Programme Area: Carbon Capture and Storage

Project: High Hydrogen

Title: Basis of Design Document For Test Rig

Abstract:

This document provides the rationale for, and a description of, the design process covering the design, manufacture and installation, commissioning and operating procedures for the test rig. The scenario of interest is one in which a CCGT/CCGE flames out for whatever reason and for the following few seconds unburnt fuel passes through the turbine (in the CCGT case) without re-igniting and into the exhaust system.

Context:

Hydrogen is likely to be an increasingly important fuel component in the future. This £3.5m project was designed to advance the safe design and operation of gas turbines, reciprocating engines and combined heat and power systems using hydrogen-based fuels. Through new modelling and large-scale experimental work the project sought to identify the bounds of safe design and operation of high efficiency combined cycle gas turbine and combined heat and power systems operating on a range of fuels with high and variable concentrations of hydrogen. The goal of the project was to increase the range of fuels that can be safely used in power and heat generating plant. The project involved the Health and Safety Laboratory, an agency of the Health and Safety Executive, in collaboration with Imperial Consultants, the consulting arm of Imperial College London.

Paul

HEALTH & SAFETY LABORATORY

Basis of Design Document for HSL WP2 Task 2 Test rig for ETI

energy technologies institute

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Contents

1 Introduction 6

1.1 Background 6

1.2 Objectives 7

2 Description of Rig 8

2.1 Instrumentation 9

2.2 Engine Conversion 9

2.3 Control System 10

2.4 Gas Mixture Supply 10

2.5 Data Collection 11

2.6 Commissioning 11

2.7 Safety Assessment 12

3 Product Specification 13

3.1 Tube Section KM 13

3.2 Engine and Butane Fuel Systems *Scitek* 15

3.3 Gas supply HSL 17

3.4 Instrumentation Scitek/ KM 18

3.5 Rig location and Enclosure 29

3.6 Site Services 29

4 HAZID 30

5 Environmental Impact 31

6 Codes and Standards 32

7 Figures 33

8 Drawings 36

9 P&ID 44

10 Instrument Datasheets 46

11 References 51

Table of Figures

Figure 1 Viper engine SN301023 before undergoing conversion to butane 16

Figure 2 Representative diagram of the proposed circular duct test rig 18

Figure 3 Representative diagram of the proposed engine section of the circular duct test rig 19

Figure 4 Example Five Hole Probe (Benson, 2009) 20

Figure 5 Representative diagram of a segment of the proposed pipe section of the circular duct test rig 23

Figure 6 Schematic diagram of a Laser Doppler Anemometry System 24

Figure 7 Location of proposed test site at HSL, Buxton relative to main buildings and with exclusion zones marked 33

Figure 8 Proposed test site 34

Figure 9 Plan of proposed test rig site showing location of butane tank and service trenches 35

Figure 10 Draft P&ID of test rig 45

1 Introduction

User Requirement statement (what you have been asked for)

This document provides the rationale for, and a description of, the design process covering the design, manufacture and installation, commissioning and operating procedures for the test rig forming the basis of Work Package 2 Task Two as required under the terms and conditions of the ETI Contract Number PE02162. Section 6, Task 2: Experimental investigation at increased scale using a circular tube.

The scenario of interest is one in which a CCGT/CCGE flames out for whatever reason and for the following few seconds unburnt fuel passes through the turbine (in the CCGT case) without re-igniting and into the exhaust system. In such circumstances and with pure hydrogen as the fuel, the average downstream mixture will be in the region of 12% v/v hydrogen in air, at temperatures of the order of 800K, depending on the degree of compression achieved in the compressor. For CCGE applications the hydrogen concentration may be twice as high. If re-ignition is then assumed to occur, the project seeks to assess the potential consequences, particularly with reference to flame acceleration and detonation propensity of the air/fuel mixtures. This is to be done using reduced scale models of an actual system such that the appropriate scaling criteria can be identified to enable predictions to be made of the hazards at full scale.

1.1 Background

Function specification (what the system is to deliver and how)

The Participants will manufacture, commission and undertake a series of experimental measurements using a test rig, comprising a jet engine to provide a hot vitiated air flow, and a nominal 600 mm diameter duct, some 12 metres long. These will quantify the ignition and flame acceleration up to and including detonative potential for the fuels systems selected.

The rationale for using this size of rig is based on the consistent experimental and theoretical evidence for hydrogen mixture compositions with marginal detonation behaviour, for which the detonation cell size is characteristically several times that for the stoichiometric fuel mixture and rises asymptotically towards the detonation limit within a few percent for further mixture dilution. With an established detonation cell width for stoichiometric hydrogen-air of approximately 10 mm at near ambient conditions and a critical channel width for detonation propagation of no more than this, it will be feasible to accommodate, close to the detonation composition limits, a potential hydrogen detonation with multiple cells across the width of the 700 mm duct.

The Participants will test and build on the findings from WP1 and WP2, Task 1 at this scale using the small gas turbine to provide a hot vitiated airflow. This will enable validation in a controlled and systematic manner for the modelling, test results and the scaling parameters used in Task 1. The facility may also provide a better appreciation of the technology required to control and operate gas turbine engines running with hydrogen-enriched fuels safely. In particular this will apply to where and when a combustible gas mixture may exist in the exhaust gas stream.

1.2 Objectives

Plant objectives (what do you want to get from this)

The specific objectives of this part of the overall programme of work are to investigate in a nominal 600 mm diameter duct its effect on the results from the small scale study of Task 1 into the auto-ignition delay times, limits of flammability, and DDT potential for the selected systems of high-hydrogen fuels as defined in the literature review from Work Package 1.

The proposed test programme also seeks to assess the risk of ignition of non-combusted hot exhaust gases on hot surfaces for a specified flow rate and exhaust gas temperature as tested in the Task 1 test programme. It will also act as a test bed for the essential configurations and diverse situations that will be encountered with the Task 3 test rig in which replicate heat exchangers will be present such that their influence on the detonation propensity can be examined.

2 Description of Rig

The test rig comprises a Rolls-Royce (R-R) Viper gas turbine, type 203, with an exhaust that feeds into the 600 mm diameter circular duct some 14,500 mm in length. The duct comprises four by 3000 mm long un-insulated sections, flanged and bolted together. It is designed to withstand a maximum static pressure of 20 barg and a maximum average wall temperature of 400^0 C. A further two 1250 mm long section's are incorporated between the engine's turbine and the start of the 600 mm diameter duct. One section, attached to the start of the duct, is designed to fail at a dynamic pressure of around 5 bar, and by doing so, is intended to minimise the back pressures reaching the engine. The second section provides a nozzle from the engine turbine into the duct such that the turbulence levels in the flow are minimised. It also contains the turbine cone and six guide vanes, which are also used as a means of injecting and mixing the test gas mixtures into the main hot gas flow from the engine. Minimising the back pressure on the engine turbine in the event of a major deflagration in the test duct is particularly important, as under the intended test conditions there will be a volume of non-combusted gas mixture on either side of the ignition point through which flame and pressure waves may propagate and accelerate. The rig and its associated components will be manufactured from a suitable grade of stainless steel. A GA drawing of the proposed test rig is shown in Fig. 1.

The operating procedure chosen requires the engine to be run for several minutes in order to heat the test duct to the desired operating temperature such that a gas temperature of not more than 500^0C along the duct is achieved. The engine is then kept running and a high-hydrogen fuel sample, together with sufficient oxygen to restore the level in the exhaust stream to approximately 21%, are injected at the same time into the engine exhaust immediately downstream of the engine turbine. The flammable gas/oxygen mixture injection process will last for no more than ten seconds, during which time ignition of the mixture will be attempted. Ignition of the injected gas mixture will be via an electrical spark, or a hot surface, these will be installed axially downstream of the fuel injection point at an appropriate distance.

The complete test facility comprising the jet engine and the duct, with its associated components will be housed in a 20 metre long by 2.5 x 2.5 metre cross section steel tunnel. This tunnel is attached to a substantial concrete pad, which is capable of withstanding the dynamic reaction loads resulting should a stochiometric hydrogen detonation occur within the test duct. The test duct itself is attached directly to this concrete pad through an anchor plate attached at the beginning of the test duct proper. The rest of the duct is simply supported in order to allow for thermal expansion. The R-R viper engine is mounted independently within the tunnel, with a gap of no more than 10mm between its turbine and the fixed cone at the entrance to the test duct. A shroud is placed around the outside of the duct/turbine interface to minimise exhaust spillage.

2.1 Instrumentation

A series of bosses will be welded along the length of the tube at 500mm intervals, drilled and tapped to take a range of fast response sensors for measuring pressures and temperatures along the tube as well as optical probes for detecting flame. In addition 80mm diameter viewing ports will also be provided in each tube section at a distance of some 500mm from the beginning of each 3000mm length of tube. A single optical glass will be provided which can be used in any of the four tubes, the other three ports being blanked off. This will allow LDA measurements to be made of the flow velocities and turbulence intensities across the tube at up to four different downstream positions.

A 32-channel data logging and processing system will be provided, which has an appropriate rate and resolution for rapid data collection. The fast response pressure sensors will measure the pressure across the wave fronts in the duct. The fast response thermocouples will measure the gas temperature outside the boundary layer, whilst other thermocouples will monitor the duct wall temperature, fully developed turbulent flow being assumed. Optical probes will detect flame passage, and all of the probes will be used to monitor flame propagation parameters i.e. distance/ time/ velocity. Several additional pressure transducers are available for measuring static pressure in the duct and around the engine exhaust as necessary.

HSL's Visual Presentation Services will provide appropriate photographic and video records of the test rig and the tests during both the commissioning and the experimental programme.

2.2 Engine Conversion

The Viper jet engine will provide a mass flow of around 15-18 kg/s, with a turndown ratio of 4:1. The engine has a power output of 3.0-3.5 MW, and jet velocities in the 600 mm diameter duct are expected to be in the region of 50-150 m/s. A dedicated mass flow meter type intake will be provided so that the airflow is smooth and the mass flow rate can be measured from the pressure drop at the throat of the intake.

It has been decided to run the jet engine on butane in order to minimise the possibility of soot particles affecting the DDT behaviour of the gasses being tested. Consequently the design of the gas turbine rig will involve modification of the engine prior to commencing the test programme and obtaining a four tonne liquid butane storage tank for the duration of the test programme. Modifications to the engine to run on butane involve the removal of its existing fuel pump and fitting an external variable speed positive displacement pump to meter the fuel flow into the engine and therefore control its speed. To this end expertise from another company, Reaction Engines, who have specialised technology for running a Viper engine on butane, is being bought in so that the risks of any unforeseen technical difficulties arising from the conversion of the engine are minimised.

2.3 Control System

The control system for the engine is an adaptation of the established control system used when running the Viper engine in its normal mode on kerosene. A dedicated PLC system will be purchased and programmed to control the engine and ensure the prescribed safe operation of the engine, rig and facility. The specialised experience of Reaction Engines will be used again in the development of the control system, as it will need to accommodate extra safety features relating to the use of butane as fuel. The engine is started using an electrical starter to spin it at 530 rpm; it then uses pilot fuel injectors to spool it to idle (5000 rpm) before switching over to the main fuel injectors.

The control system reads and records a number of engine and rig parameters such as RPM, oil pressure, compressor pressure, exhaust temperature and pressure, intake mass flow rate etc. Software will be written to communicate with the PLC system and display these parameters on computer screens as well as storing them on a hard drive. The clock of the control system will be synchronised with that of the data acquisition system so that data from other instruments can be correlated to engine parameters.

The PLC will be located in close proximity to the engine whilst the part of the control system responsible for displaying and storing the engine parameters will be in the control room which for safety reasons will be situated some 200 metres from the engine. Engine start, speed settings and shutdowns will be carried out from the control room. Failsafe hardware will be installed, which in the event of a power failure, gas leakage, and engine over speed or over temperature will automatically shut down the engine.

2.4 Gas Mixture Supply

The system of gas supply will consist of two stainless steel pressure vessels with a maximum capacity of 100 litres and a MWP of 200 barg. One vessel will contain oxygen the other the fuel mixture. The latter will comprise mixtures of hydrogen/methane/carbon monoxide and nitrogen when required. Specific gas mixtures will be prepared from individual gas cylinder packs using a booster pump. Mixtures will be quantified using partial pressures. Mixtures and individual gases up to 100% concentration can be prepared in this way.

