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DEPARTMENT OF DEFENCE

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AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Aero Propulsion Technical Memorandum 440

AN INVESTIGATION INTO LOW FUEL PRESSURE WARNINGS ON A MACCHI-VIPER AIRCRAFT (U)

by

D.E. Glenny

Approved for Public Release

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SUMMARY

The results of an onsite investigation into the performance of the low pressure fuel system for two Macchi-Viper Jet Trainer aircraft are presented. Data analysed indicated little difference in the pressure drops in the fuel systems of both aircraft. However induced or suction pressure drops during engine accelerations can have a marked influence on pressure levels at the high pressure pump inlet. The low pressure pump in Aircraft A7-097 was significantly low in performance, resulting in illumination of a warning light.

DSTO ARL MELBOURNE

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1. INTRODUCTION

In the past 18 months there have been two incidents in RAAF Macchi Jet Trainers which have resulted in the loss of the aircraft. Despite extensive investigations it has not been possible to attribute, definitively, a precise cause of the accidents. In the most recent incident, in Western Australia, the pilot reported a low fuel pressure warning light illumination prior to an engine flame out; the engine was restarted but it subsequently flamed out again. This present investigation stems from a subsequent incident, at RAAF Base East Sale, in which a low fuel pressure warning illumination occurred, but without loss of engine power or aircraft. Due to the association of incidents the RAAF, rather than initially dismantling the low fuel pressure supply system of the East Sale aircraft, sought to carry out some in-aircraft tests (on ground) to monitor the performance of the components of the fuel system, and then to inspect the individual fuel system components. To help in this investigation RAAF HQSC (AIRENG2) personnel approached ARL, Reference 1, for assistance in determining the performance of the low pressure fuel system during engine acceleration and decelerations. It was confirmed by ARL, that it was able to help, and could use its (mobile) transient monitoring system (MODAS). This system had previously been used in offsite engine investigations at RAAF Williamtown (Atar) and in the Australian Government Aero Engine Test Facility (AGAETF) at HDHV (F404) and was able to record the required measurands. The MODAS System is described in Reference 2. A preliminary brief of the incident was given by RAAF personnel, to ARL, by telephone on 22 April 1988 and indicated that the RAAF wished to determine, in the aircraft, the performance of the low pressure fuel system from the low pressure fuel pump delivery pipe, in the aircraft fuel tank, to the high pressure pump inlet on the engine. Figure 1 gives a schematic of the system indicating the main components. The trial was to be carried out on two aircraft/engines, the first representing a "good system" to establish a base line, whilst the second series of tests was to be on the aircraft/engine which had indicated a low fuel pressure warning illumination. Preliminary results were required by 26 April 1988.

2. TEST EQUIPMENT

The ARL (Engine Performance Group) Mobile Data Acquisition System (MODAS) is capable of recording up to 32 analogue and 8 digital signal channels at rates in excess of 100 samples per sec per channel. The system is portable, easily installed using standard transducers and cabling. For this investigation 9 analoque and 2 digital channels were utilised; the location of instrumentation and data acquisition channel identification is given in Figure 1. Details of measurands and their ranges are given in Table 1. Due to the short notice for carrying out the trial and lack of immediate knowledge on pressure levels and pressure drops in the system, all pressure measurements were made with absolute reading transducers. As indicated by a subsequent measurment uncertainty analysis pressure drops in the fuel system should have been assessed using differential reading transducers. For the tests very high accuracy and repeatable Rosemount Series 1332 general purpose capacitive type pressure transducers were used in the low pressure fuel system measurements while a Setra 204 Series transducer was used for pressure measurement at the exit of the high pressure fuel pump (HPFP). Both types of transducers have outputs in the range 0-5 volts, and were hard mounted to the engine, as close as possible to the source of the measurand without any signal filtering. Direct current electrical voltages were used to indicate the electrical activity level of a number of engine components, eg low pressure warning light; these indicators were installed using a range of resistors to give a 0-10 volt output at the data acquisition input. Engine speed and fuel flow measurements were made by direct connection to the tacho genera[illegible]r and fuel flow meter frequency outputs; again no signal filtering was utilised. The data acquisition equipment, including input and output visual display units, were located in an RAAF van situated some 10 metres from the test aircraft, Figure 2. Test control and data recording was initiated using radio transmitters between aircraft and RAAF van. A seperate Astro-Med multichannel oscillograph monitored the output of the engine fuel flow pressure transducers and one of the voltage sources during the trial. These traces gave a real time display output of the pressure levels in the low pressure fuel system, and provided an immediate perspective of the performance of the engine and its low pressure fuel system.

3. TEST PROCEDURE

The test procedures used, conformed basically to the Viper Engine Ground Test schedule, in that following normal engine start up procedures a series of controlled accelerations were carried out. These were followed by a series of rough handling checks. The test schedule was as follows :

a. Steady state - idle

b. Steady state - max

c. Accels
    90% - 100%
    80% - 100%
    70% - 100%
    60% - 98%
    60% - 98%
    42.5% - 98%
    42.5% - 98%

d. Rough Handling Checks : A series of controlled engine "Slams" from max power to idle and back to max power were carried out. The acceleration back to maximum power was initiated during the deceleration phase as soon as the engine speed (sequentially) reached 80%, 70%, 60% and 50%.

Data were recorded at rates of 32 samples per second per channel, record lengths of 32 seconds were used except in the rough handling tests when these were extended to 64 seconds.

4. RESULTS AND DATA ANALYSIS

During the Macci/Viper trial, a total of four test runs were carried out, two on aircraft A7-11 with engine CAC106, (Runs 1 and 2) and two on the "faulty" aircraft A7-097, CAC067, (Runs 3 and 4). Test run data are given in Table 2. The tests on the former aircraft were used for shake down purposes and for setting a baseline against which the nominally faulty data could be compared. The major objective however was to record data on A7-097 when the low pressure warning light was illuminated, and to assess the pressure levels and, if any, drops in the low pressure fuel supply of the faulty aircraft. A subsequent analysis would then be carried out to compare the operating behaviour of the low pressure fuel systems of both aircraft.

4.1 Low Fuel Pressure Warning - A/C A7-097

In the course of Test Runs 3 and 4 on Aircraft A7-097, the Low Fuel Pressure Warning light was observed to be illuminated at least five times, four of which were recorded. The light observed in Test 4, when a RAAF pilot was operating the controls was not captured on either to the Astro-Med oscillograph or the MODAS data acquisition system. The light was first observed during a controlled acceleration from idle to maximum engine speed (42.5 - 98% - File block VIPC.010) and three times during a rough handling test (File block VIPC.012).

An analysis of the data acquired from block VIPC.010 indicates that the minimum pressure level as recorded by the transducer located downstream of the fuel filter was 17.3 psia or 2.6 psig. The level as indicated in Figure 3 occurred during the transient or acceleration phase, and was sufficient to activate the low pressure warning light. The pressure switch is normally set to a differential of between 2.5 - 3 psi. Partial illumination* of the light is indicated in Figure 4. More definite results for light illumination will be seen later in the analysis of the rough handling tests. The effect of the HPFP in "sucking down" or reducing pressure levels in the low pressure fuel line, especially during the acceleration phase, can be seen in Figures 5, 6 and 7 for different locations in fuel supply line. An "impulsive" drop in pressure of the order of 6 psig from the steady state idle values (or 2 psig below the final steady state value) is readily apparent. The pressure level then rises to a level consistent with operation at maximum engine speed. It is this transient reduction in low fuel pressure levels that is responsible for the warning light illumination, and not operation at any given steady state engine speed. The fuel flow response, consistent with the output from the HPFP, is given by the traces of Figure 8. The signal, at low fuel flow rates, exhibits considerable noise due to the low frequency signal from the turbine impeller. Unfortunately the engine speed signal was incorrectly connected and no records were available. From Figures 3, 5 and 6 it is immediately apparent that the delivery pressure from the low pressure boost pump is low. At an engine speed of 42.5% with minimum demand from the HPFP the level is about 24.7 psia or 10 psig; it is not known, at this stage, what minimum acceptance value is specified in the maintenance manual. It should be noted that overall pressure levels in the low pressure line are dependent, not only on the boost pump performance and pressure drops in the fuel pipes and filter but are also dependent on the suction demand imposed by HPFP during acceleration, or transient operation. The steady state suction values are highly dependent upon engine speed; at 100% the low fuel pressure level is 19.8 psia or 5.1 psig, just on the limit recommended in the maintenance manual. Operation in this condition gives only a 2.1 psig margin for light illumination, if the pressure switch is set at 3 psig, and gives little scope for extra pipe or filter losses when the suction demand or depression from the HPFH is imposed on the low pressure fuel system during rapid accelerations.

The performance of the low pressure fuel system can be seen more dramatically in the results for the rough handling tests. Composite pictures for fuel pressure levels after the filter and HPFP, light illumination and ambient pressure, are given in Figures 9 and 10. Immediately apparent are the small operating margins, 2.5 psig, under which the fuel system operates and the poor low pressure fuel pump performance on aircraft A7-097. There is also no doubt about the coincidence of light illumination and the low fuel pressure levels. Data output for the remaining channels recorded during the tests are given in Figures 11 - 15, Figures 13 and 14, in particular, indicate that the low fuel pressure warning light illumination is not

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* It should be noted that all the traces presented in this report have been reconstructed from data acquired at a rate of 32 samples/sec/channel: a flickering light, as reported by the observer, would have been on only for 1/50 - 1/25 of a second - just within the limits of the recording speed used.

related to a variability in boost pump voltages, or stray voltages at the solenoid valve resulting in its unscheduled closing.

4.2 Comparison of Low Fuel Pressure Systems - in Aircraft A7-11 and A7-97

A direct comparison of the differences in the low pressure fuel system performance of aircraft A7-11 and A7-097 can be seen in Figures 16 and 17, in which a superposition of pressure levels after the filter and HPFP has been made for similar controlled accelerations. The difference in low pressure pump supply, and delivery levels after the filter for both aircraft, Figure 16, is self evident, whilst for all purposes the pressure drops across the filters are equal. There is little difference in the relative performances of the HPFPs, Figure 17, notwithstanding the different (low pressure) inlet conditions. There are however minor differences in signal to noise ratios and acceleration times for both sets of traces, but considering the relatively crude and hurried test procedures used, on the tarmac at RAAF Base East Sale, this was to be expected. A more direct comparison of data could have been made if a power level angle (throttle) position or rotor rpm record had been acquired. More specific performance characteristics of the aircraft fuel systems can be obtained by determining absolute pressure levels, and pressure drops in the fuel pipework, at stations 14, 1 and 26, for a range of engine speeds. Figures 18, 19 and 20 respectively gives examples of the raw data, for the fuel systems of both aircraft for the three nominated stations for an acceleration from 70% - 100%. Using these types of data traces, pressure levels at the beginning and end of each acceleration were determined by sampling up to 256 nominally steady state points (8 seconds of data) and calculating the signal mean $\bar{x}$, its standard deviation σ and the coefficient of variations CVA. Sample values of $\bar{x}$, σ and CVA are presented in Table 3 for data in Figures 18 - 20. Using the steady state values of pressure, $\bar{x}$, system pressure levels and filter pressure drops were plotted as a function of engine speed. Figure 21 gives the pressure drop in the fuel piping and the low pressure filter, stations 14 - 1 and 1 - 26 respectively. As mentioned earlier there is a degree of uncertainty about these levels as they are differences between two numbers of similar magnitude. Notwithstanding the method of analysis the data and trends appear to be consistent. From the data it appears that there is little if any difference in pressure drops across the filter for both aircraft, with the pressure drop increasing from 0.2 psi to 0.65 psi as the "steady state" speed increases from idle to maximum. There is however a minor difference in pressure drops across the pipework from the solenoid valve to the filter. The ducting in Aircraft A7-097 (warning light illuminated) having an approximately 0.1 psi larger pressure drop: no explanation can be given for this difference. A comparison of the fuel boost pump pressure levels with engine speed (steady state) for both aircraft is given in Figure 22 at station 14, just after the solenoid valve. As indicated earlier in Section 4.1, the fuel boost pump pressures are consistently lower for aircraft A7-097 than for A7-011, a difference of at least 7 psi existing across the speed range. The absolute level for A7-011 is appoximately 32 psia (17 psig) at idle and 28 psia (13 psig) at maximum engine speed: the values for aircraft A7-097 are 25 psia (10 psig) and 20 psia (5 psig) respectively. This later value gives only a 2 psig margin for suction pressures imposed by the HPFP during accelerations if the pressure switch is set between 2.5 - 3 psig. Any untoward pressure resistance in the fuel delivery line and filtering system would soon erode this margin, remembering that accelerations from any speed level can impose suction pressure drops of the order of 2 psig lower than the final steady state value: this would leave only a small margin for induced cavitation at the inlet of the HPFP.

