NH
Nozzle Pressure (psi)
450
400
350
300
250
200
150
100
50
0
70
80
90
100
110
120
130
Fuel Temperature (F)

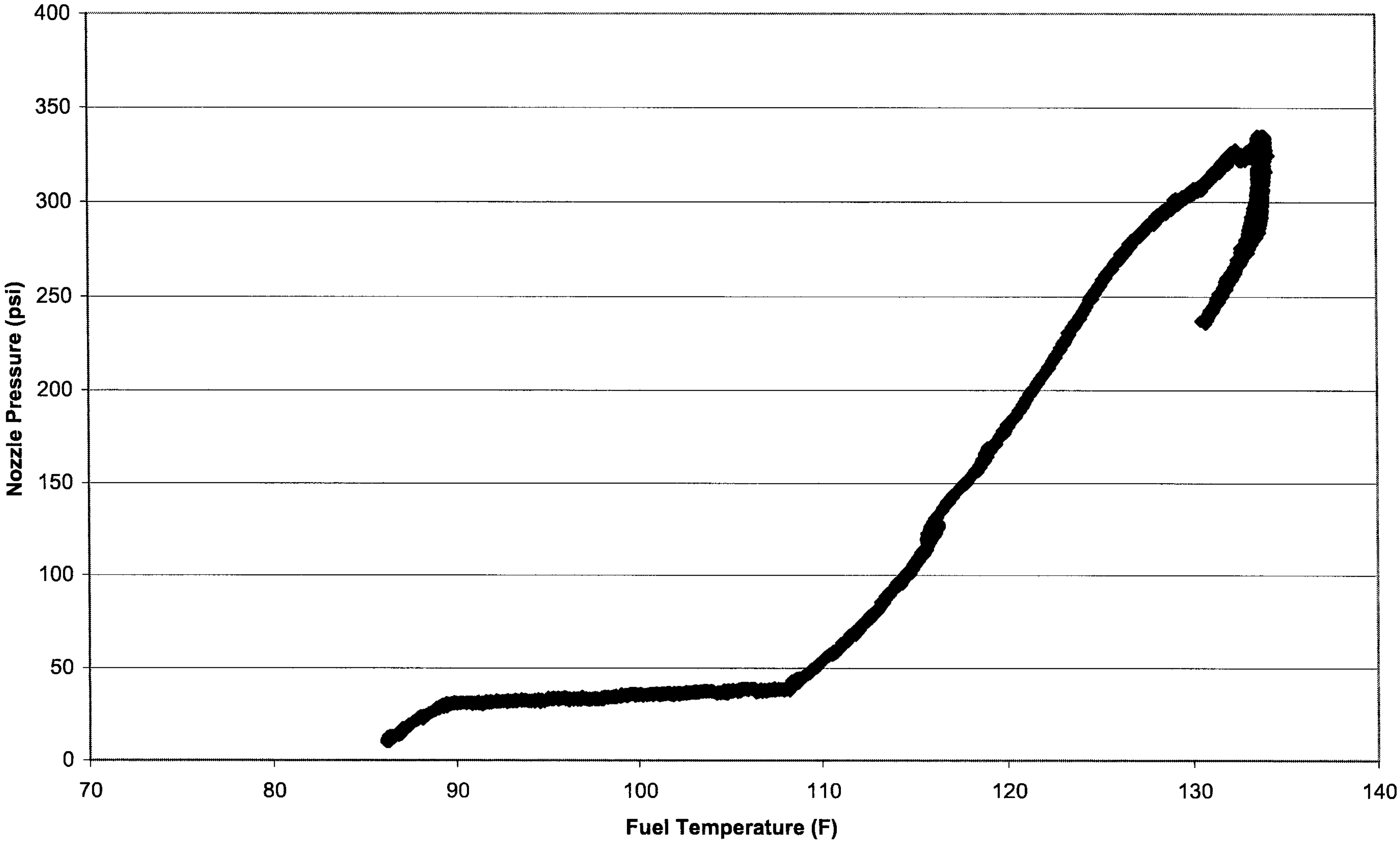
Nozzle Pressure versus Temperature OC-D1-NH-R