The means of injecting the gas mixtures will be a flow through system, injecting directly into the exhaust stream and relying on the injection process to ensure that the gases are fully mixed with the exhaust stream. This avoids waste and reduces the risk of a flash back. The mass flow rates of the injected gasses will be measured using individual mass flow controllers, and the supply line pressures will be regulated using pressure regulators.

The gas supply system will be located in a well-ventilated area and will be piped to the rig, which for safety reasons will be located at some distance away. The pipe work with its associated pressure regulators and flow controllers will be designed and installed to accord with the Pressure Systems Regulations.

2.5 Data Collection

SCITEK will design and install the data acquisition system for the rig, using hardware from National Instruments in the form of cRio, PXI / SCXI systems that have fast data acquisition capability as well as signal conditioning capability for different types of sensors. This system will also be interfaced to the engine control system, which is also a PXI / SCXI system. The data collection software will ensure that all critical data is displayed in numerical and graphical form and stored for more detailed analysis in due course. The software for data acquisition and control will be written by SCITEK in LabView, which is the industry standard.

2.6 Commissioning

The completed rig will be mounted on a solid steel frame and installed on a concrete pad that is within the experimental test area of the HSL site. The rig including the Viper jet engine will be fully enclosed, for safety reasons within an existing mild steel blast tunnel. This tunnel comprises several 2.5 metre long sections bolted together to give a total length of 15-20 metres. Its cross-sectional dimensions are 2.5 X 2.5 metres. This enclosure will provide protection from inclement weather and a suitable working environment, as well as containing any debris in the unlikely event of an engine or duct failure.

The rig will be operated from a nearby control room, some 100 metres away, where the data collection and processing system will also be housed. An exclusion zone will be declared and maintained around the test rig during its operation. Fig. 2 gives a plan view of the test site and Fig. 3 shows the blast tunnel.

The engine will be commissioned first to ensure that the control system is responding correctly such that the operating conditions can be maintained and controlled such that the engine starts without flameouts as these may release unburnt gas.

Engine running tests will follow to ensure that steady state gas flow temperatures are established in all parts of rig within an acceptable time scale. The steady state temperatures and operating conditions will be recorded. Once the required gas flow conditions have been achieved further tests will be undertaken to validate the fuel mixture and oxygen injection systems, that adequate mixing is being achieved, and that the instrumentation is functioning correctly together with the data collection system. The test programme currently includes a total of five commissioning tests.

2.7 **Safety Assessment**

HSL will undertake the risk assessment of the rig and will have responsibility for the safety of the rig; others will contribute to this process particularly with respect to the operation of the Viper jet engine. All work done will be in compliance with the relevant CDM, DSEAR and Pressure Systems regulations.

As part of the safety measures a gas detection system will be installed within the fuel storage and engine areas to detect any fuel leakages, this will be linked via the engine control system to safety cut-off valves. Other fire prevention measures will be included as necessary.

3 Product Specification

3.1 Tube Section KM

3.1.1 Description

The tube comprises four sections each of which is 3.0 metres long, together with a 0.450 metre long sacrificial section and a 1.270 metre long interface section. Each section of tube is flanged in accordance with the code. Proof of conformity with the code will be provided for both the tube and flange materials.

The sections mate with adjacent sections such that any radial misalignment between sections does not exceed 0.5 mm at any point around the circumference of the mating surfaces. The sections are spigotted and bolted together without the use of gaskets; the mating surfaces are machine finished, as the joints do not have to be leak proof. ("O" ring seals are used for hydrostatic proof testing purposes.)

The tubes are to be manufactured from 304L grade of stainless steel, with their seams ground internally to provide a smooth surface along the length of the finished tubes.

Each section of tube has a series of bosses welded along their length at 0.5 metre intervals, starting at a distance of 0.25 metres from the tube ends. These are drilled through and tapped to 1.0-inch BSP parallel female pipe threads flat bottomed. Each tube also has a single 80mm diameter optical viewing port at a distance of 0.5 metres from one end.

A cradle, whose height is adjustable, supports each section. Each cradle runs within two channels with sideways movement being prevented by adjustable castors. This enables the sections to be easily moved within the enclosing tunnel (Fig. 2), and to be aligned and bolted correctly to each successive tube section.

The sacrificial tube comprises a 400 mm long thin walled section that is held, without end-load between two flanges by twelve tie rods.

There is an interface section attached directly to the sacrificial tube section, this contains the engine exhaust cone that is held in place by six guide vanes. There is provision for injecting the test fuel mixtures into the exhaust stream circumferentially through the vanes together with the make up oxygen. It is not rigidly connected to the engine exhaust turbine housing, as an opening between it and the rotating engine turbine is required in order to vent any excessive backpressures.

A turbulence generator has also been provided, comprising a removable vertical grid of five tubes whose diameter may be changed from 25mm up to 50mm. This unit can be mounted at the inlet to the first of the four 3.0 metre long tubular sections.

The completed tube is fixed, at a centre-line height of 1.0 metre from the base of the surrounding tunnel (Fig. 1). It is anchored at one point only to the underlying concrete base. The attachment point is from the flange on the interface section. Expansion of the tube when in operation is accommodated through movement of each section on its respective cradle.

A series of detail design/concept drawings are enclosed as Figs. X-XX for all of the components described.

3.1.2 Assumptions

It is assumed that the internal diameter of the tube is nominally 600mm and that it is capable of withstanding an internal static pressure of 20 bars maximum. The maximum average wall temperature is taken as 400^0C.

The tube is also designed to comply with ASME B31-3 Pressure Piping code and ASME B16-5 Flange Code. In addition all components will comply with the Pressure Equipment Regulations 97/23/EC, and HSL will sign-off all manufacturing drawings prior to manufacturing commencing.

The sacrificial section is designed to fail at dynamic pressures of the order of 3-5 bars.

The turbulence generator can withstand an impulsive pressure load of 20-bar acting normally across the full section.

It is assumed that the engine exhaust cone and supporting vanes may be subjected to an impulsive reaction due to a pressure not exceeding 20 bars acting along the pipe centreline towards the gas turbine. The mounting system may also be subjected to this pressure but it is assumed to apply over the whole cross-section of the tube.

3.1.3 Calculations

Tube and flange design: Designed in accordance with ASME B31.3 Pressure Piping Code then the maximum allowable working pressure at 400^0C is 23.9 barg (which is adequate for the requirement of 20 barg). Prof. Saville from Imperial College comments that the 600 mm x 9.53 mm wall should be good for 30 bars.

A forged flange according to ASME B16.5 in 304L of 300lb dimensions is rated at 23.9 bar at 400^0C and is therefore adequate. These flanges are quite big, 36" dia for a 600 mm pipe. The flange thickness is equally large at 2.75". The weight of the flanges alone is substantial. A 3 metre section of completed tube is estimated to weigh about 1.5 Tns.

The use of this tube size also allows for any unforeseen significant overpressures in the unlikely event of a DDT occurring, when very short durations/transient dynamic pressures of 30-40% in excess of static loading could occur. For the most energetic conditions of very hydrogen rich systems, which we may well not encounter, this will still mean peak pressures below the static proof test conditions. Of course, this assumes any such event would not occur repeatedly at the same location.

The assumed design pressure has been confirmed from the calculations undertaken under contract by both BAES and Dr. G. Munday. The former assuming a hydrogen detonation occurs under stoichiometric conditions then the predicted maximum pressure is 22 bars, with peak pressure spikes some 2-3 X greater but lasting for less than 10 micro-seconds. Consequently these may be ignored as their duration is well below the period of the natural frequency of the tube.

Instrument ports: The bosses are some 50mm in diameter and are welded directly to the outside of the tube sections in accordance with the ASME code.

Sacrificial section: Wall thickness calculations to follow.

Interface section: The walls of this section are manufactured from 304Lplate with a slightly thicker section (10.0 mm) than that used for the four tube sections. It strength is therefore adequate based on the previous tube section calculations.

Turbulence generator; details to be added...

Anchor plate: This comprises both the attachment to the tube at the interface section and the mounting to the concrete base underneath the containing tunnel. The reinforced concrete base is located 1.52 metres below the centre-line of the test rig and its dimensions are 32 x 3.25 x 0.375 metres. It weighs some 94 Tnf. Calculations to follow.

3.1.4 Implementation/ design

A series of detail design/concept drawings are enclosed as Figs. X-XX for all of the components described above in section 3.1.1.

3.2 Engine and Butane Fuel Systems *Scitek*

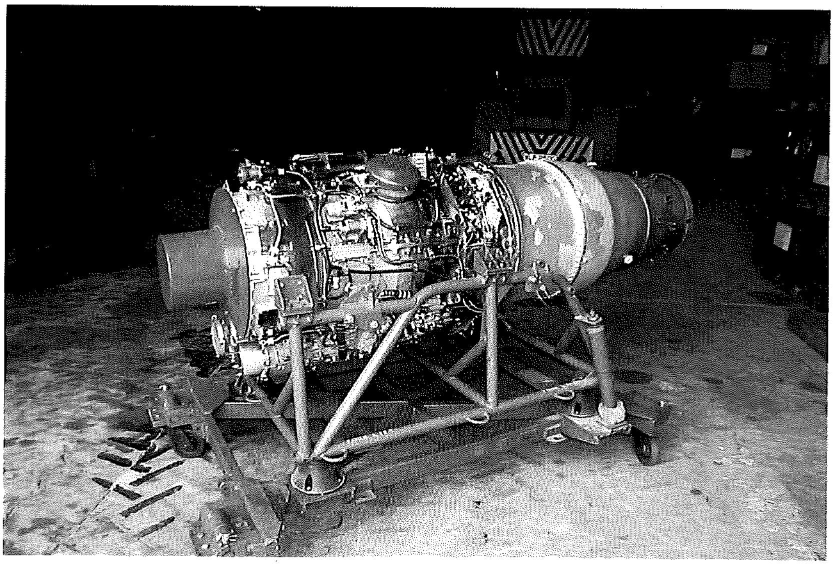
The Rolls-Royce Viper mk301 engine is a single shaft axial flow turbojet that produces a maximum thrust of approximately 2500 lbs. The engines purchased for this particular research project were both previously installed on Hawker Siddeley HS.125 aircraft, a small business jet that was also used by the RAF for navigation training under the designation Dominie T-1. For this experiment one engine has been converted to operate with butane fuel in order to reduce the amount of soot produced in the exhaust. The second engine will be kept as a spare for unforeseeable failures with the first.

The engine will be mounted on a frame manufactured by SCITEK (see Figure 1 ~~Viper engine SN301023 before undergoing conversion to butaneFigure 1~~) such that he centreline of the engine is 1.0 m above the floor. The engine frame will be secured to the floor by means of an A-frame which will be bolted to the engine frame by 8 M10 bolts and to the floor by 8 M10 bolts (2 on each of the four feet). Previous experience running the engine in this configuration has proven to be perfectly satisfactory. Before every engine run it will be required to check that the floor anchoring bolts are tight and did not become loose during a previous run.

An electric starter motor will be fitted to the underside of the engine and it will be powered by one of two 12V rechargeable batteries. After the starter begins to turn butane fuel will be introduced into the engine via a flexible pipe directly from the fuel system's engine pump. The volume of fuel introduced and the starter motor operation will all be controlled remotely using SCITEK's control panel which will utilise a National Instruments cRIO system (PLC). A number of other parameters, such as the mass flow rate of air in the intake, the engine RPM, the oil pressure and exhaust temperature will also be monitored by the cRIO.

A PC will be used to communicate with the cRIO while at the same time providing a user interface. The cRIO will be housed in a 19 inch rack enclosure and will also feature engine start and stop buttons as well as other hard wired safety systems.

Figure 1 **Viper engine SN301023 before undergoing conversion to butane**



The butane required to run the engine will be stored 40 m away from the engine in an existing tank with a water capacity of approximately 4500L. This tank was previously used to store propane, but it will be refurbished by HSL for use in this fuel system. The tank will be fitted with a refill point, over flow valve, pressure relief valve, level sensor and excess flow valves. The exact specifications for these components are yet to be determined, however it is anticipated that most will be similar to those currently installed on a similar butane fuel system at Reaction Engines in Oxford.