5. CONCLUSIONS

An analysis of a series of engine tests carried out at RAAF Base East Sale on the fuel systems of two Macchi Jet Trainers has shown that the low pressure fuel system warning light illumination in Aircraft A7-097 was a direct consequence of poor fuel boost pump performance. There was up to a 7 psig difference in pressure levels between the two aircraft tested. Pressure drops in the fuel systems of both aircraft were similar with no difference being measured across the filters and only a minor variation (0.1 psig) being recorded in the ducting between the solenoid valve and the filter: aircraft A7-097 having the greater pressure drop.

Of greater interest was the suction pressures imposed on the low pressure fuel system by the high pressure fuel pump HPFP. Depressions of at least 2 psig below *steady state, maximum speed*, values at the HPFP entrance were consistently recorded during engine accelerations, and in the case of A7-097 they activated the illumination of the low pressure warning light. Incorrect adjustment of pressure switch levels, poor low pressure pump performance and excessive pressure drops in the low pressure fuel piping could easily result in pressures at the HPFP entrance sufficient to cause pump cavitation: personnel setting up the fuel system should be made aware of the effects of impulsive suction demands on the low pressure line during rapid accelerations.

REFERENCES

1. RAAF HQSC Minute - 2601/7/110-97(25) of 27 April 1988

2. GLENNY, D E; VIVIAN, A.S. — MODAS - Mobile Data AcquisitionSystem for Investigatory Engine Testing, Its Capabilities and Applications. (ARL Tech Memo- In Preparation)

ACKNOWLEDGEMENT

The author would like to acknowledge the considerable assistance and expertise received from Mr A S Vivian of the Engine Performance Group at ARL in carrying out this investigatory trial and in processing data.

TABLE 1: DESCRIPTION OF MEASURANDS

DATA ACQUISITION CHANNEL NUMBER	MEASURAND	SERIAL NO	TRANSDUCER RANGE
13	Low pressure boost pump outlet	Rosemount (R) 7597	0–50 psia
14	Low pressure solenoid valve outlet	R–6600	0–50 psia
1	Low pressure fuel filter inlet	R–6599	0–50 psia
26	Low pressure fuel filter outlet	R–6598	0–50 psia
25	High pressure fuel pump (HPFP) outlet	SETRA (S)	0–1000 psia
30	Low pressure boost pump voltage	Resistor	10 volts
2	Low pressure fuel filter warning light – master caution	Resistor Network	0–10 volts
3	Low pressure solenoid valve – stray volts		0–28 volts
0	Ambient pressure	R–11159	22–32" Hg
34	Engine speed – RPM	Engine Tacho	Frequency
37	Engine fuel flow GPM	Engine Flow Meter	Frequency

TABLE 2 TEST RUN - DATA FILES

RUN NUMBER	1	2	3	4
A/C-ENG NO	A7-11:CAC 106	A7-11:CAC 106	A7-97:CAC 067	A7-97:CAC 067
FILE: PREFIX	VIPA.	VIPB.	VIPC.	VIPD.
SUFFIX				
.000	Calibration	Calibration	Calibration	42.5 - 100%
.001	S/S-IDLE	S/S-IDLE	S/S-IDLE	42.5 - 100%
.002	S/S-MAX	S/S-MAX	S/S-MAX	42.5 - 100%
.003	90 - 100%	90 - 100%	90 - 100%	— (LIGHT ON)
.004	S/S 80%	—	90 - 100%	—
.005	80 - 100%	80 - 100%	80 - 100%	42.5 - 100%
.006	90 - 100%	70 - 100%	70 - 100%	60 - 100%
.007	—	60 - 98%	70 - 100%	60 - 100%
.008	—	60 - 98%	60 - 98%	ROUGH HANDLING
.009	—	42.5 - 98%	60 - 98%	ROUGH HANDLING
.010	—	42.5 - 98%	42.5 - 98% (LIGHT ON)	
.011	—	—	42.5 - 98%	
.012	—	—	ROUGH HANDLING (LIGHT ON)	

TABLE 3 "SAMPLE" STEADY STATE DATA

DATA FILE VIPB. 006 **SAMPLE SIZE 128 POINTS**

CHANNEL	14		1		26	
SPEED	70%	100%	70%	100%	70%	100%
$\bar{x}$	31.682	28.332	31.124	27.416	30.903	26.778
σ	.631	.788	.271	.32	.326	.29
CVA%	1.99	2.78	.872	1.17	1.06	1.09

DATA FILE VIPC. 007 **SAMPLE SIZE 64 POINTS**

CHANNEL	14		1		26	
SPEED	70%	100%	70%	100%	70%	100%
$\bar{x}$	24.614	21.461	23.973	20.6	23.752	20.005
σ	.464	.366	.138	.173	.266	.246
CVA%	1.89	1.71	.578	.841	1.12	1.233

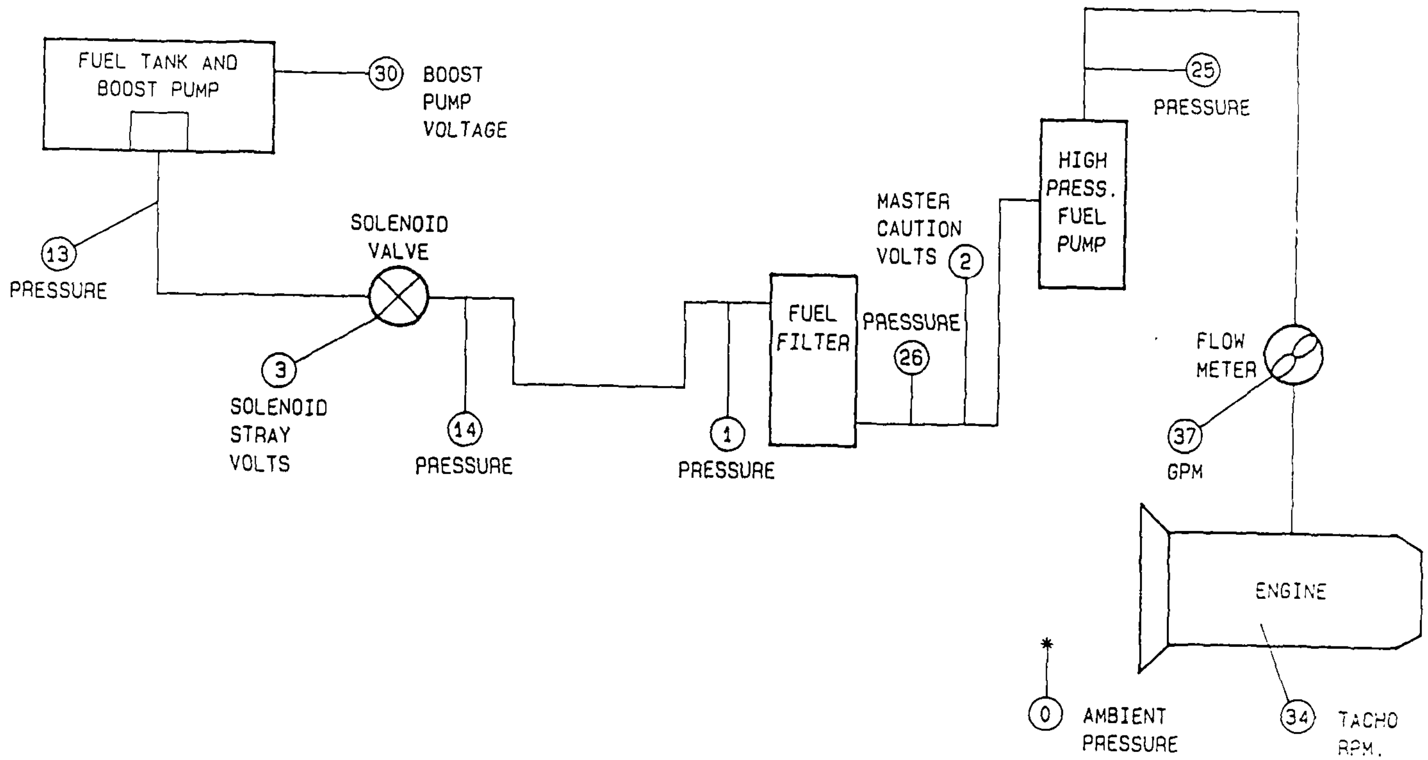
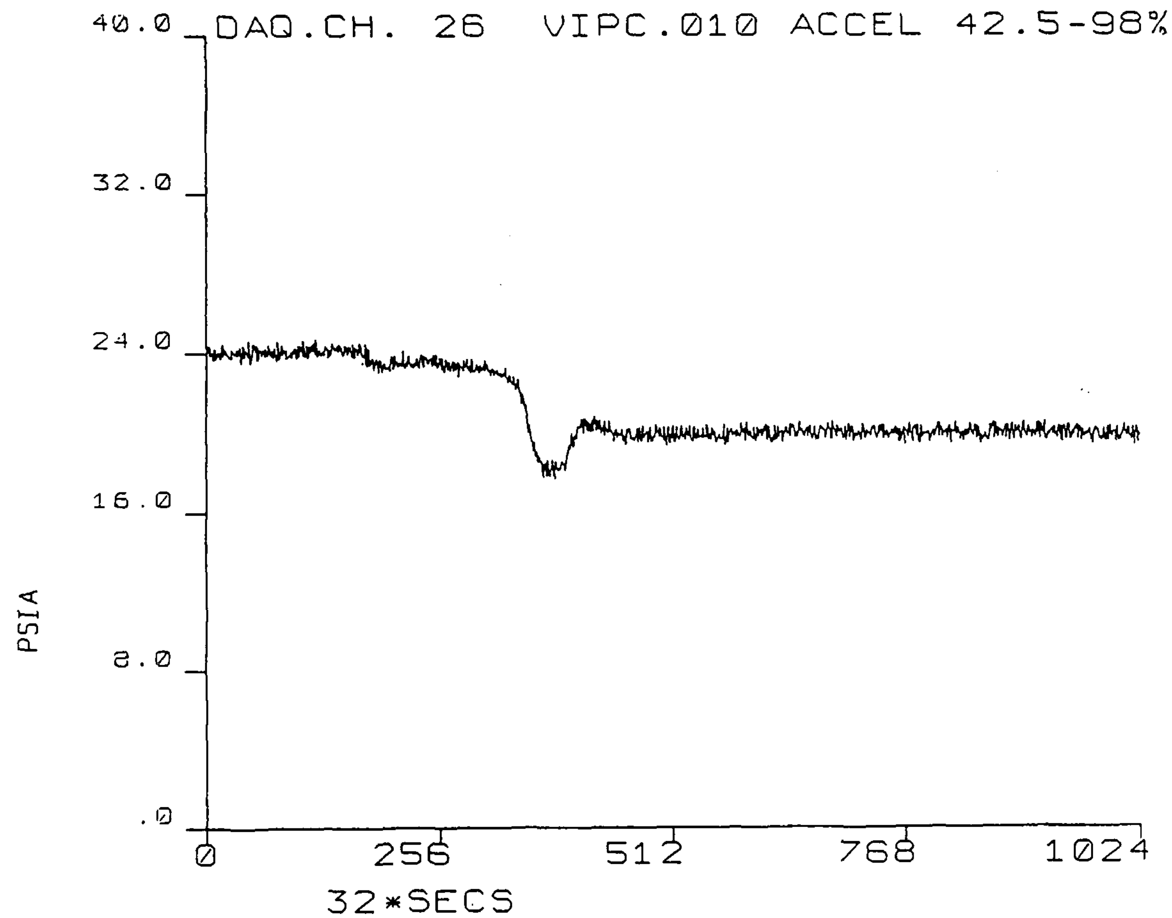


FIG. 1. INSTRUMENTATION AND CHANNEL/STATION NUMBERING MACCHI/VIPER TEST SERIES.