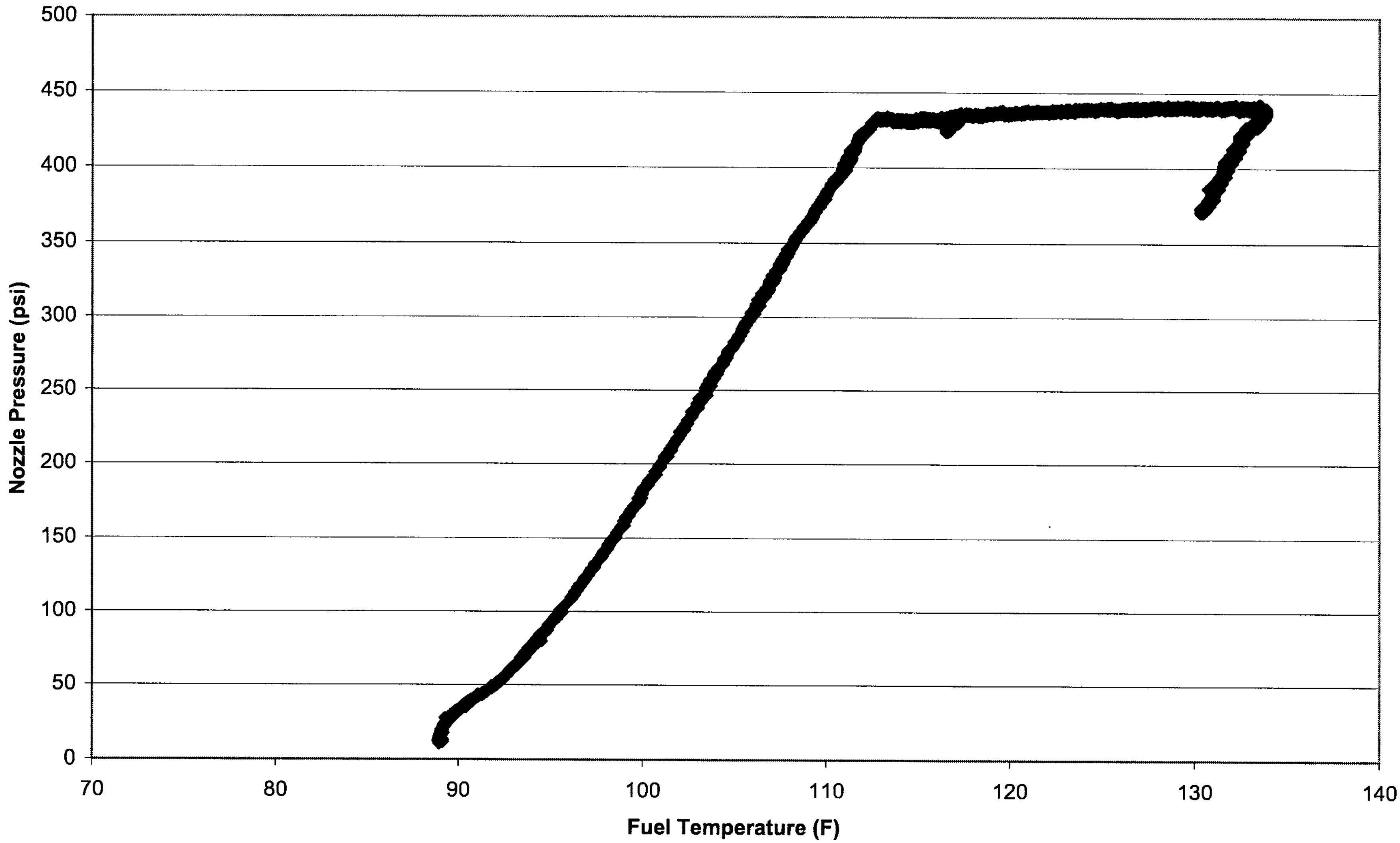
Nozzle Pressure versus Temperature OC-D1-NH