The fuel will be pumped from the tank by a boost pump towards the engine along a 1" to 2" bore pipe. The boost pump specified for the fuel system is a 2.2 kW M Pumps CT MAG-M6/2S coupled multistage peripheral pump with ATEX certification. This pump requires 3-phase power and is capable of moving approximately 2.5 m^3 of butane around the fuel system per hour.

Nearer the engine the pipe work splits into two lines, where one returns fuel to the tank (1" bore pipe) and the other (1½" bore pipe) sends fuel onto the engine. Approximately 30 minutes before the engine is due to start fuel will be circulated around the return loop in order to ensure that all pipes are filled with liquid at engine start. At engine start a remotely actuated valve fitted to the engine frame is opened and fuel is allowed to flow through to the engine pump.

The engine pump installed will be a 7.5 kW Hydra-Cell diaphragm pump model G25SMCTHFECA. This pump also requires 3 phase power and is capable of achieving the desired flow rate of 2.5 m^3/hr at 629 rpm. At full speed the pump can achieve a rate of 2.5 m^3/hr. The pump will be fitted with a remotely controlled AC inverter which will allow the pump speed to vary. This therefore controls the fuel flow into the engine, effectively throttling the engine and controlling the engine speed.

Four remotely actuated valves will be fitted at various locations around the system. Each valve will be an ATEX certified ball valve and will have ATEX limit switches fitted so that the open/closed position will be relayed back to the control system. The first of these valves will be located on the fuel line leaving the tank, the second immediately before the boost pump, the third on the return line and the fourth immediately before the engine pump. This final valve will also as an emergency shut off valve in the event of the engine having undergo an emergency shutdown. The exact specifications of these valves are yet to be determined, at the time of writing SCITEK are waiting on advice from Reaction Engines.

A number of pressure relief valves, manual valves and non-return valves will also be placed throughout the system A revised design to suit the site at HSL Buxton is in progress and so the number, locations and ratings of these valves will be specified in due course.

3.3 Gas supply HSL

3.3.1 Description

The gas supply system consists of two stainless steel pressure vessels with a maximum capacity of 100 litres and a MWP of 200 barg. One vessel contains oxygen the other the fuel mixture. The latter will comprise mixtures of hydrogen/methane/carbon monoxide and nitrogen when required. Specific gas mixtures are prepared from individual gas cylinder packs using a booster pump, and the mixtures quantified using partial pressures.

The gas mixtures are injected directly into the exhaust stream and rely on the injection process to ensure that the gases are fully mixed with the engine exhaust stream. The mass flow rates of the injected gasses are measured using individual mass flow controllers, with the supply line pressures regulated using pressure regulators, PRV's and stop valves. The proposed system is shown in the P&ID diagram as Fig. XX.

3.3.2 Assumptions

It is assumed that the maximum mass flow rate from the gas turbine will be 15 kg/s and that the maximum v/v concentration of gas mixture to be injected will be 15%. In addition makeup oxygen is injected at a rate sufficient to restore the oxygen levels in the exhaust stream to 21%. The gases injected are stored at ambient temperature and rely on the mixing process to heat them to the required operating temperatures of up to 5000C.

It is further assumed that a test will last no longer than 10 seconds; consequently the quantities of gases stored are based on this time.

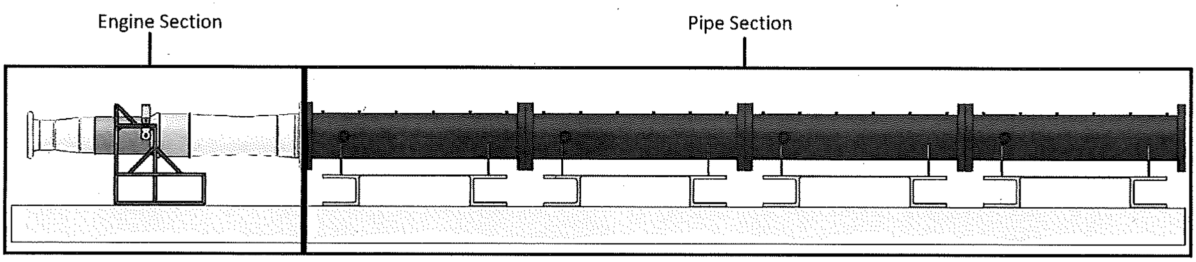
3.3.3 Calculations

3.3.4 Implementation/ design

3.4 Instrumentation Scitek/ KM

The proposed circular duct test rig has been divided into four major sections, the engine, the butane fuel system, the gas delivery system and the pipe section, for the purpose of demonstrating the locations and specifications of the required instrumentation. Figure 3.1 shows the schematic layout of the engine and pipe sections (the fuel system and gas delivery system are not shown here).

Figure 2 Representative diagram of the proposed circular duct test rig



3.4.1 Engine Instrumentation

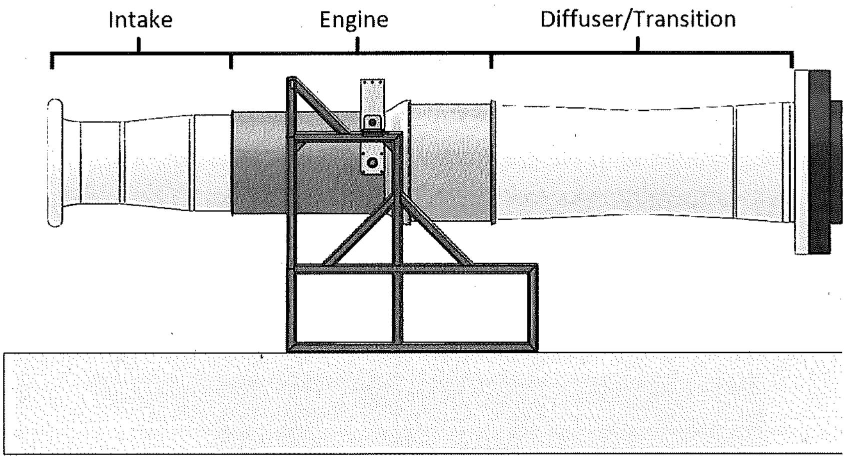
The Engine section outlined in figure 3.2 will be instrumented in three parts, the intake, the Viper mk 301 engine and the diffuser/transition. At the intake the mass flow rate of air entering the engine will need to be known so that the correct mixture of gases can be injected downstream of the turbine. To determine the air mass flow entering the engine a specially designed intake (based on methodology recommended by Rolls-Royce) is used. The intake features static pressure tappings at its throat and by measuring the static pressure during operation the mass flow can be inferred.

Typically the mass flow rate is calculated via the following equation:

$$\dot{m} = A_T \sqrt{2\rho\left(P_{atm} - P_T\right)}$$

where $\dot{m}$ is the mass flow rate of air, A_T is the effective flow area of the intake at the throat, ρ is the density of the air, P_{atm} is the atmospheric pressure and P_T is the static pressure in the intake at the throat.

Figure 3 Representative diagram of the proposed engine section of the circular duct test rig

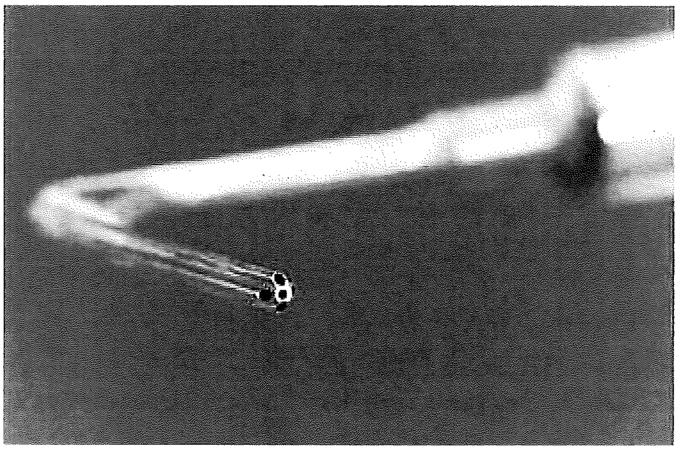


The atmospheric pressure will be measured by a Druck PTX1400 or equivalent absolute pressure transducer with a typical range of 800 mbar to 1200 mbar situated near to, but not on, the engine. The static pressure at the throat of the intake will also be measured by a Druck PTX 1400 or equivalent pressure transducer, but this sensor will measure gauge pressure with a maximum range 500 mbar below ambient. The density of the air is known, however it does vary with temperature so for this reason a PT100 platinum resistance thermometer such as an Omega RTD805/6 will also be installed near the engine. All three instruments will be sourced from existing SCITEK stock where available, but some may need to be purchased specifically for this rig.

At present the calibration curve to convert static pressure at the throat to mass flow has been obtained from CFD predictions, however for this experiment a more accurate calibration will be required. To do this a five hole probe will be inserted into the air stream at the throat of the intake. The probe is a group of five parallel hollow tubes arranged so that the open ends lie in the centre of and on the four points of a cross. The leading edge of each tube on the outer points of the cross is cut at a 45° angle to allow air to enter the probe from multiple directions (see figure 3.3). The difference in pressure recorded at directly opposing tubes yields the flow direction, while the pressure recorded over all of the tubes yields the total flow velocity. By traversing this probe along the radial of the intake the total mass flow rate will be determined. At the time of writing a five hole probe suitable for the mass flow rate calibration has yet to be identified. When a probe is found, SCITEK will arrange for purchase or temporary loan of the instrument.

Five engine parameters will be monitored to track the engine health when in use, the engine RPM, the butane fuel flow and pressure, the engine oil pressure and the compressor delivery pressure. A frequency generator that already exists on the engine will send a signal that is proportional to the engine RPM back to the control system where it will be interpreted. The butane mass flow rate will be monitored via a turbine flow meter located on the engine. It is envisaged that a flow meter from an existing viper engine will be used following a recalibration, however if one cannot be sourced an equivalent 3rd party turbine or coriolis flow meter will be fitted to the fuel line. A Druck PTX1400 (or equivalent) pressure transducer with a maximum range of 50 bar will be installed upstream of the flow meter for safety purposes; for example if the fuel pressure recorded falls outside of the operational limits an emergency shutdown of the engine will be triggered. Lastly two further Druck PTX1400 (or equivalent) pressure transducers with a maximum range of 10 bar will be fitted to the engine in order to monitor the oil and compressor delivery pressures. Each of these pressure transducers will be acquired and fitted by SCITEK.

Figure 4 Example Five Hole Probe (Benson, 2009)



The Diffuser, or Transition section as it is also referred to, expands from an annular geometry immediately aft of the turbine through to a cylinder at the interface with the pipe section. The temperature of the gas exiting the turbine will be monitored to ensure the engine is not operated outside its safety constraints and for comparison with measurements made throughout the pipe section. Three K-type thermocouples with a maximum temperature rating of 1100 °C will be purchased by SCITEK and inserted into the air stream through equally spaced ports around the circumference of the diffuser.

The engine control system will monitor all of the parameters described here. If, for example, an over temperature in the exhaust or an overspeed in the engine RPM is detected the control system will automatically cut the fuel supply to the engine. This is necessary in order to ensure the longevity of the engine and its safe operation.

For more detailed information on the instrumentation planned for the engine section refer to table 3.1.

3.4.2 Butane Fuel System Instrumentation

The Viper engine in the proposed circular duct test rig will be fuelled by an on-site butane supply. A large tank, with a water capacity of approximately 4500 L, will be situated 40 m away from the test site and the fuel will pumped to the engine via two pumps. The amount of fuel remaining in the tank must be known during testing so a level sensor will be installed in the tank and the data recorded will be fed directly into the control system. At the time of writing a suitable level sensor has yet to be identified, however SCITEK will work with HSL to specify, purchase and install a sensor before the experimental program commences.

Two pumps will feed the Viper engine with butane, a boost pump and an engine pump. The boost pump, manufactured by M Pumps, cycles fuel around the supply system (see Section 3.5) by turning at a constant rate so a remotely operated on/off switch will be used to control it. The engine pump, manufactured by Hydra-Cell, will be fitted with a 3-phase inverter (supplied with the pump by Hydra-Cell) so that the flow of fuel into the engine can be controlled by varying the pump speed. The pump RPM will be monitored remotely while in operation by the control system.