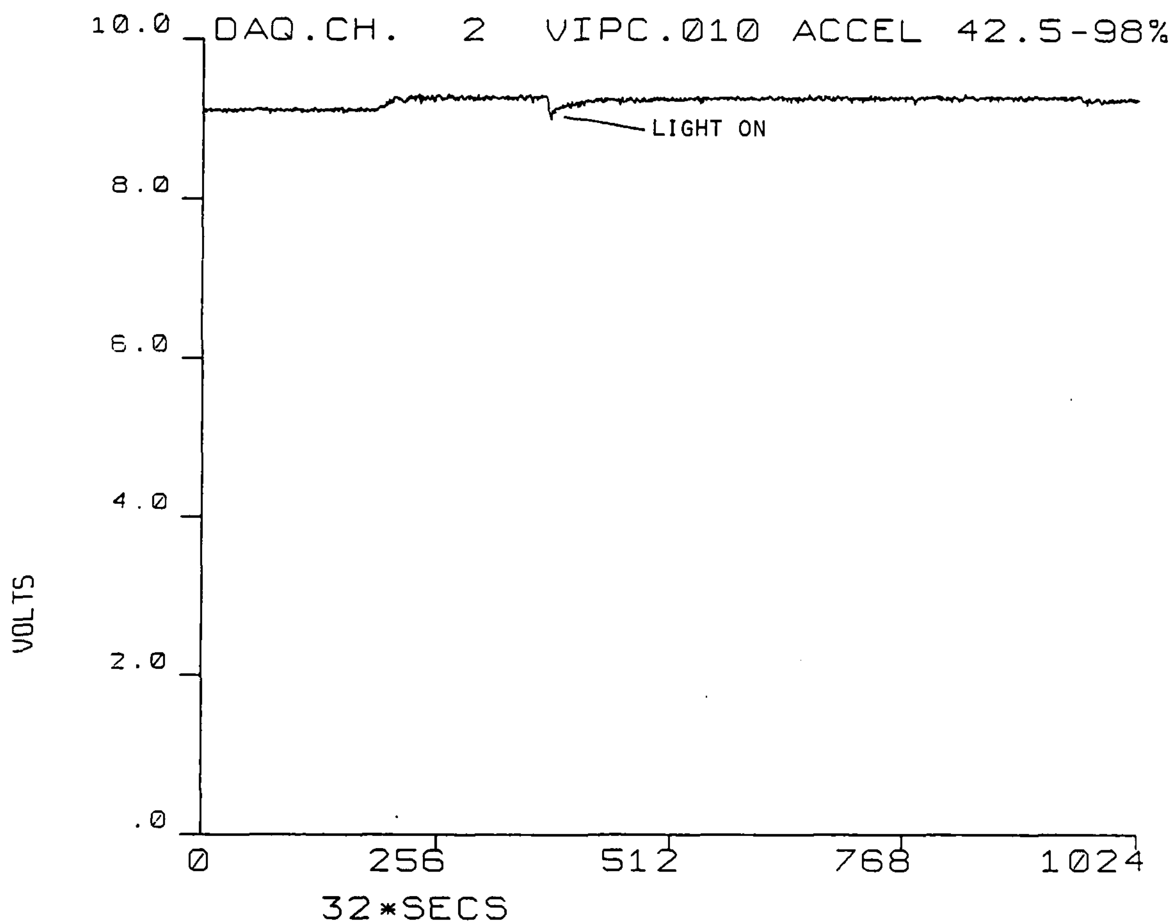
View of test site lay-out, RAAF Base, East Sale