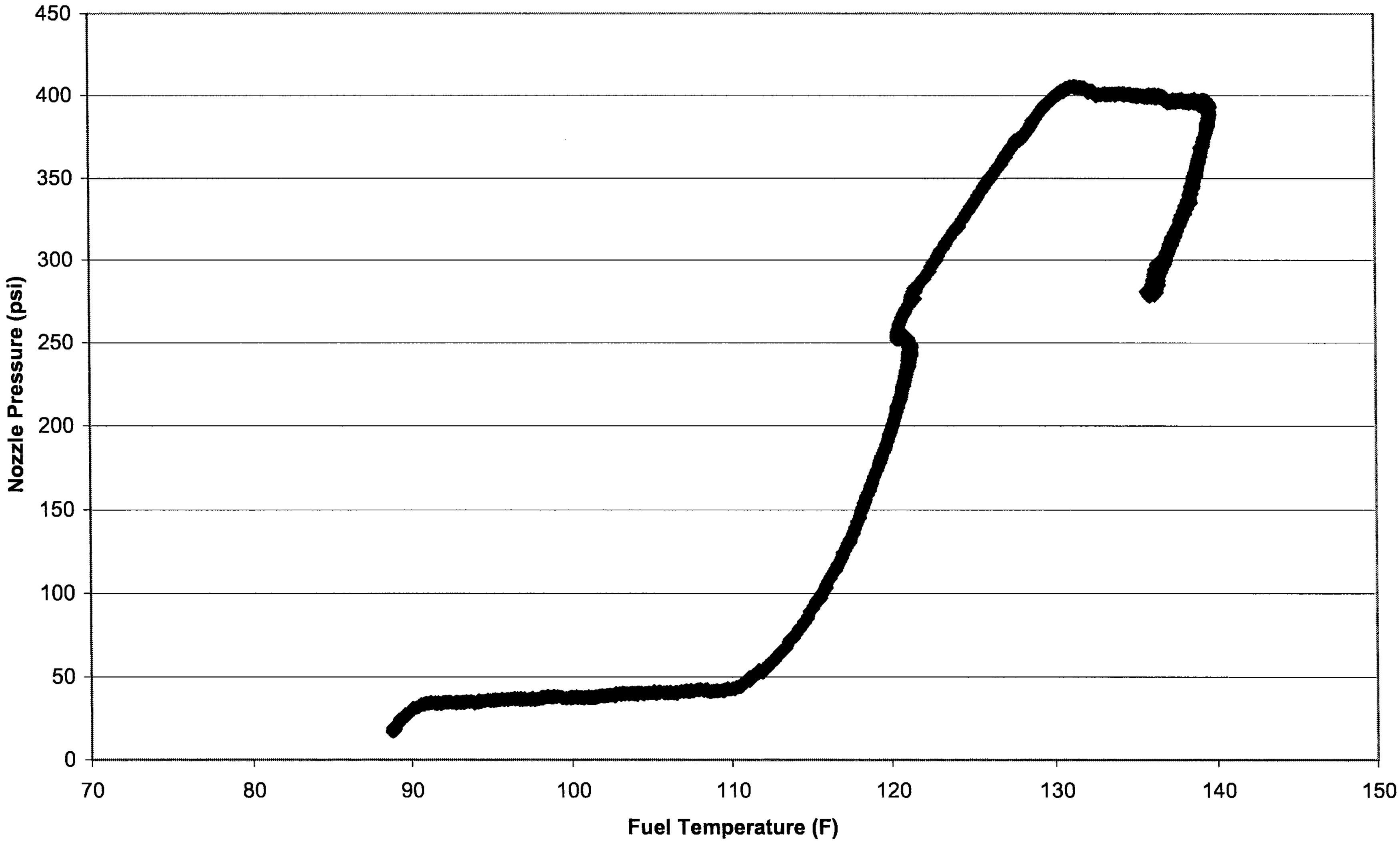
Nozzle Pressure versus Temperature OC-D1-NH-R



Nozzle Pressure versus Temperature OC-D1-NH



Nozzle Pressure versus Temperature OC-D1-NH-R



Nozzle Pressure versus temperature OC-D1-NH