Four remotely actuated ball valves will be fitted at various locations in the butane fuel system (see Section 3.5). Each ball valve will be ATEX rated and fitted with two ATEX rated limit switches that will return a signal to the control system when activated. This will allow for remote monitoring of the open/closed status of the valve. Finally, to ensure the safe operation of the butane fuel system, a Druck PTX1400 ATEX rated pressure transducer will be installed between the boost pump and the engine pump (immediately before the shut off valve). With a range of 0 to 25 bar, this sensor will send a 4-20 mA signal to the control system allowing the system pressure to be monitored remotely. The signal from the pressure transducer will also be monitored by the emergency stop system, which will be activated if the fuel pressure falls outside of the pre-defined operational limits.

For full details of the butane fuel system see Section 3.5. For more information regarding the instrumentation used in monitoring and controlling the fuel system see table 3.2.

3.4.3 Gas Delivery System Instrumentation

Mixtures of Hydrogen, Oxygen, Methane and Carbon Monoxide gas will be injected into the engine exhaust stream between the turbine and the diffuser. Stored in a rack of bottles held at pressures of up to 200 bar, the quantities of each gas injected into the engine must be controlled with high accuracy so a number of flow controllers will be installed on the rig. The mass flow rates for each gas are not expected to exceed

0.19 kg/s for Hydrogen, 1.12 kg/s for Oxygen, 2.74 kg/s for Carbon Monoxide and 1.57 kg/s for Methane. If required a PT100 platinum resistance thermometer will accompany each flow controller (depending on type installed) so that the mass flow rate can be corrected for any changes in temperature. SCITEK and HSL will work with suppliers such as Bronkhorst and Emmerson Process Management to identify the type of flow controllers most suited to the rig and arrange for purchase. For further information on the instrumentation required for the gas delivery system refer to table 3.3.

3.4.4 Pipe Section Instrumentation

The pipe section of the rig consists of four 3.0 m long tubes that are flanged together. Each tube will have six 1" BSP ports aligned along the radial spaced 500 mm apart, with the first and last ports 250 mm from each end (see figure 3.4). These small ports will allow a number of different measurements to be made when the rig is operational.

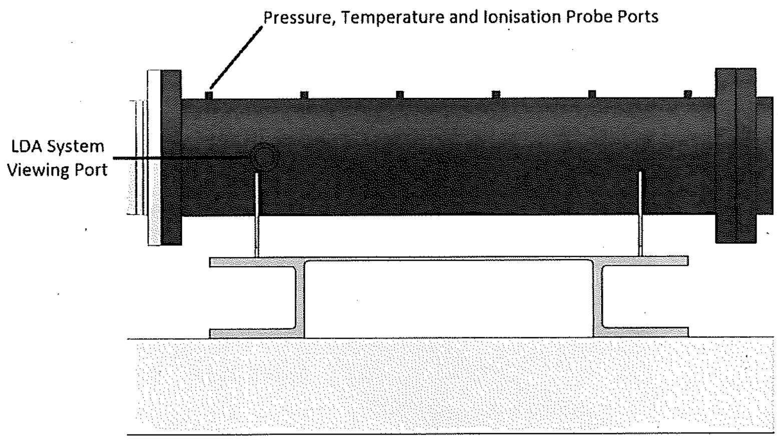
In order to ensure that the rig is at the temperature desired for the deflagration/detonation experiments, the gas temperature immediately adjacent to the wall must be monitored. Eight K-type thermocouples, sheathed in a tube of approximately 3 mm diameter and up to 30 cm in length, will be fitted into a number of the 1" ports so that the tip of the sensor is sampling the air temperature within 5 mm of the inner wall surface. The long length of the sheath enables temperature measurements further into the tube to be made if desired. SCITEK will arrange for the purchase of these thermocouples when the final rig design is completed.

Flames produced as a result of a deflagration or detonation will be detected using ionisation probes and it is expected that up to 8 of these probes will be used at any one time. At the time of writing the specifications for this instrument were yet to be received from Imperial College.

If a deflagration or detonation occurs within the pipe it is likely that a shock wave will travel along its length. By fitting a series of pressure transducers in selected 1" ports, the magnitude and velocity of the shock wave can be determined. The sensors required for these dynamic measurements should also be able to measure the static pressure to reasonable accuracy within a hot environment (~500° C). One sensor capable of recording both dynamic and static pressure at temperatures of up to 1000 °C is the Kulite WCTV-312 water cooled transducer. With a natural frequency of 1000 Hz at 70 bar maximum range, the Kulite will measure short transient peaks down to 10 μs at an accuracy of 0.1 % FSO. At the time of writing SCITEK is waiting to receive a quote for 8 of these sensors from Kulite.

The flow from the exhaust of the Viper engine is required to spread evenly and flow uniformly through the tube. In order to confirm that it is uniform the flow will be characterised by inserting a rake into the flow stream. The rake, approximately 700 mm long, will enable the temperature and flow velocity across the diameter of the tube to be measured. Temperature measurements throughout the flow will be made using 8 small k-type thermocouples evenly spaced along the rake. Likewise the head pressure will be measured at 8 locations along the rake. The flow velocity is then inferred from the difference between the head recorded at each transducer and the static pressure measured by the Kulite sensor in a neighbouring port. This rake will be manufactured by SCITEK.

Figure 5 **Representative diagram of a segment of the proposed pipe section of the circular duct test rig**



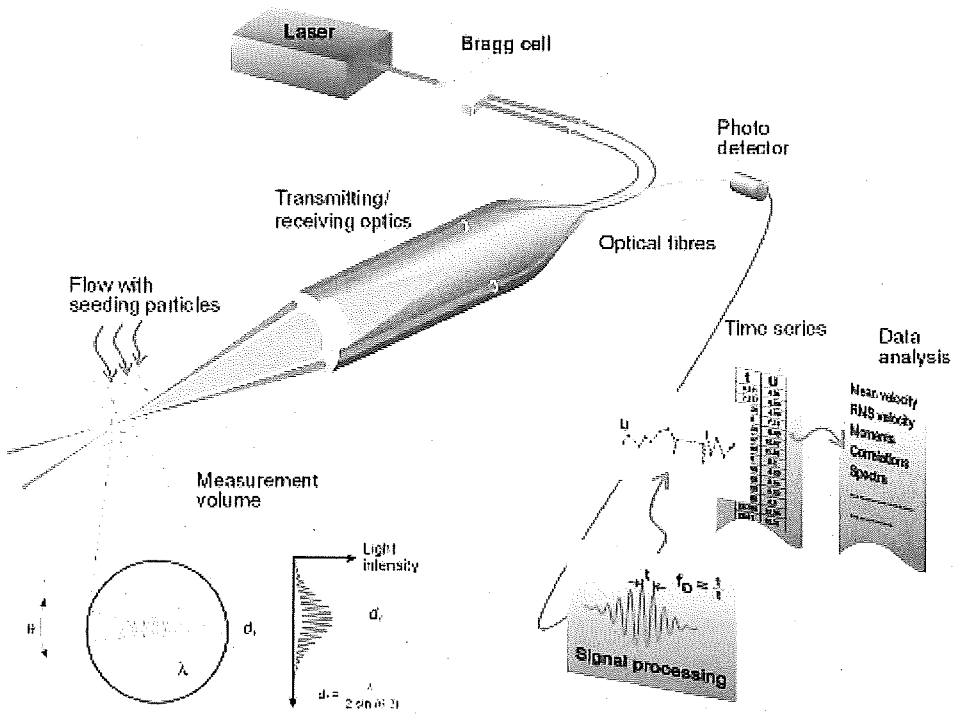
requires update: - ports now all on side (in line with LDA window)

A larger port approximately 100 mm in diameter will be located 500 mm from the front of the tube segment at 90° to the smaller 1" ports. This 100 mm port will suit an optical window, which will be fitted when performing flow characterisation experiments using a Laser Doppler Anemometer (LDA). The LDA crosses two beams of collimated, monochromatic, and coherent laser light in the flow of the fluid being measured. The two beams are usually obtained by splitting a single beam, thus ensuring coherence between the two. The transmitting optics focuses the beams to intersect at their waists (the focal point of a laser beam), where they interfere and generate a set of straight fringes. As particles (either naturally occurring or introduced using seeding generators) entrained in the fluid pass through the fringes, they scatter (reflect/refract) light that is then collected by the receiving optics and focused on a photodetector (typically a photo-multiplier tube). The particles are small, typically less than 3 microns, so that they can accurately follow the airflow.

As the particle travels through the fringe pattern (fringe spacing usually around 14 microns) a series of scattered light pulses are seen by the receiving optics. The period of these pulses represents the time taken for a particle to cross two fringes. As the fringe spacing is very accurately known the velocity of each particle can be calculated. The calculated velocity represents the component of particle velocity which lies in the plane of the two laser beams. By using lasers that produce more than one wavelength (colour) and by arranging the fringe pattern produced to be perpendicular to each other all three flow velocity components can be simultaneously measured. For the tests to be carried out in this project a two-component LDA system will be used to measure the axial and tangential component of the flow. The radial component of the flow will not be measured but it is assumed that it will not vary. By measuring thousands of particles the average velocity and the turbulent intensity of the flow can be calculated at a single point.

The SCITEK LDA is a two component Dantec Dynamics system making use of an Argon-ion laser producing two wavelengths (Green and Blue) to measure each component. The processor is a modern FFT processor capable of measuring 100,000 particles per second for each component. The system is capable of measuring flow velocities from near zero to supersonic speeds, so it is well suited to the current project.

Figure 6 **Schematic diagram of a Laser Doppler Anemometry System**



The large port on the side of the tubing will also be used to collect samples of the gas for analysis in a small mass spectrometer. A mass spectrometer takes a sample of gas, ionises the molecules contained within it and then separates them into groups of like ions by virtue of their molecular weight. The number of molecules in each group is a representation of the overall composition of the gas at the location the sample was taken.

A study of the function and type of mass spectrometers available for this application was completed by Bruce Ewen (Chementech) as part of work package 3. The investigation recommended two suitable mass spectrometers, the Proline from Ametek Process Instruments and the GAM300 from InProcess Instruments. The Proline, detailed here as it is the cheaper and smaller alternative ($125000US for ATEX), measures masses from 1 to 300 amu, with a detection range of 1ppm to 100% and accuracy better than 0.5% of the measured range. The mass spectrometer was not listed in the original specifications document, however if used it will provide detailed information about the composition of the exhaust gases both before and after mixing with the introduced gases.

For further information on the instrumentation required for the pipe section of the rig refer to table 3.4.

Section	Sub-Section	Measurement	Instrument	Type	Range	Signal	Quantity
Engine	Intake	Air mass flow rate	Absolute pressure transducer	Druck PTX1400 (or equivalent)	0.8 to 1.2 bar	4 - 20 mA	1
		Air mass flow rate	Gauge pressure transducer	Druck PTX1400 (or equivalent)	0.5 bar max.	4 - 20 mA	1
		Air mass flow rate	PT 100 thermometer	Omega RTD 805/6 (or equivalent)	230 °C max.	Conditioned	1
		Air mass flow rate	Five hole probe	Unknown 2/7/12	Unknown	Unknown	1
	Engine	Engine RPM	Frequency generator	Unknown	Unknown	Unknown	1
		Fuel flow rate	Turbine flow meter	Unknown 2/7/12 – Possibly Viper	Unknown	Unknown	1
		Fuel pressure	Gauge pressure transducer	Druck PTX1400 (or equivalent)	50 bar max.	4 - 20 mA	1
		Compressor pressure	Gauge pressure transducer	Druck PTX1400 (or equivalent)	10 bar max.	4 - 20 mA	1
		Oil pressure	Gauge pressure transducer	Druck PTX1400 (or equivalent)	10 bar max.	4 - 20 mA	1
	Diffuser	Exhaust temperature	K-Type Thermocouple	K-Type sheathed 3 mm	1100 °C max.	Conditioned	3

Table 3.1 – Engine instrumentation list for the proposed circular duct test rig.