Figure 2



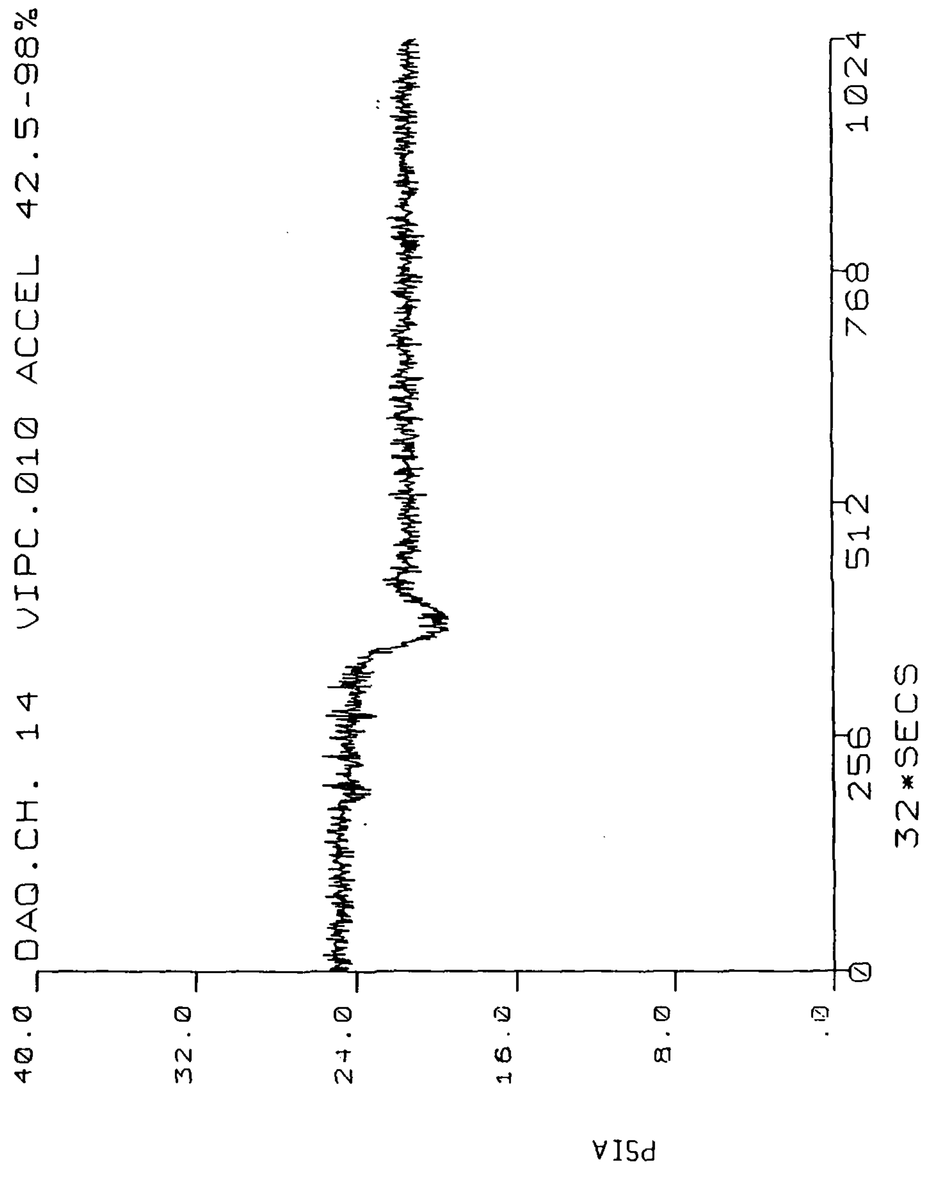
PRESSURE, FILTER OUTLET

FIGURE 3



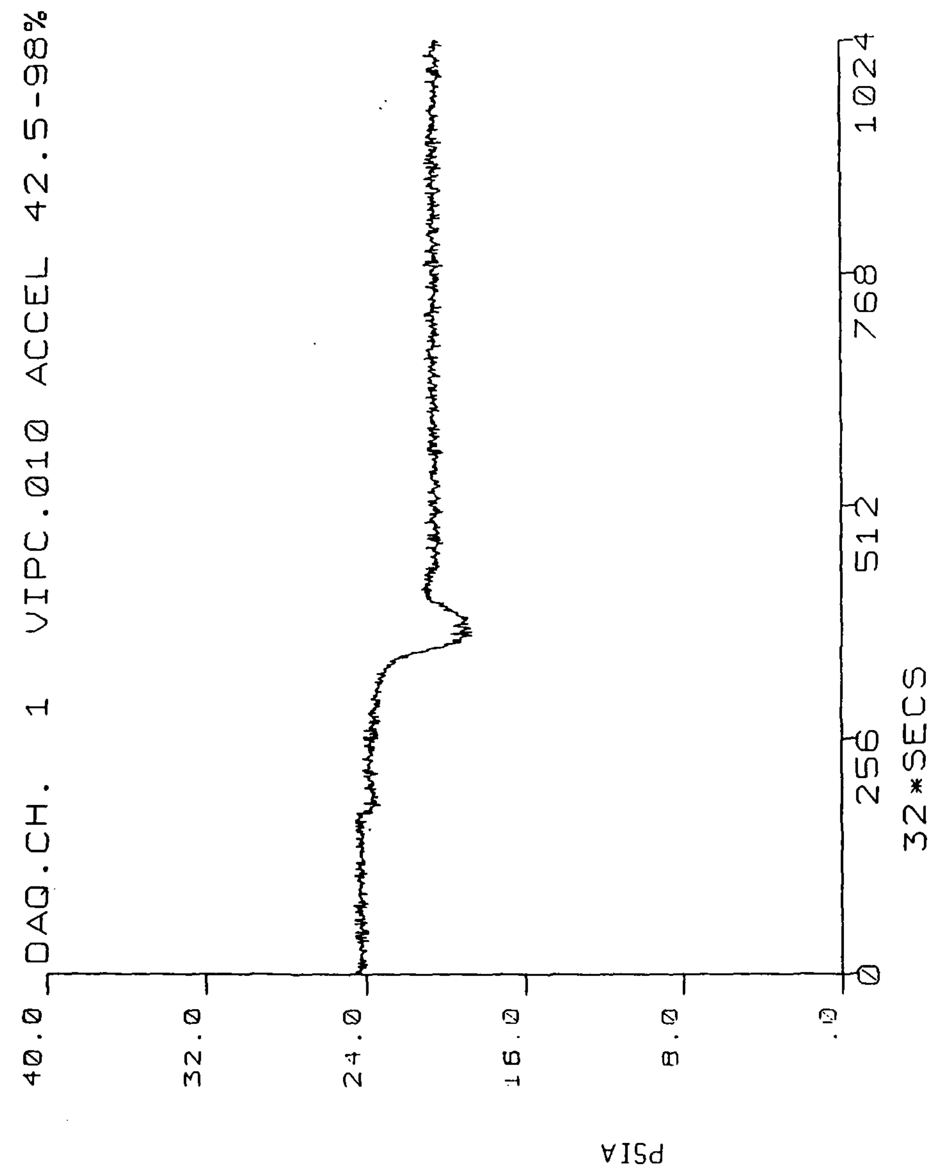
CAUTION LIGHT VOLTAGE-

FIGURE 4



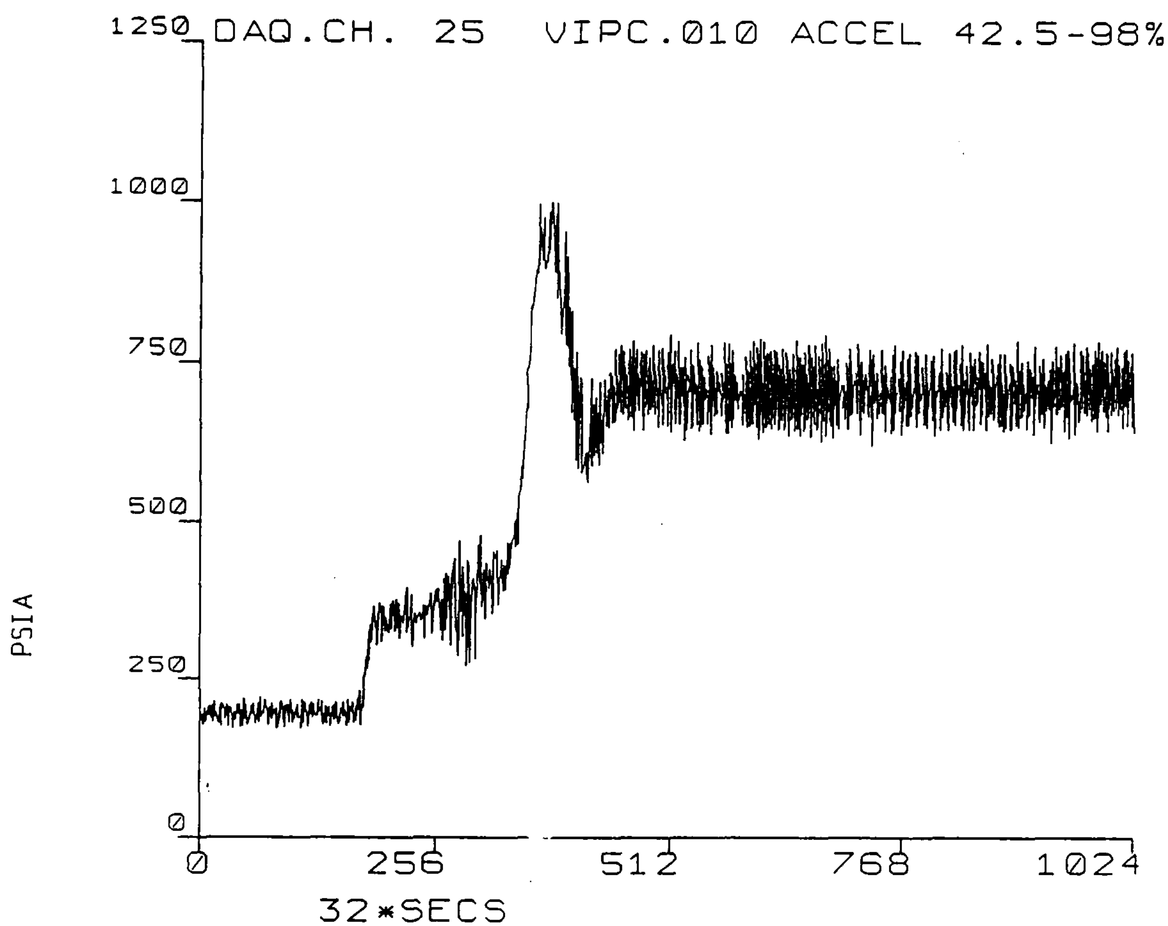
PRESSURE, SOLENOID VALVE OUTLET

FIGURE 5



PRESSURE, FUEL FILTER INLET

FIGURE 6



PRESSURE, HIGH PRESSURE PUMP OUTLET

FIGURE 7

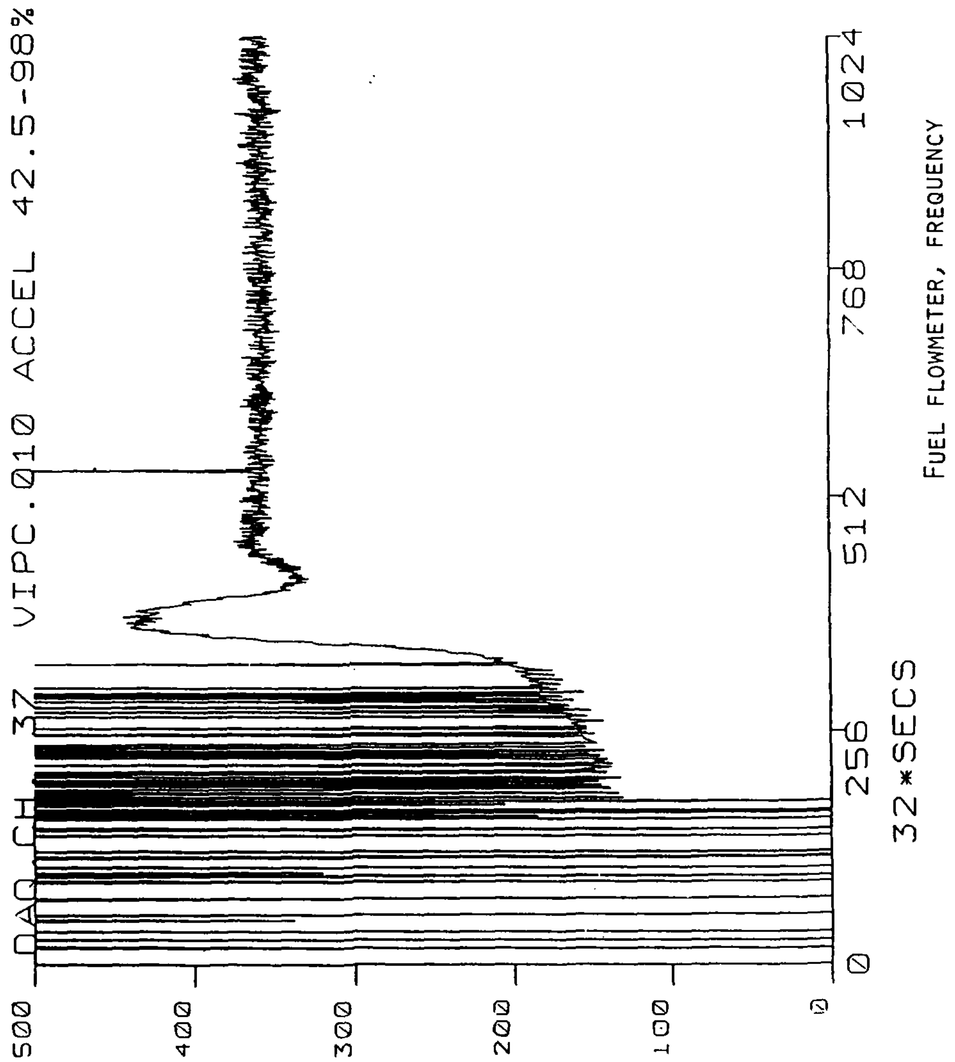
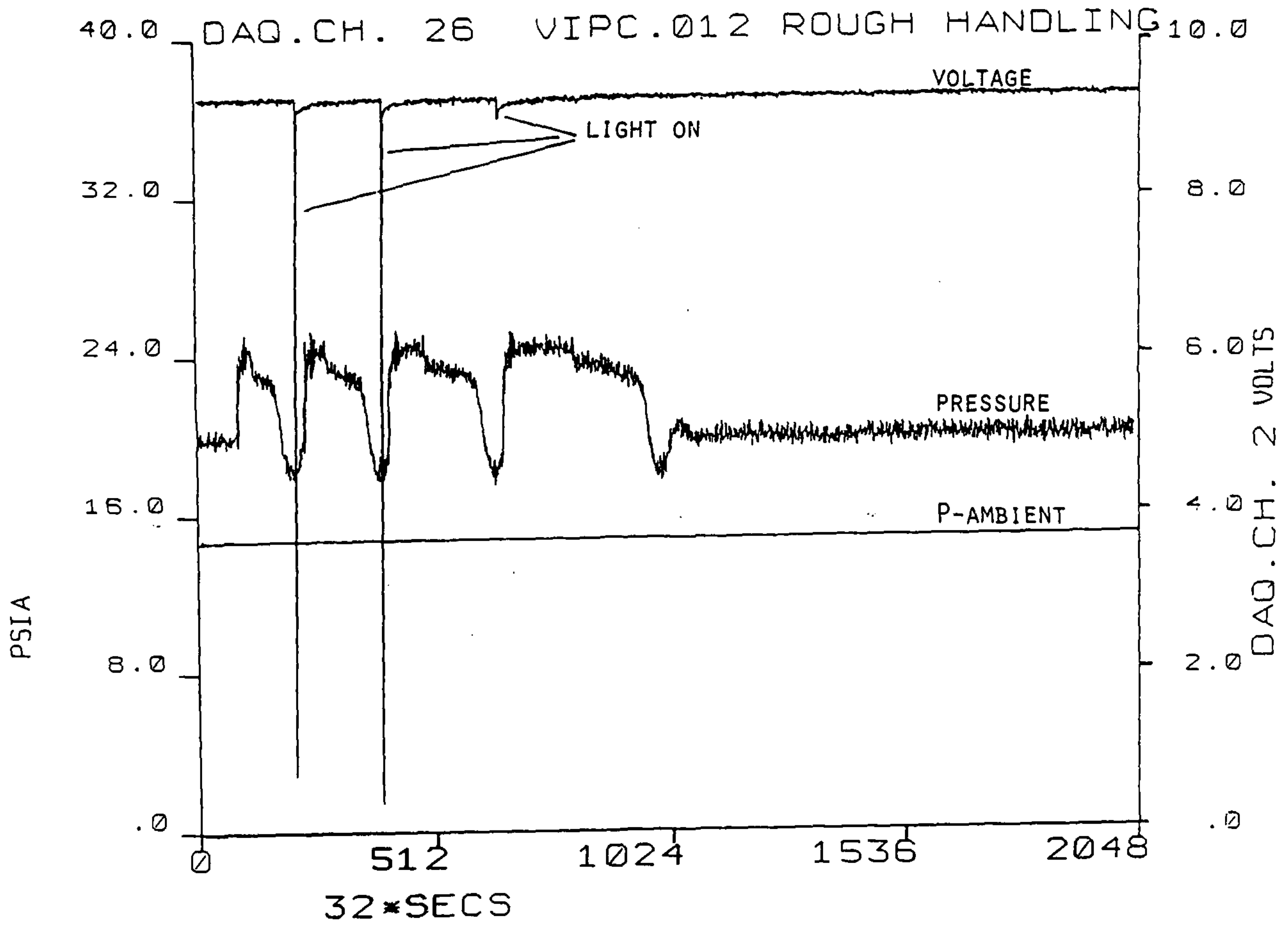
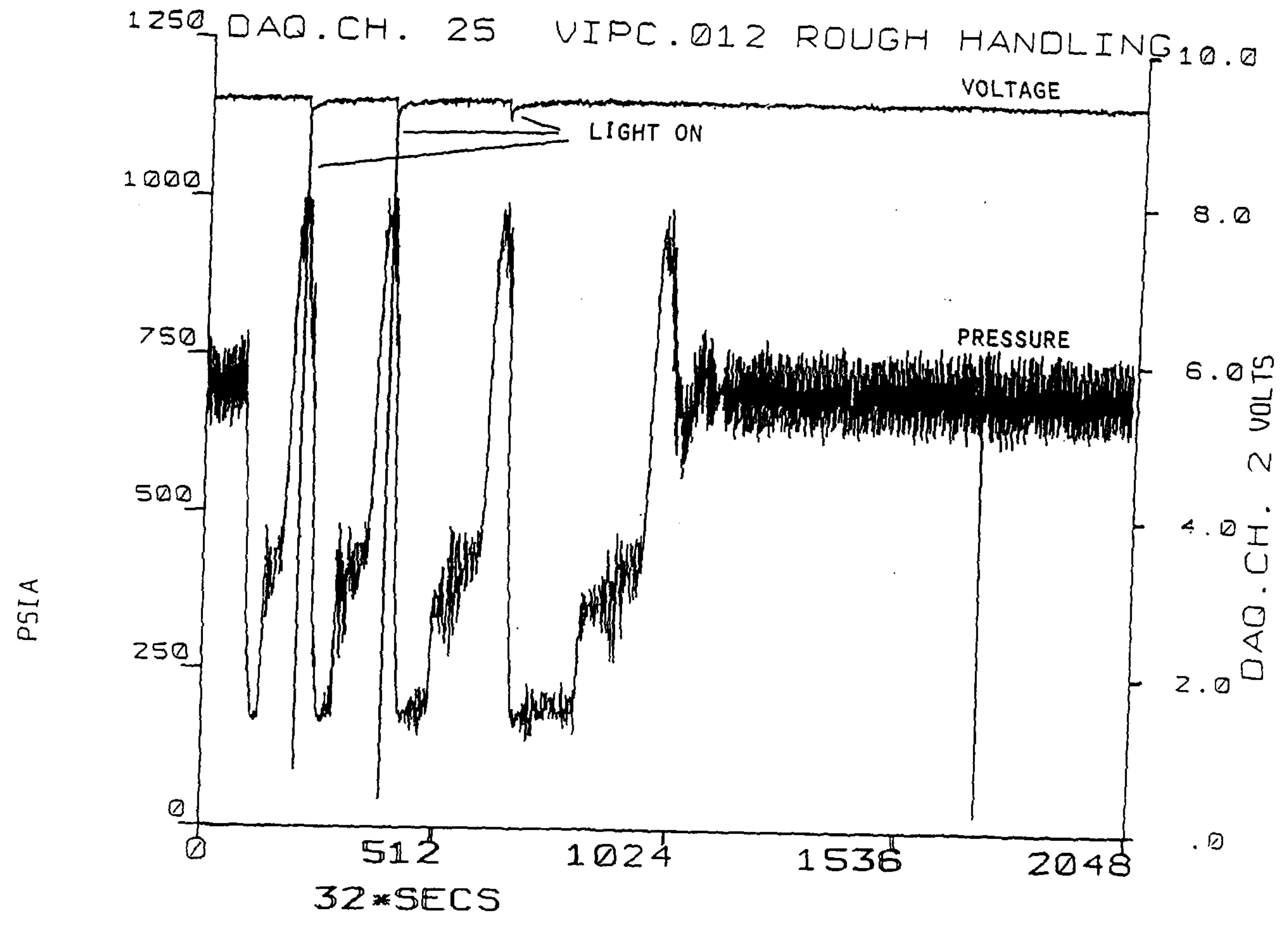

DAQ CH 37 VIPC.010 ACCEL 42.5-98%
500
400
300
200
100
0
0
256
512
768
1024
32*SECS
FUEL FLOWMETER, FREQUENCY

FIGURE 8



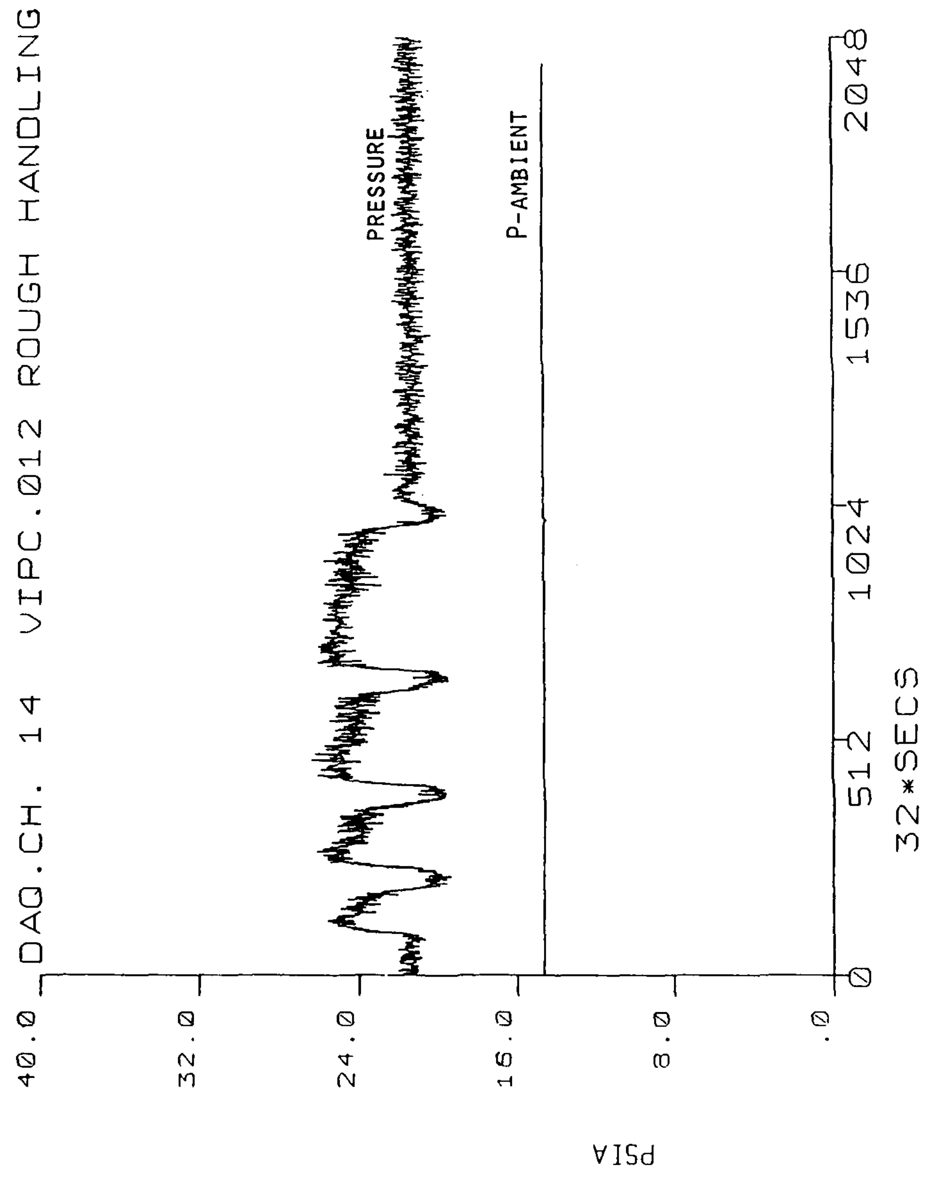
FUEL FILTER EXIT PRESSURE & CAUTION LIGHT VOLTAGE

FIGURE 9



HIGH PRESSURE PUMP OUTLET PRESSURE & CAUTION LIGHT VOLTAGE

FIGURE 10



PRESSURE, SOLENOID VALVE OUTLET

FIGURE 11

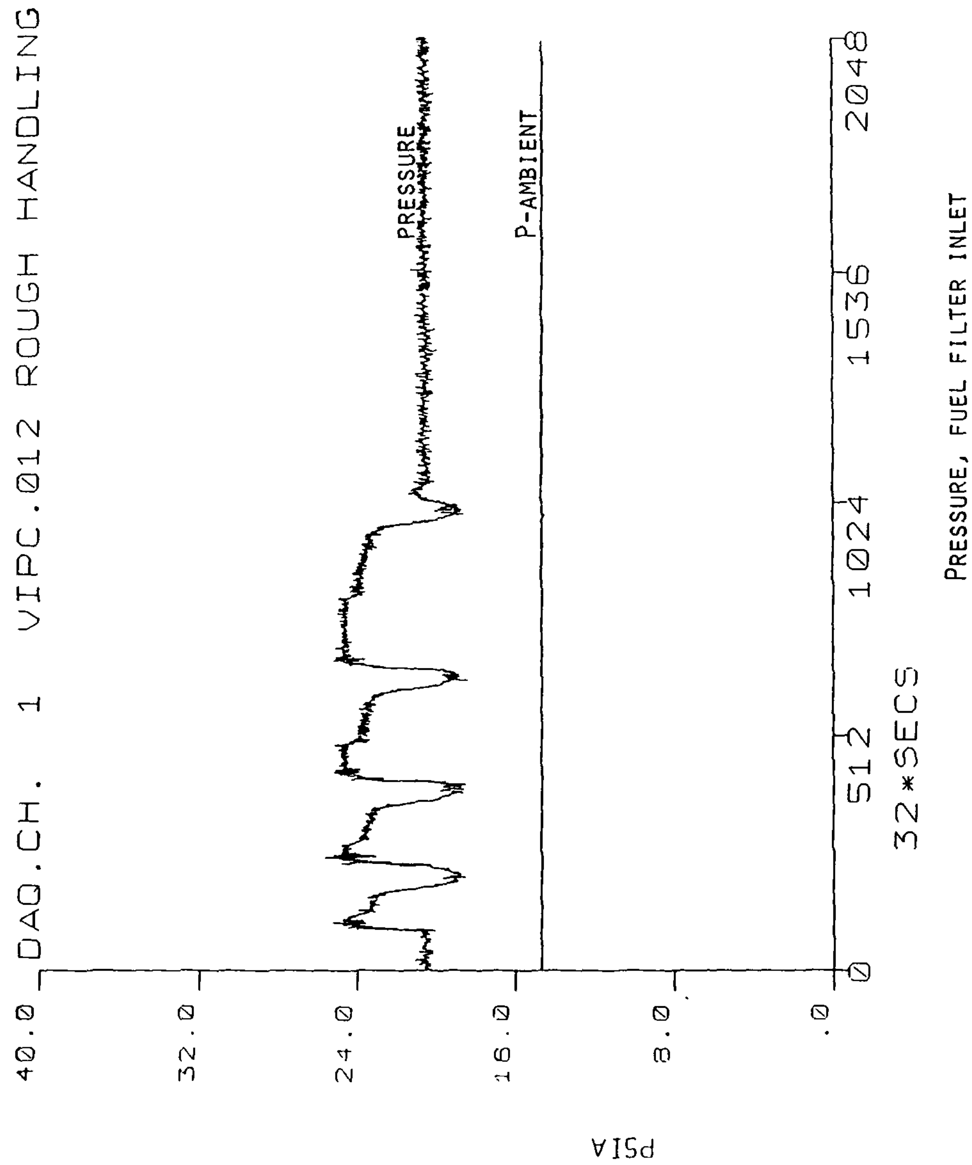
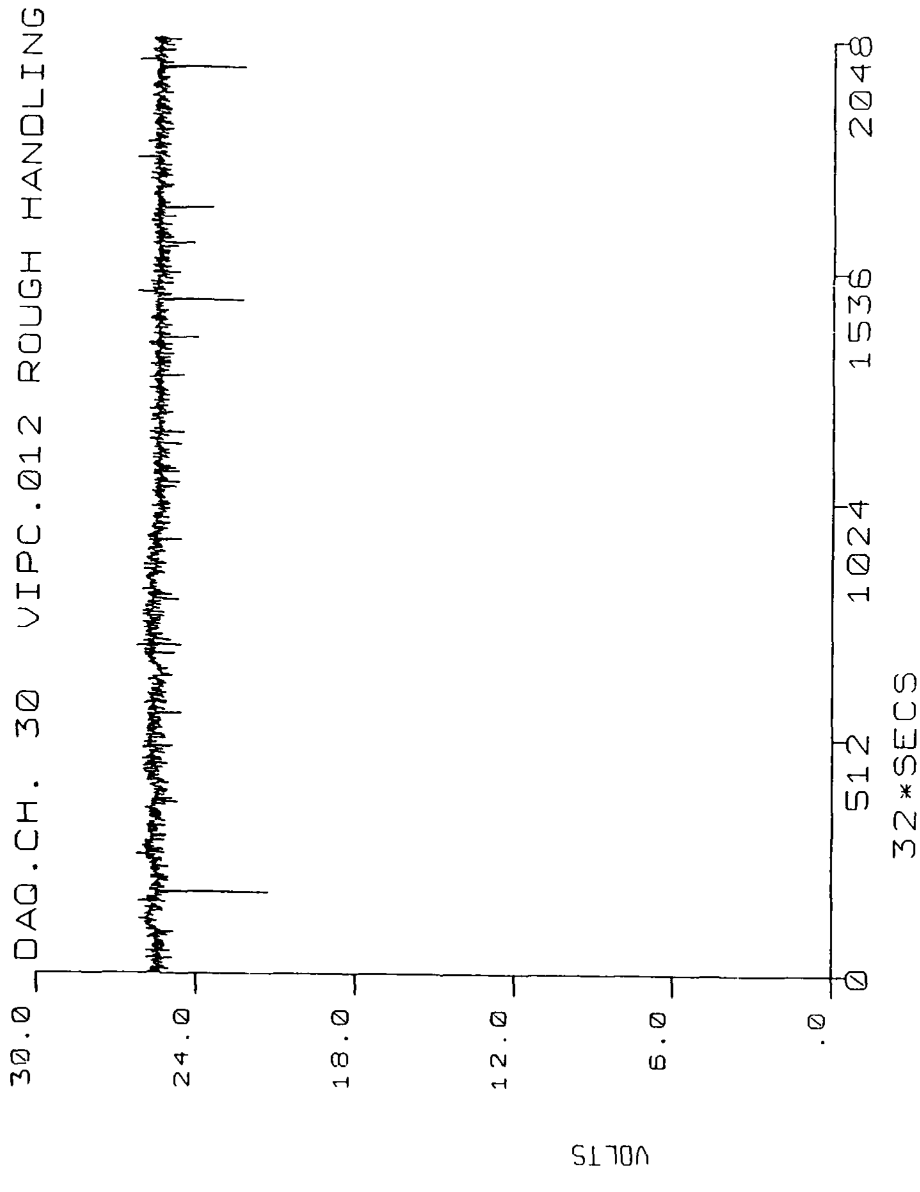
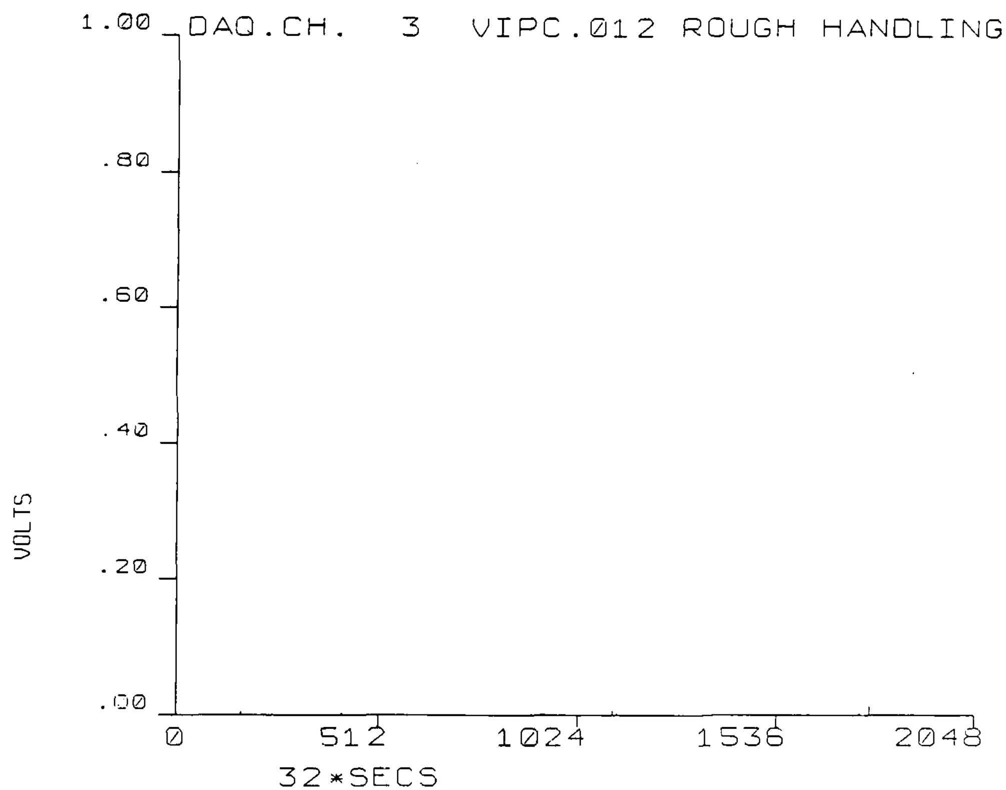