Section	Sub-Section	Measurement	Instrument	Type	Range	Signal	Quantity
Butane fuel delivery	Fuel lines	Boost pump status	On/Off	On/Off	-	Unknown	1
		Engine pump RPM	Inverter	Hydra-Cell 3 phase inverter	Unknown	4-20 mA	1

system		Valve On/Off	Remotely actuated valve	ATEX ball valve with positioning	Unknown	Unknown	4
		Fuel pressure	Gauge pressure transducer	Druck PTX1400 (or equivalent)	20 bar max.	4 - 20 mA	1
	Storage tank	Fuel level	Level sensor	Unknown 2/7/12	Unknown	Unknown	1

Table 3.2 – Butane fuel system instrumentation list for the proposed circular duct test rig.

Section	Sub-Section	Measurement	Instrument	Type	Range	Signal	Quantity
Gas delivery system	Gas flow	H mass flow rate	Mass flow controller	Make unknown	0.19 kg/s max.	Unknown	1
		CO mass flow rate	Mass flow controller	Make unknown	1.57 kg/s max.	Unknown	1
		O_2 mass flow rate	Mass flow controller	Make unknown	1.12 kg/s max.	Unknown	1
		CH_4 mass flow rate	Mass flow controller	Make unknown	1.57 kg/s max.	Unknown	1
		Gas line temperature	PT100 thermometer	Omega PT100	230 °C max.	Conditioned	5

Table 3.3 – Gas delivery system instrumentation list for the proposed circular duct test rig.

Section	Sub-Section	Measurement	Instrument	Type	Range	Signal	Quantity
Pipe	Gas	Flame detection	Ionisation probe	Unknown – Imperial to Advise	Unknown	Unknown	Unknown
		Gas composition	Mass spectrometer	Proline – Ametek Process Inst.	1ppm to 100%	Unknown	1

	Flow	Turbulence	LDA System	Dantec 2D	10^6 particles/s	N/A	1
		Free stream velocity	Pressure rake	Array of 8 pressure transducers	10 bar max.	4 - 20 mA	1
	Temperature	Boundary layer T	Thermocouple	K-Type sheathed 3 mm	1100 °C max.	Conditioned	8
		Free stream T	Thermocouple rake	Array of 8 K-Type thermocouples	750 °C max.	Conditioned	1
	Pressure	Dynamic and static	Water cooled transducer	Kulite WCTV-312	70 bar max.	4 - 20 mA	8

Table 3.4 – Pipe section instrumentation list for the proposed circular duct test rig.

3.5 Rig location and Enclosure

3.5.1 Description

The test rig will be situated near the 50 metre pad at the Turncliff Farm site and will be sited on an existing concrete pad whose dimensions are 30m x 3.2m x 0.375m

- Pendyne blocks
- Enclosure details – clad temporary structure
-

3.5.2 Assumptions

3.5.3 Calculations

3.5.4 Implementation/ design

3.6 Site Services

- Water – for pressure transducers -
- Electrical
- Compressed air

3.6.1 Description

3.6.2 Assumptions

3.6.3 Calculations

3.6.4 Implementation/ design

4 HAZID

Description and outcome from HAZID study will be included here

5 Environmental Impact

A description of the environmental impact assessment will be documented here

6 Codes and Standards

References to relevant codes and standards will be inserted here

7 Figures

Figure 7 Location of proposed test site at HSL, Buxton relative to main buildings and with exclusion zones marked