DAQ.CH. 1 VIPC.012 ROUGH HANDLING
PRESSURE
P-AMBIENT
40.0
32.0
24.0
16.0
8.0
.0
PSIA
0
512
1024
1536
2048
32*SECS
PRESSURE, FUEL FILTER INLET

FIGURE 12



BOOST PUMP VOLTAGE

FIGURE 13



SOLENOID VALVE, "STRAY" VOLTAGES

FIGURE 14

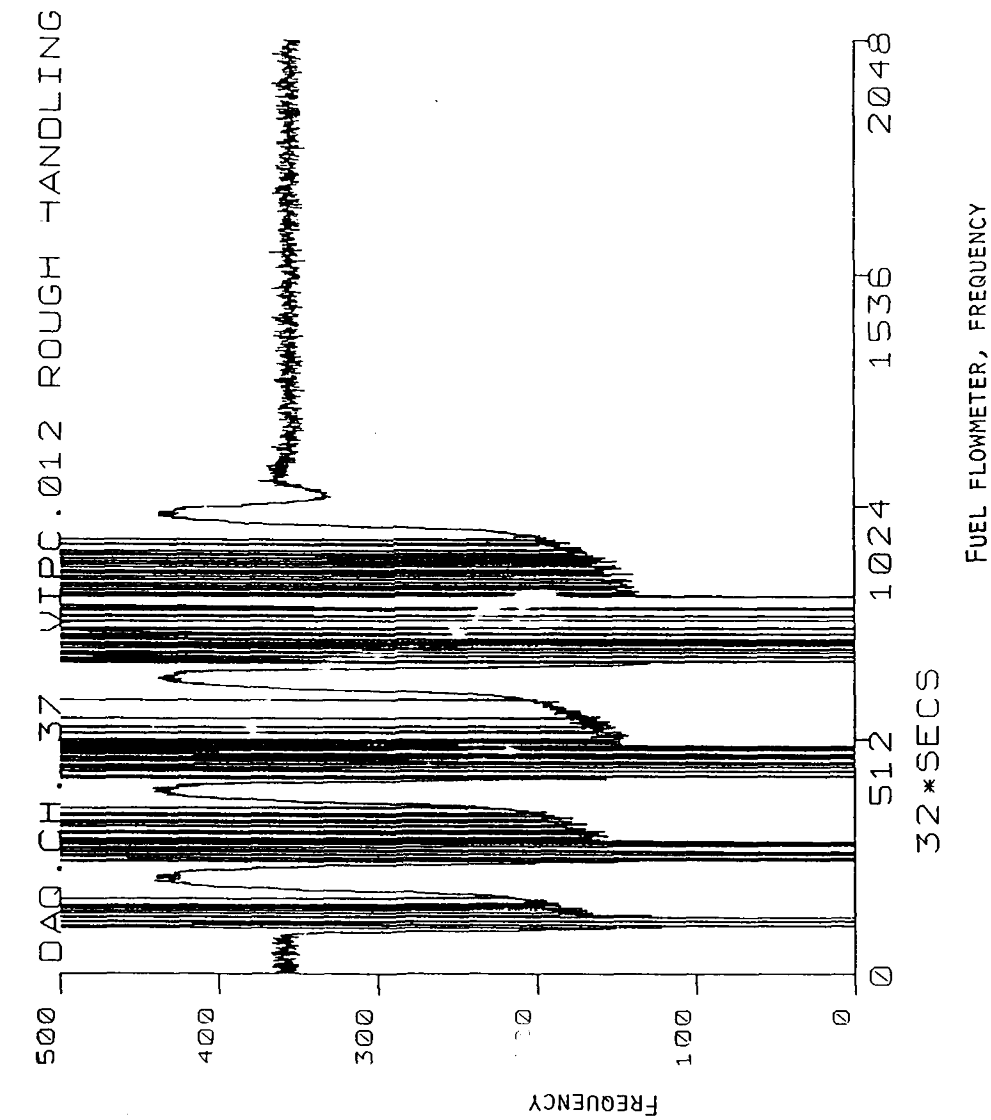
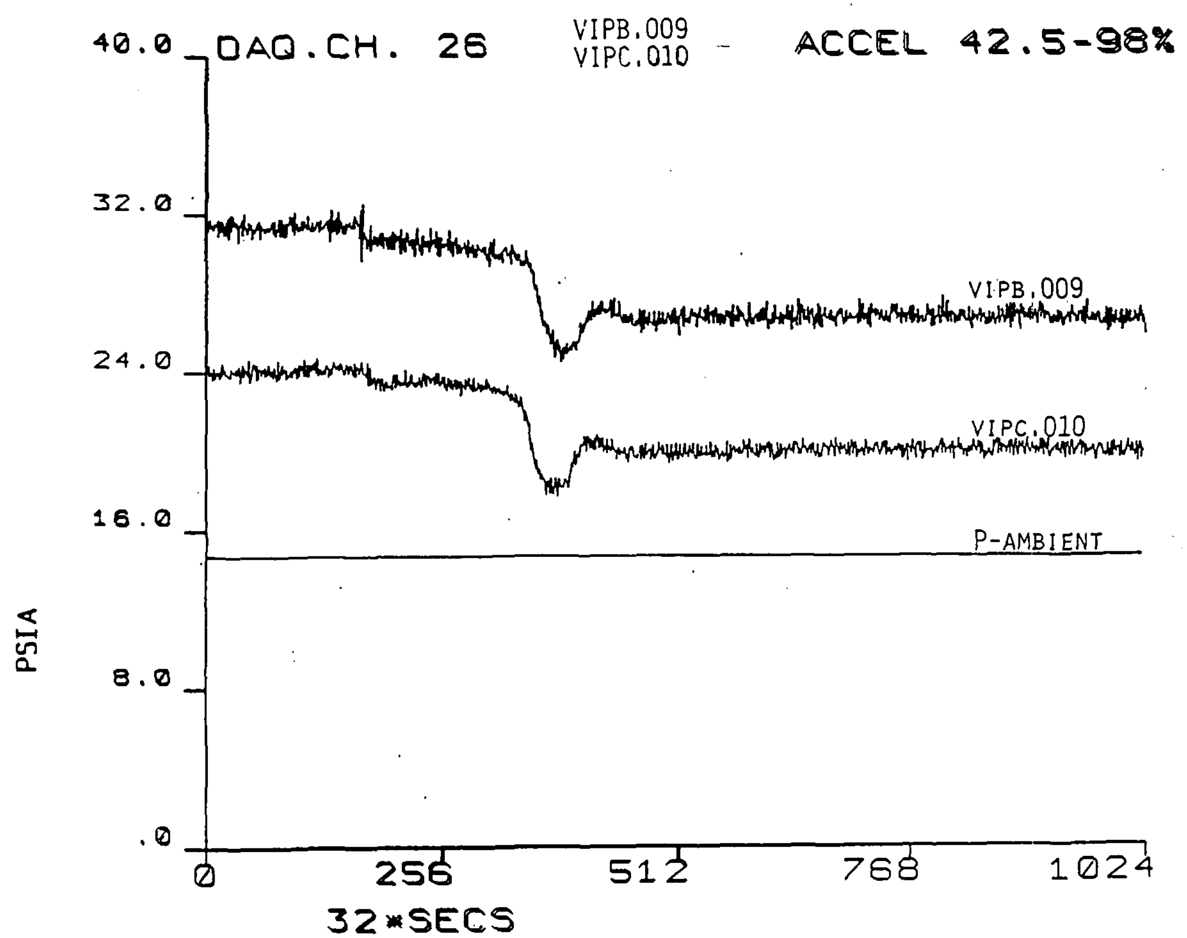
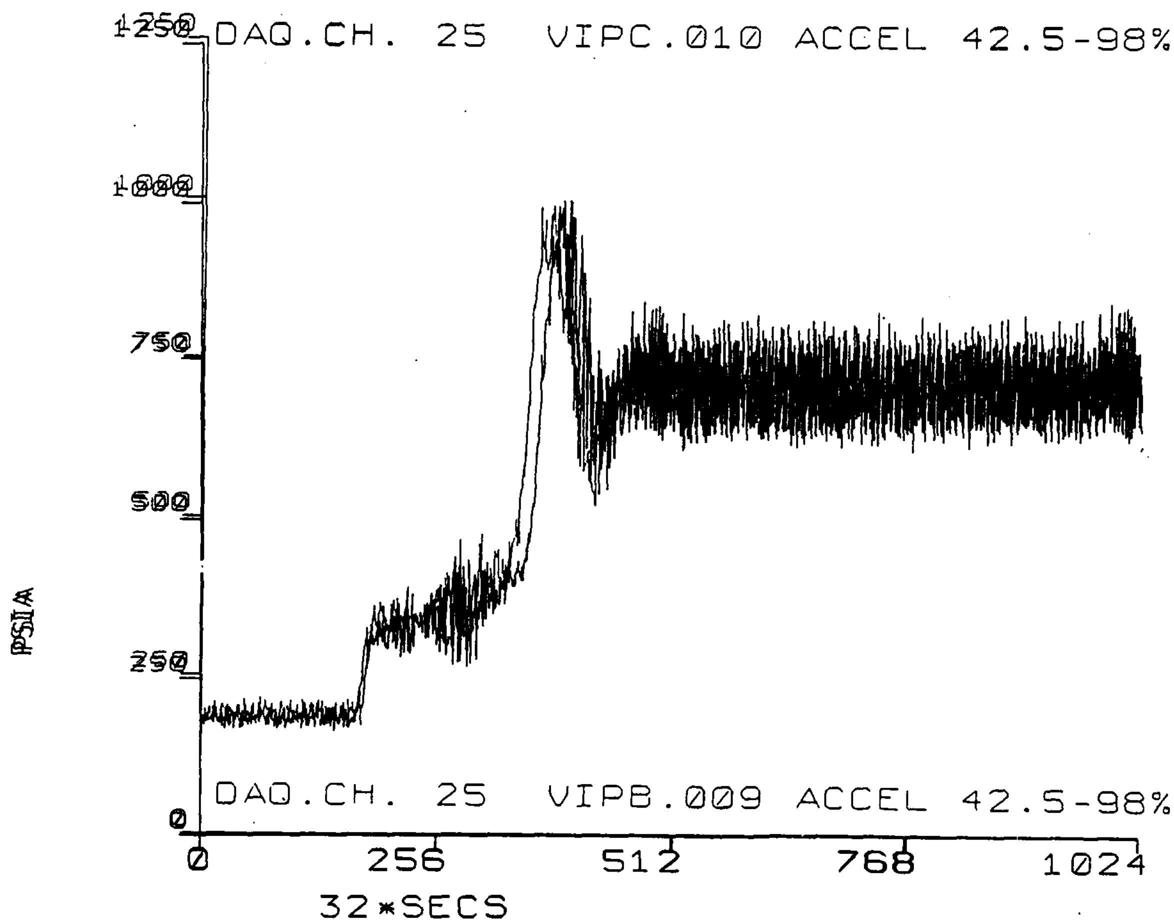