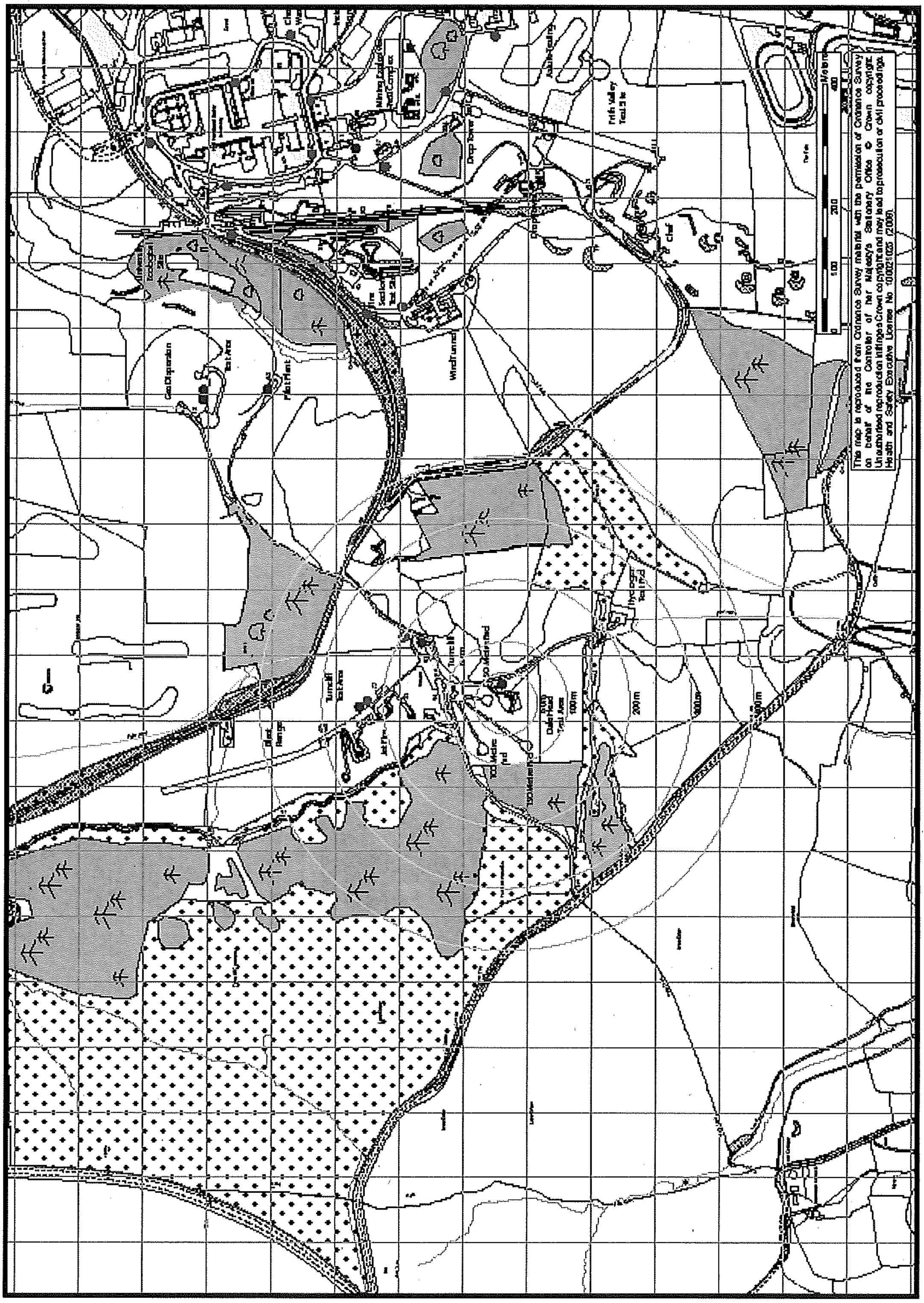


Figure 8 Proposed test site

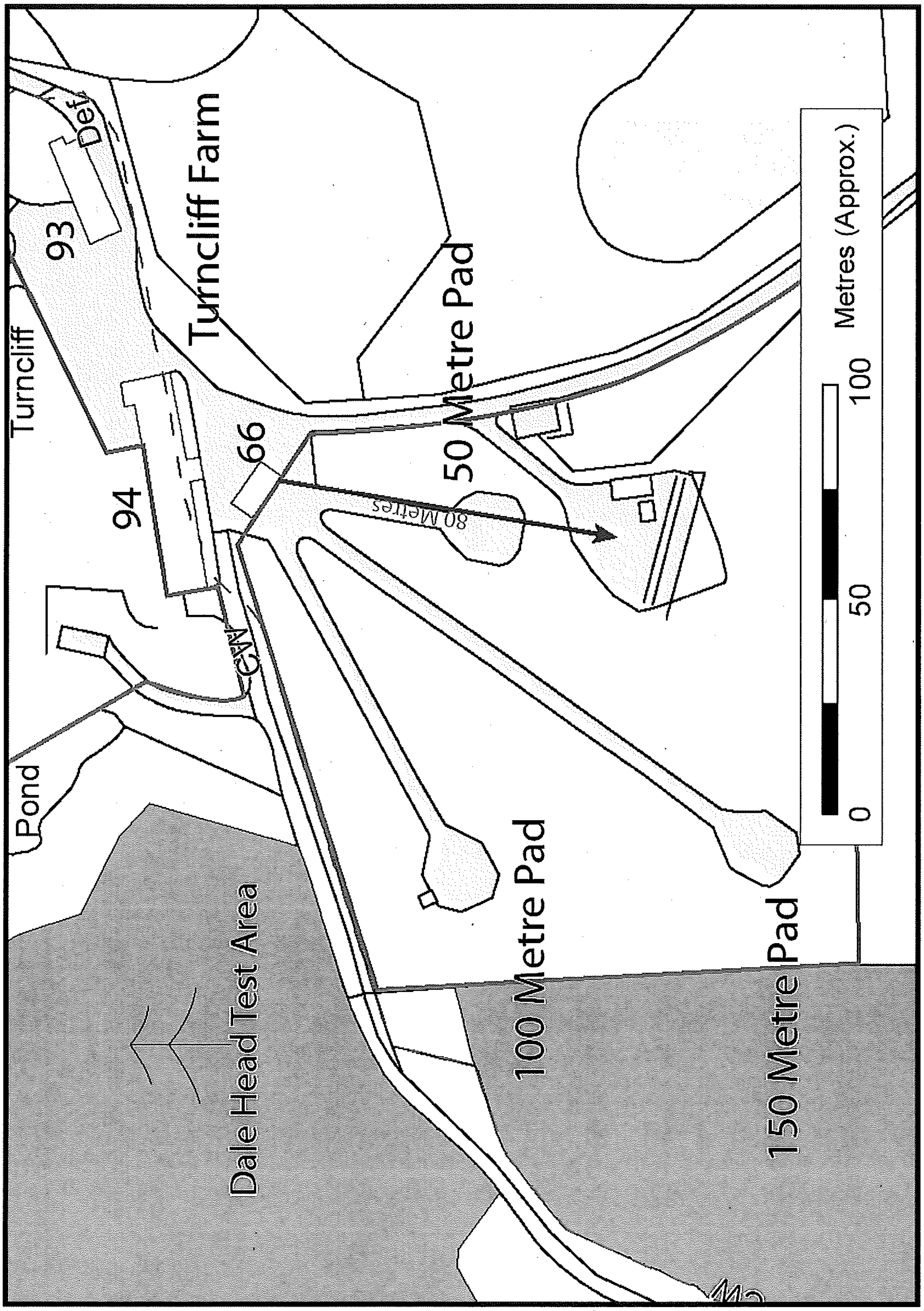
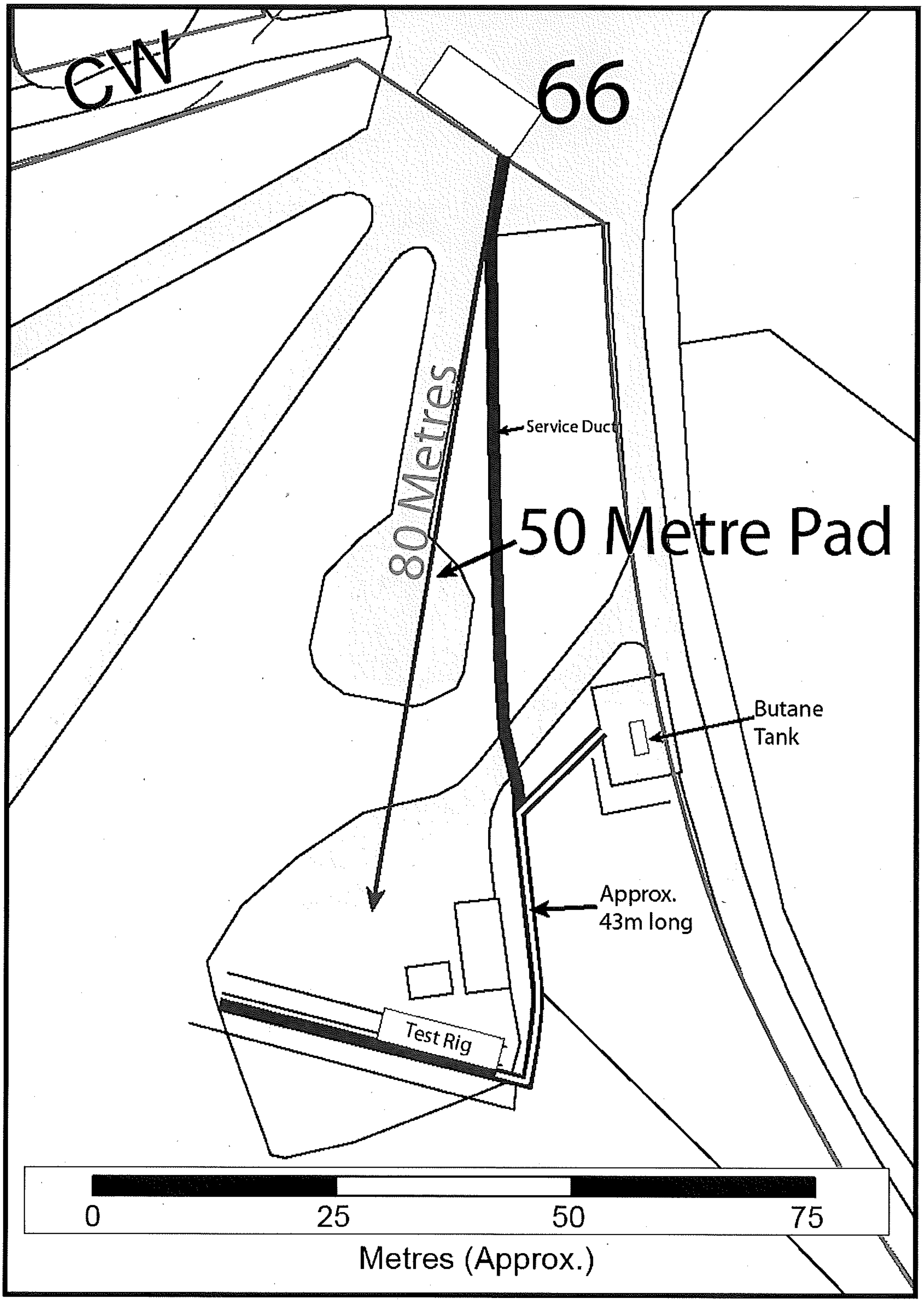
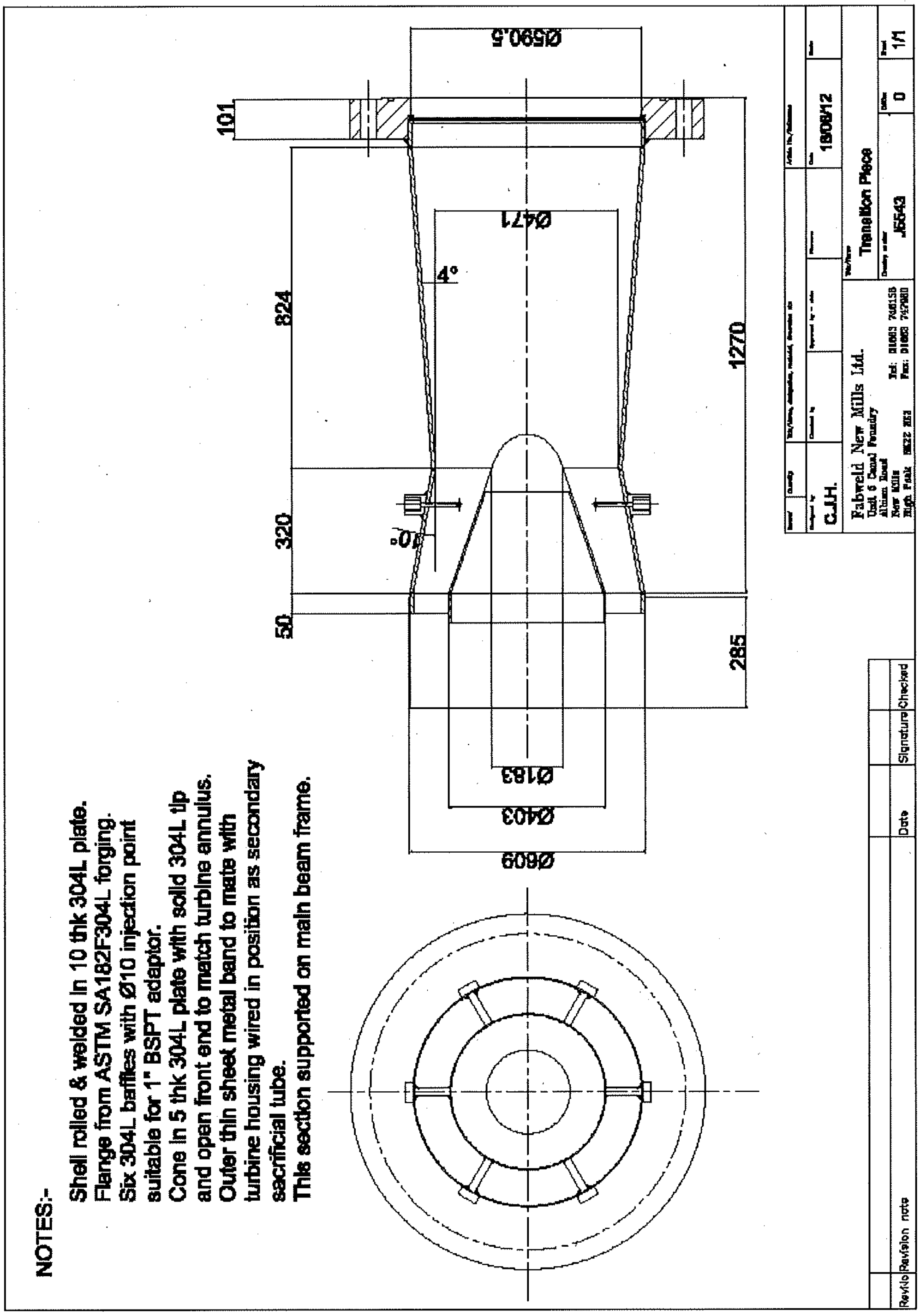
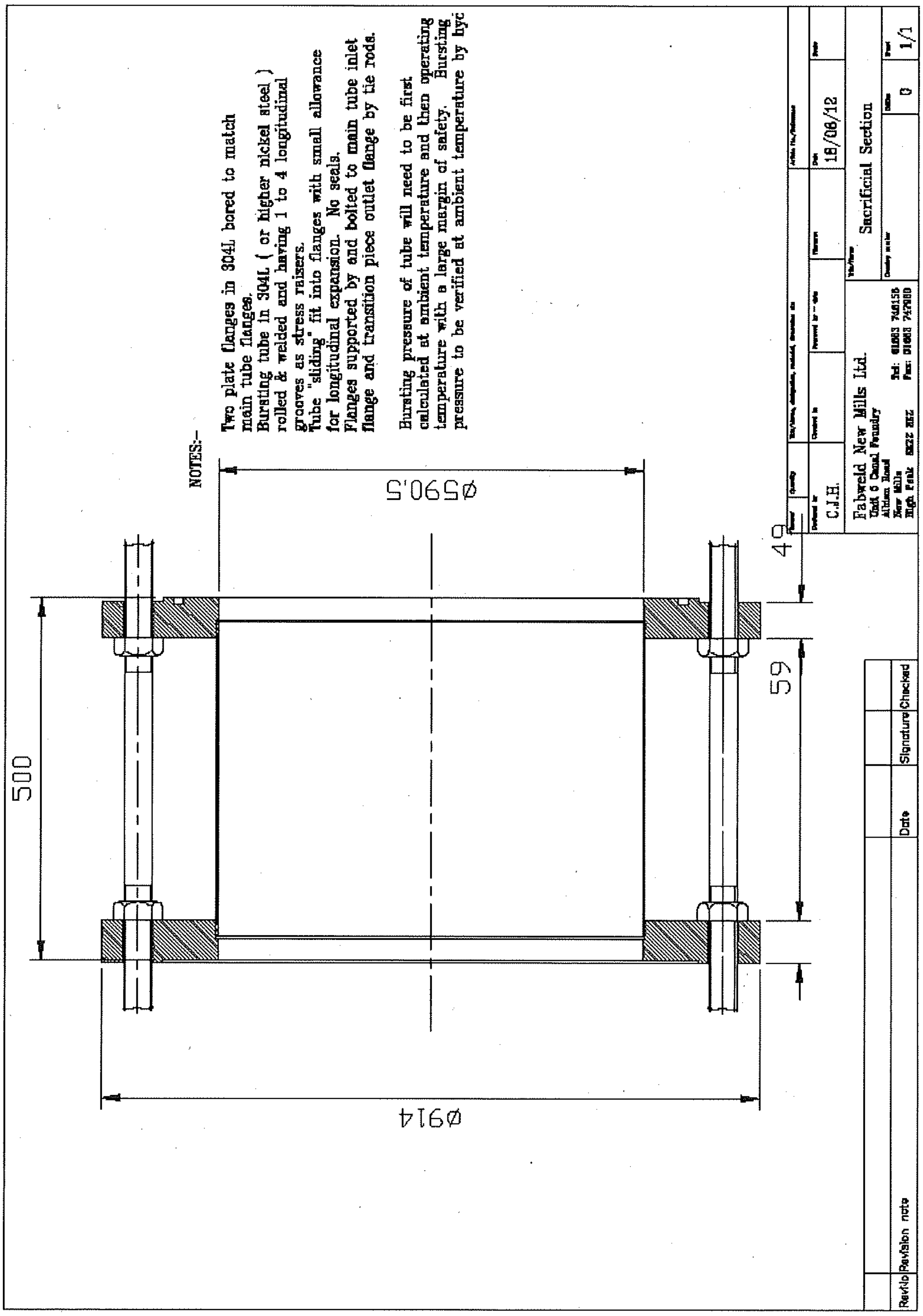


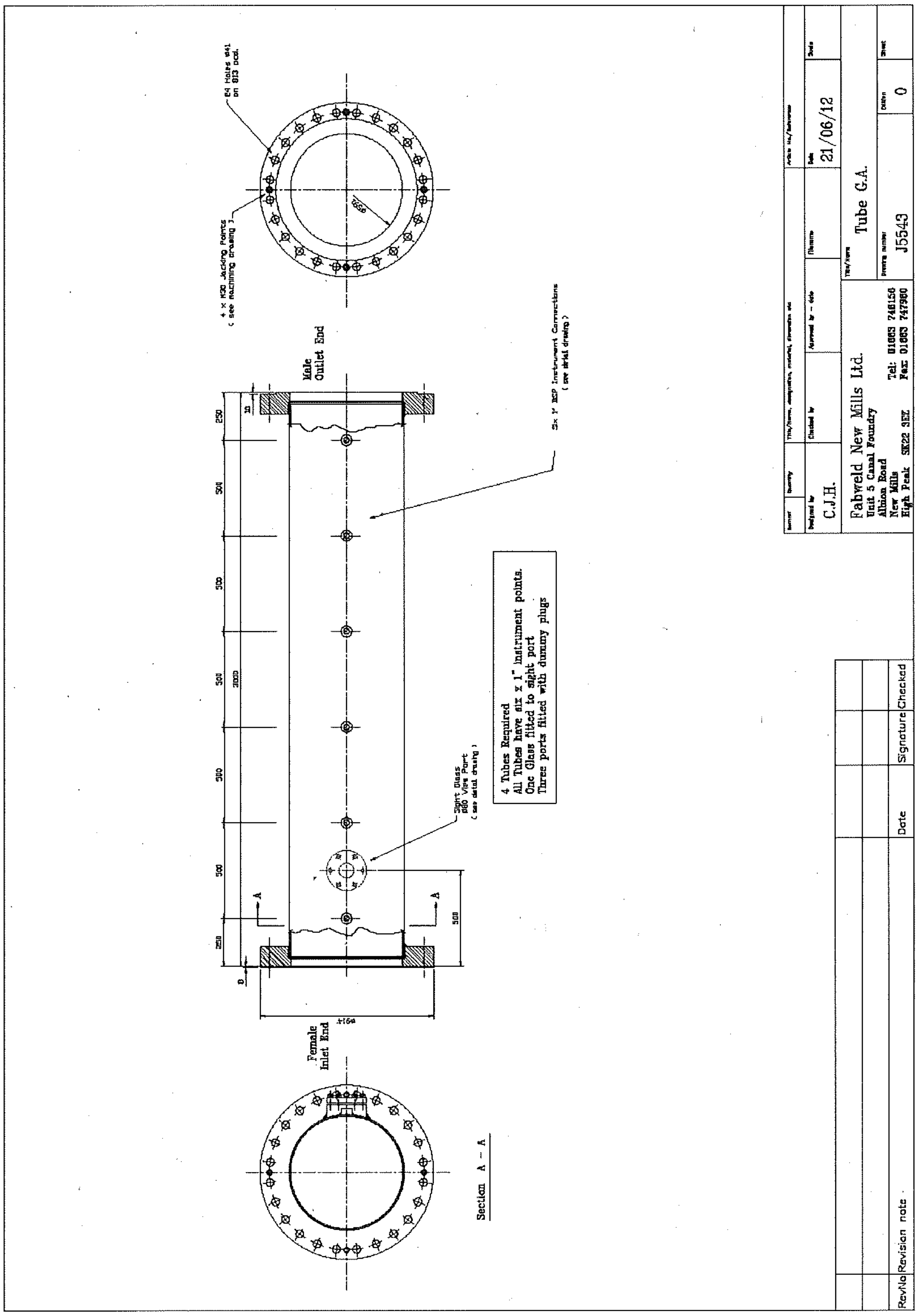
Figure 9 **Plan of proposed test rig site showing location of butane tank and service trenches**



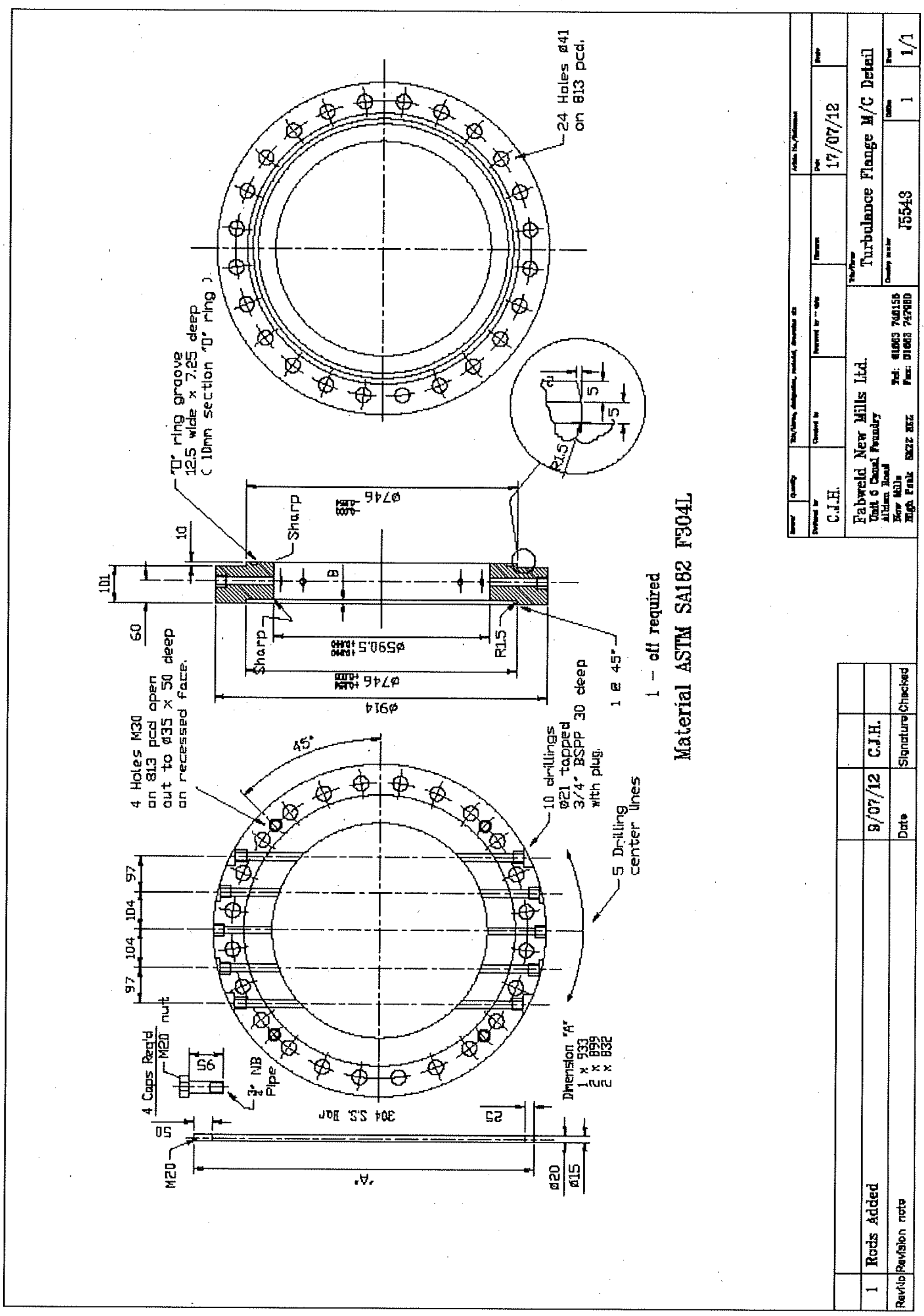
8 Drawings

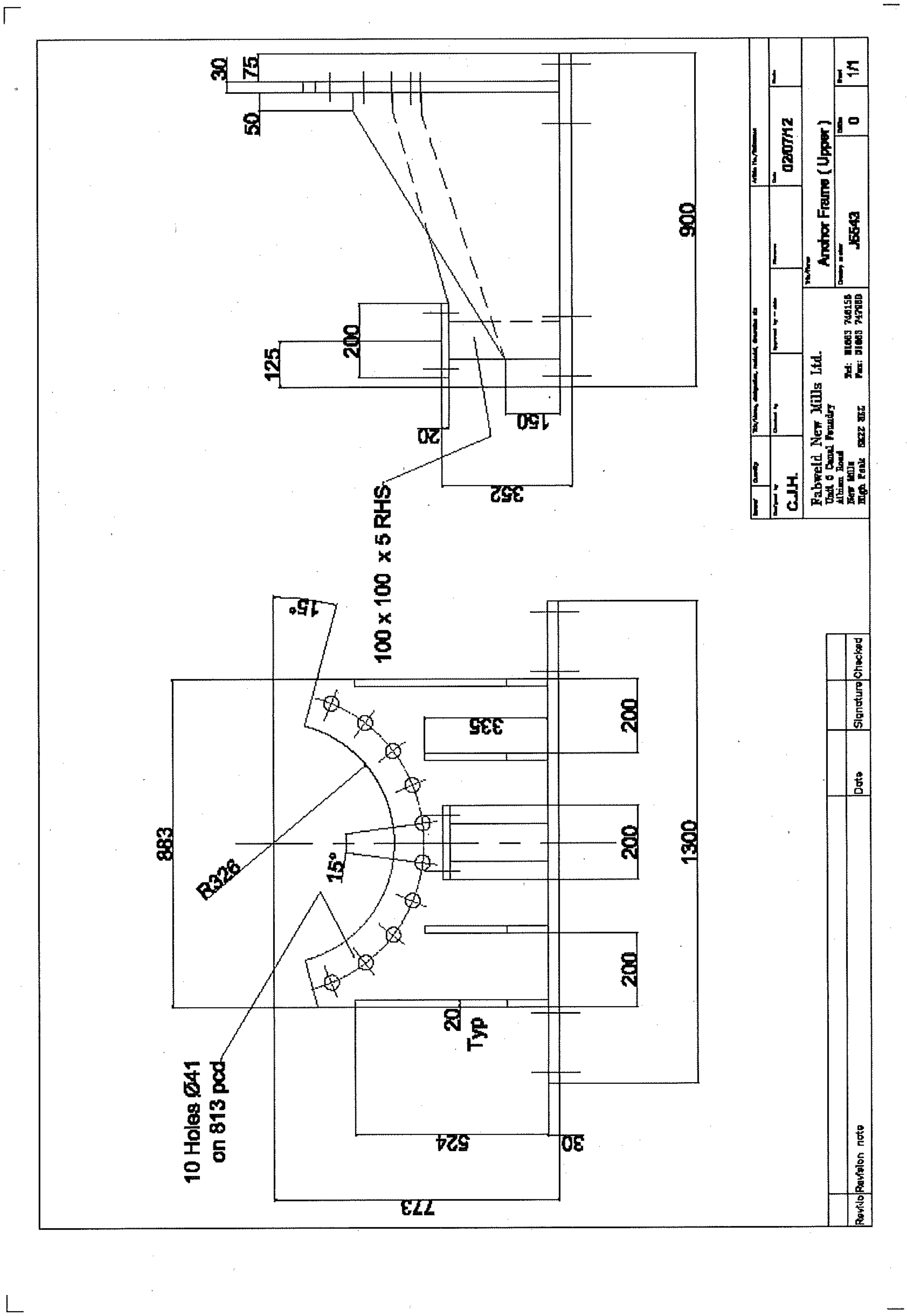

NOTES:-
Shell rolled & welded in 10 thk 304L plate.
Flange from ASTM SA182F304L forging.
Six 304L baffles with Ø10 injection point suitable for 1" BSPT adaptor.
Cone in 5 thk 304L plate with solid 304L tip and open front end to match turbine annulus.
Outer thin sheet metal band to mate with turbine housing wired in position as secondary sacrificial tube.
This section supported on main beam frame.
Ø590.5
Ø471
Ø183
Ø403
Ø609
101
824
320
50
1270
285
4°
10°
C.J.H.
18/06/12
Fabweld New Mills Ltd.
Transition Piece
J5543
0
1/1
Rev'n
Revision note
Date
Signature
Checked