DAQ.CH.37 VTPC.012 ROUGH HANDLING
FREQUENCY
500
400
300
100
0
0
512
1024
1536
2048
32*SECS
FUEL FLOWMETER, FREQUENCY

FIGURE 15



PRESSURES, FUEL FILTER OUTLET

FIGURE 16



PRESSURE, HIGH PRESSURE PUMP OUTLET

FIGURE 17

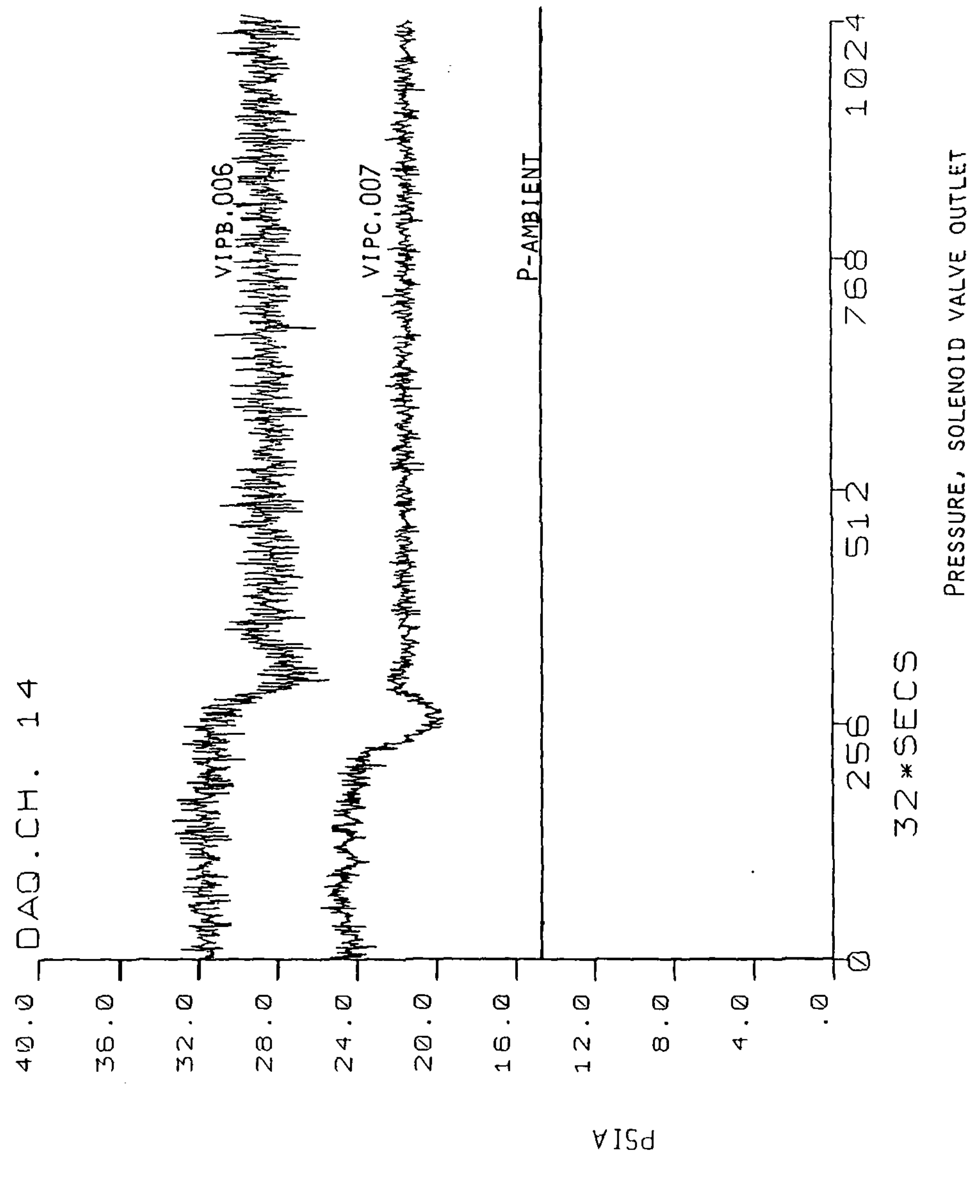
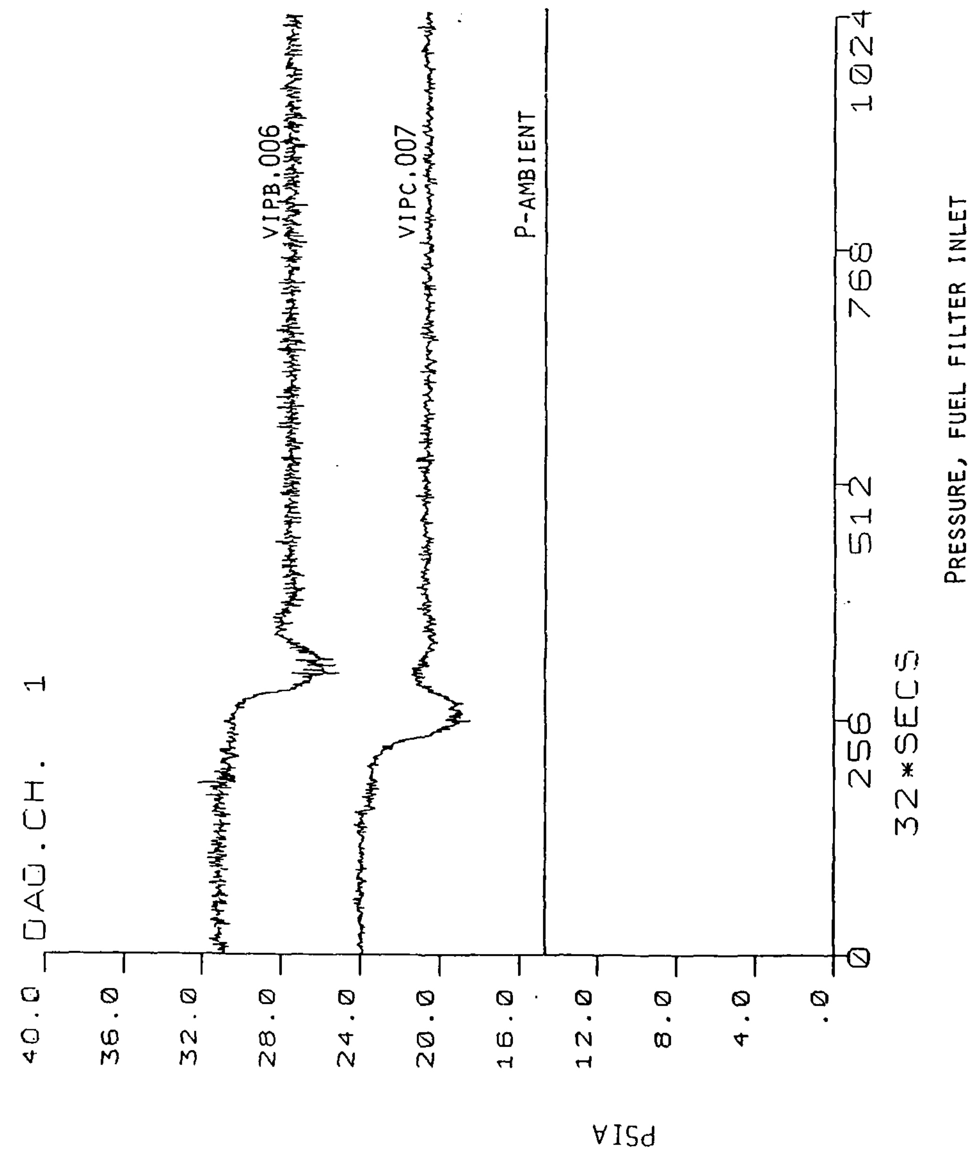
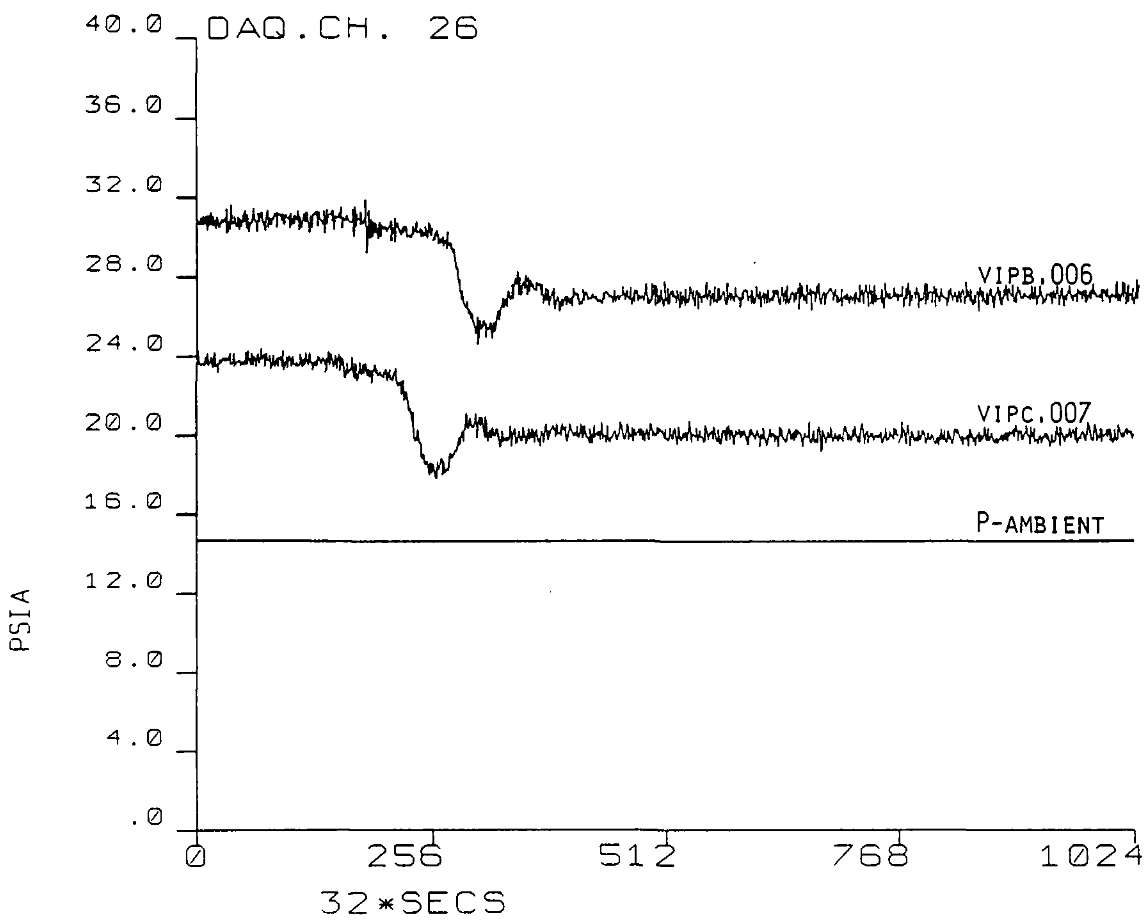

DAQ.CH. 14
VIPB.006
VIPC.007
P-AMBIENT
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
.0
PSIA
0
256
512
768
1024
32*SECS
PRESSURE, SOLENOID VALVE OUTLET

FIGURE 18



DAQ.CH. 1
VIPB.006
VIPC.007
P-AMBIENT
PSIA
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
.0
0
256
512
768
1024
32*SECS
PRESSURE, FUEL FILTER INLET

FIGURE 19



PRESSURE, FUEL FILTER OUTLET

FIGURE 20

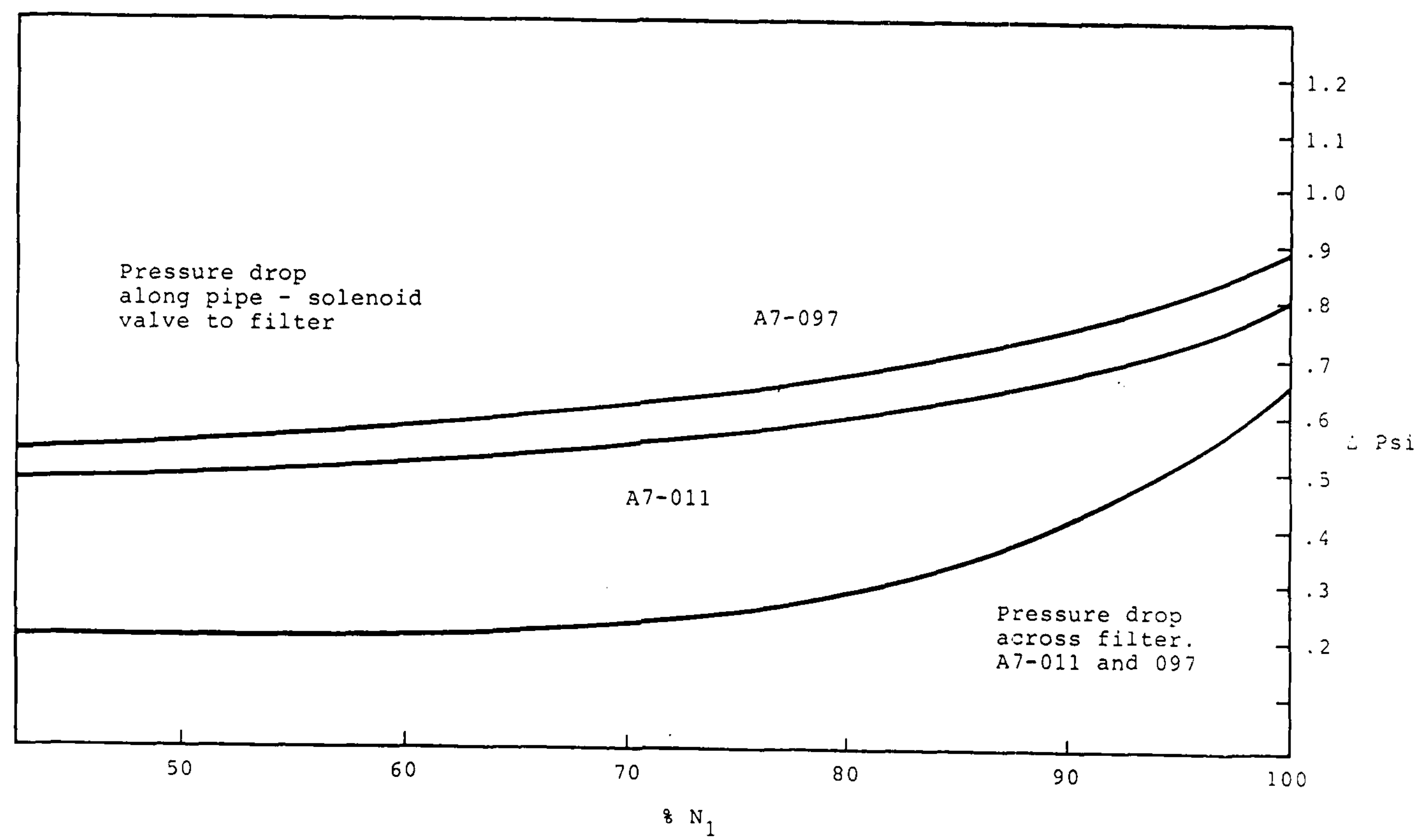


FIG. 21 SYSTEM PRESSURE DROPS V ENGINE SPEED

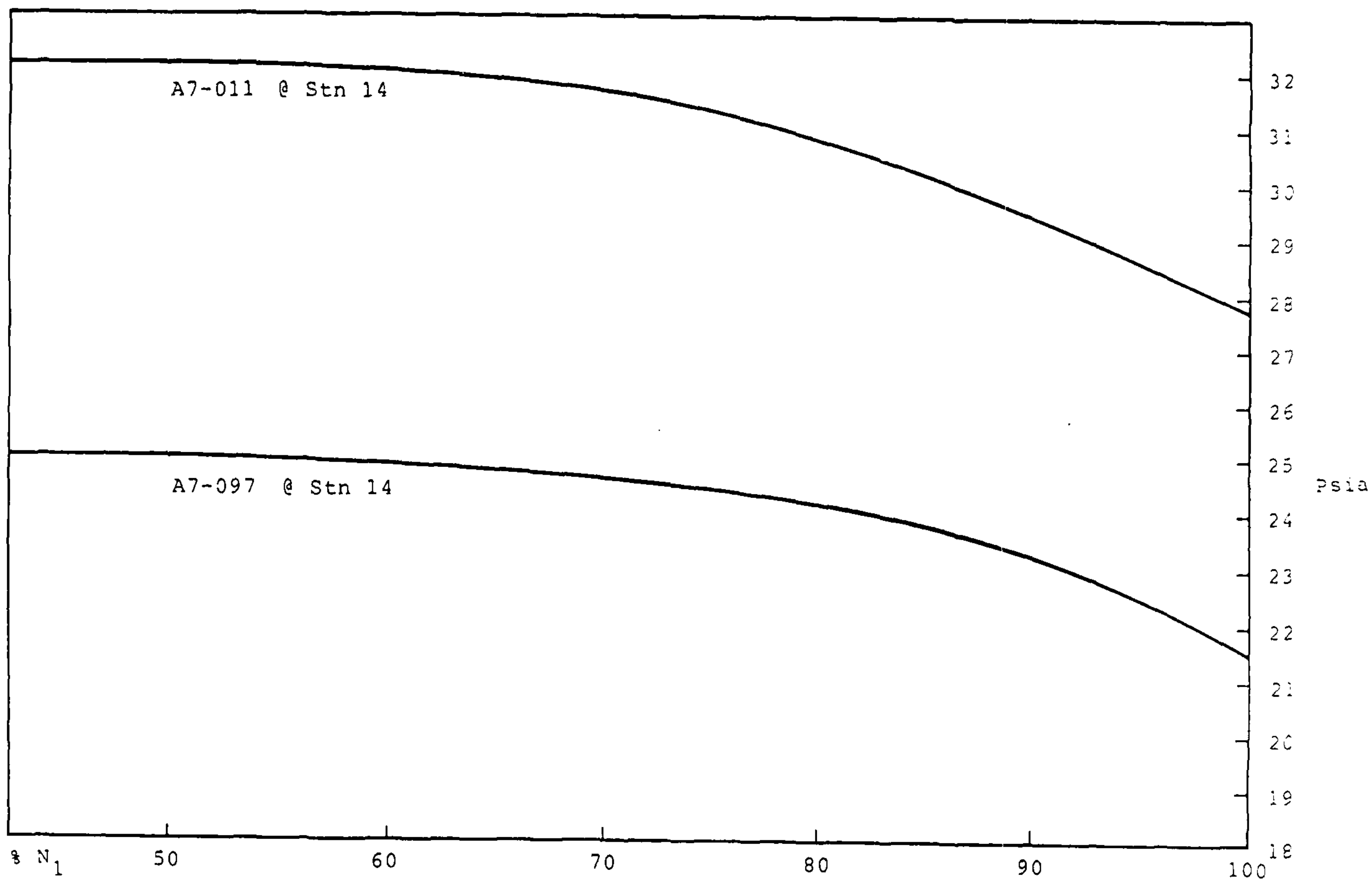


FIG. 22. PRESSURE LEVELS IN LOW PRESSURE FUEL SYSTEM v ENGINE SPEED (SOLENOID VALVE/SHUT OFF COCK OUTLET)

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The results of an onsite investigation into the performance of the low pressure fuel system for two Macchi-Viper Jet Trainer aircraft are presented. Data analysed indicated little difference in the pressure drops in the fuel systems of both aircraft. However induced or suction pressure drops during engine accelerations can have a marked influence on pressure levels at the high pressure pump inlet. The low pressure pump in Aircraft A7-097 was significantly low in performance, resulting in illumination of a warning light.

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