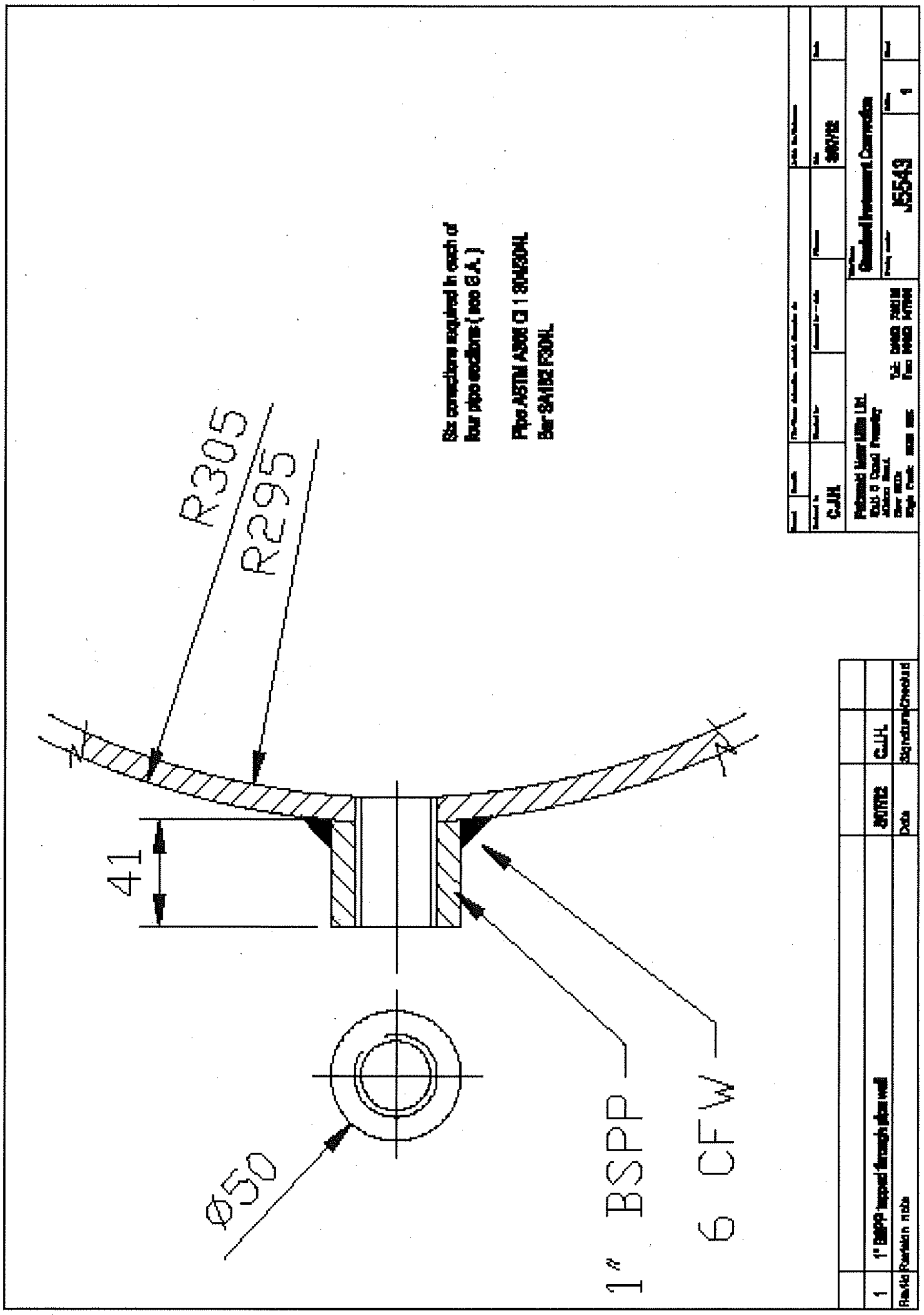

500
Ø914
Ø590,5
59
49
NOTES:-
Two plate flanges in 304L bored to match main tube flanges.
Bursting tube in 304L (or higher nickel steel) rolled & welded and having 1 to 4 longitudinal grooves as stress raisers.
Tube "sliding" fit into flanges with small allowance for longitudinal expansion. No seals.
Flanges supported by and bolted to main tube inlet flange and transition piece outlet flange by tie rods.
Bursting pressure of tube will need to be first calculated at ambient temperature and then operating temperature with a large margin of safety. Bursting pressure to be verified at ambient temperature by hyd
C.J.H.
18/06/12
Fabweld New Mills Ltd.
Unit 6 Canal Foundry
Albion Road
New Mills
High Peak SK22 3EZ
Tel: 01663 746155
Fax: 01663 747980
Sacrificial Section
0
1/1
RevNo
Revision note
Date
Signature
Checked

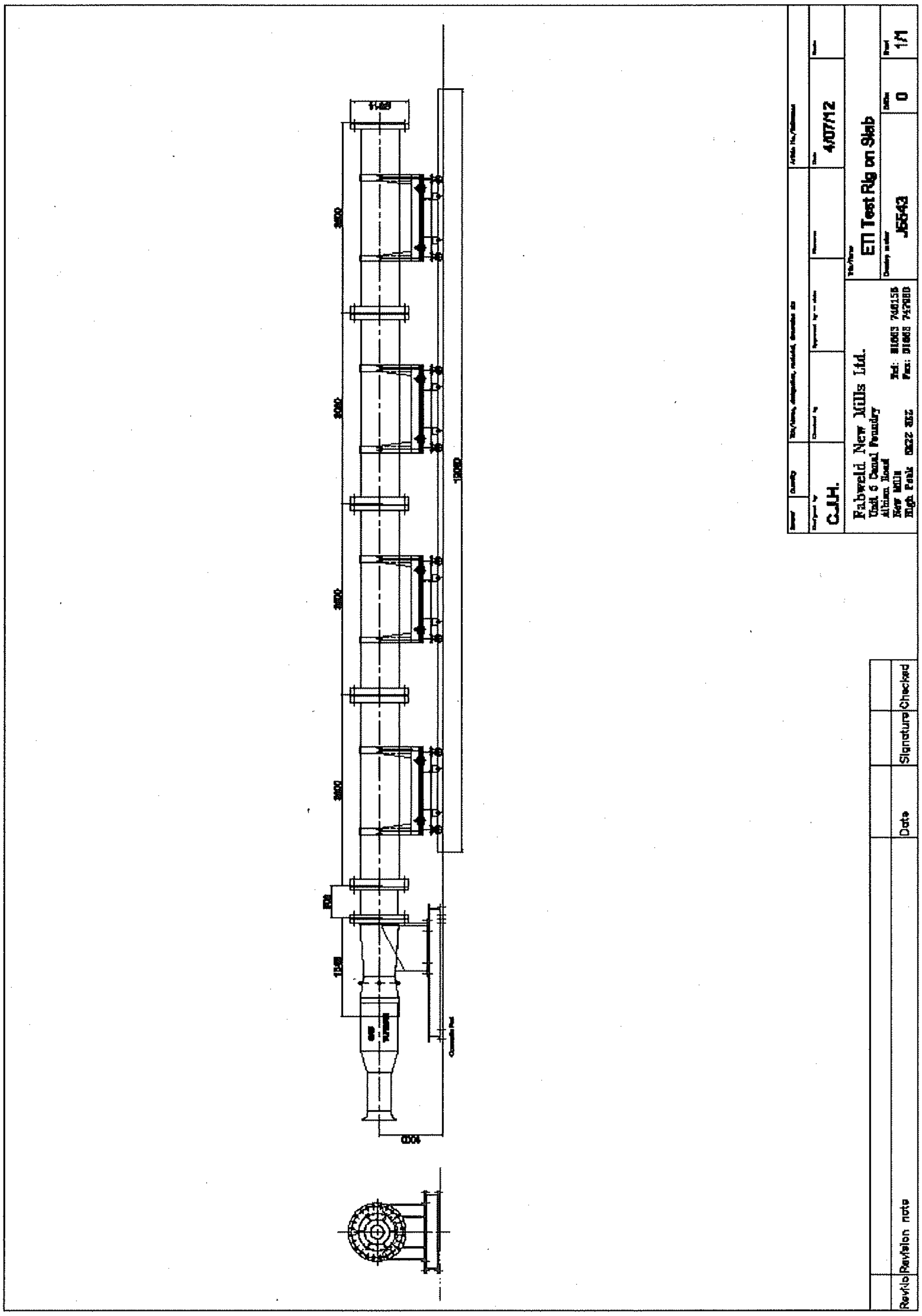


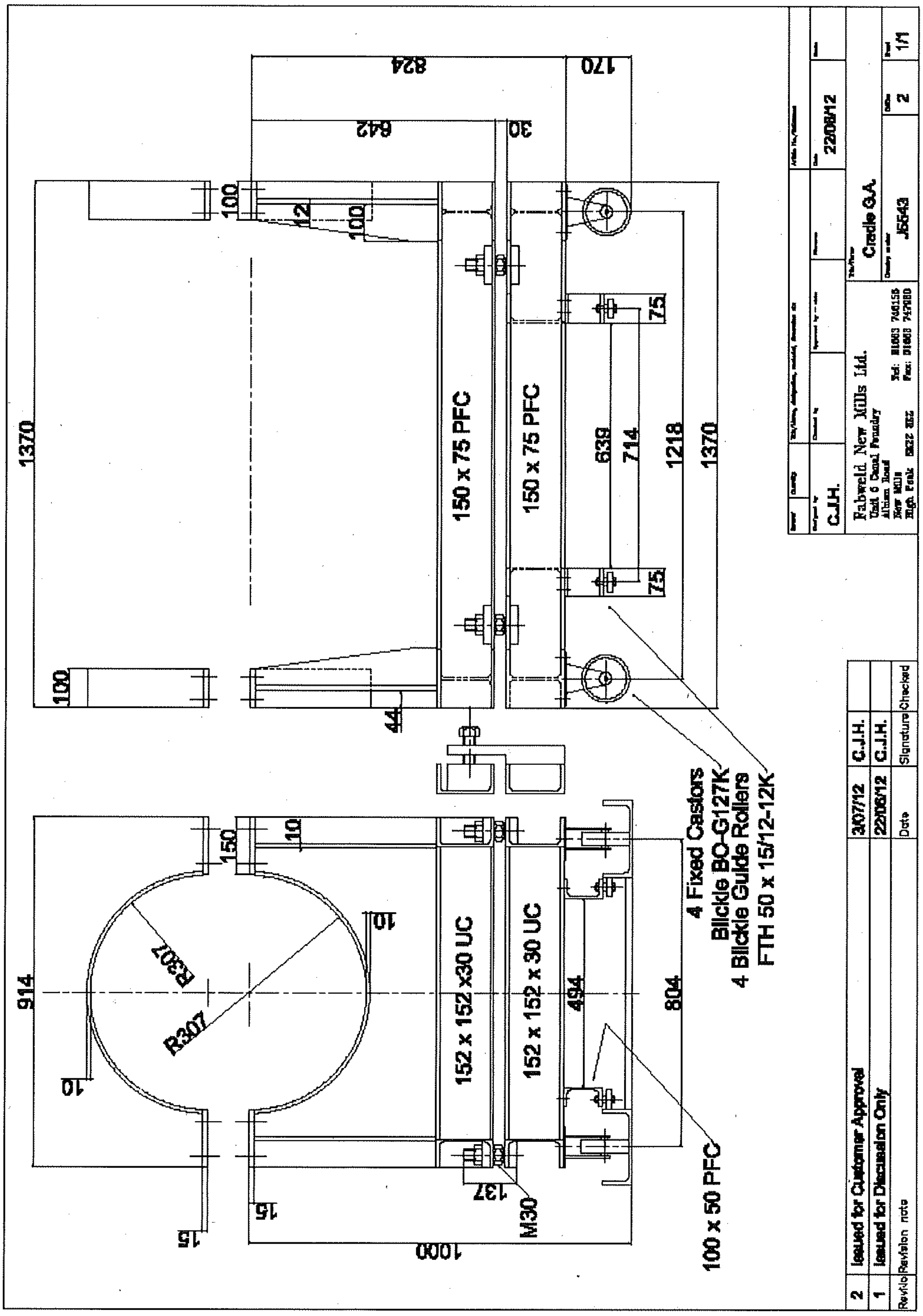
Male
Outlet End
Female
Inlet End
Section A - A
4 Tubes Required
All Tubes have six x 1" instrument points.
One Glass fitted to sight port
Three ports fitted with dummy plugs
C.J.H.
21/06/12
Fabweld New Mills Ltd.
Unit 5 Canal Foundry
Albion Road
New Mills
High Peak SK22 3EZ
Tel: 01663 746156
Fax: 01663 747960
Tube G.A.
J5543
0
RevNo
Revision note
Date
Signature
Checked


24 Holes ø41 on 813 pcd.
"O" ring groove 12.5 wide x 7.25 deep (10mm section "O" ring)
4 Holes M30 on 813 pcd open out to ø35 x 50 deep on recessed face.
10 drillings ø21 tapped 3/4" BSPP 30 deep with plug.
5 Drilling center lines
304 S.S. Bar
1 - off required
Material ASTM SA182 F304L
Fabweld New Mills Ltd.
C.J.H.
17/07/12
Turbulance Flange M/C Detail
J5543
1/1
1
Rods Added
9/07/12
C.J.H.
Rev.No
Revision note
Date
Signature
Checked


10 Holes Ø41
on 813 pcd
100 x 100 x 5 RHS
R326
15°
15°
883
773
524
30
1300
200
200
200
335
20
Typ
900
352
150
20
125
200
50
30
75
Fabweld New Mills Ltd.
C.J.H.
02/07/12
Anchor Frame (Upper)
J5543
0
1/1
Rev/No
Revision note
Date
Signature
Checked


R305
R295
41
Ø50
1" BSPP
6 CFW


C.J.H.
4/07/12
Fabweld New Mills Ltd.
Unit 6 Canal Foundry
Albion Road
New Mills
High Peak SK22 3EZ
ETI Test Rig on Slab
J5543
0
1/1
Rev'n
Revision note
Date
Signature
Checked

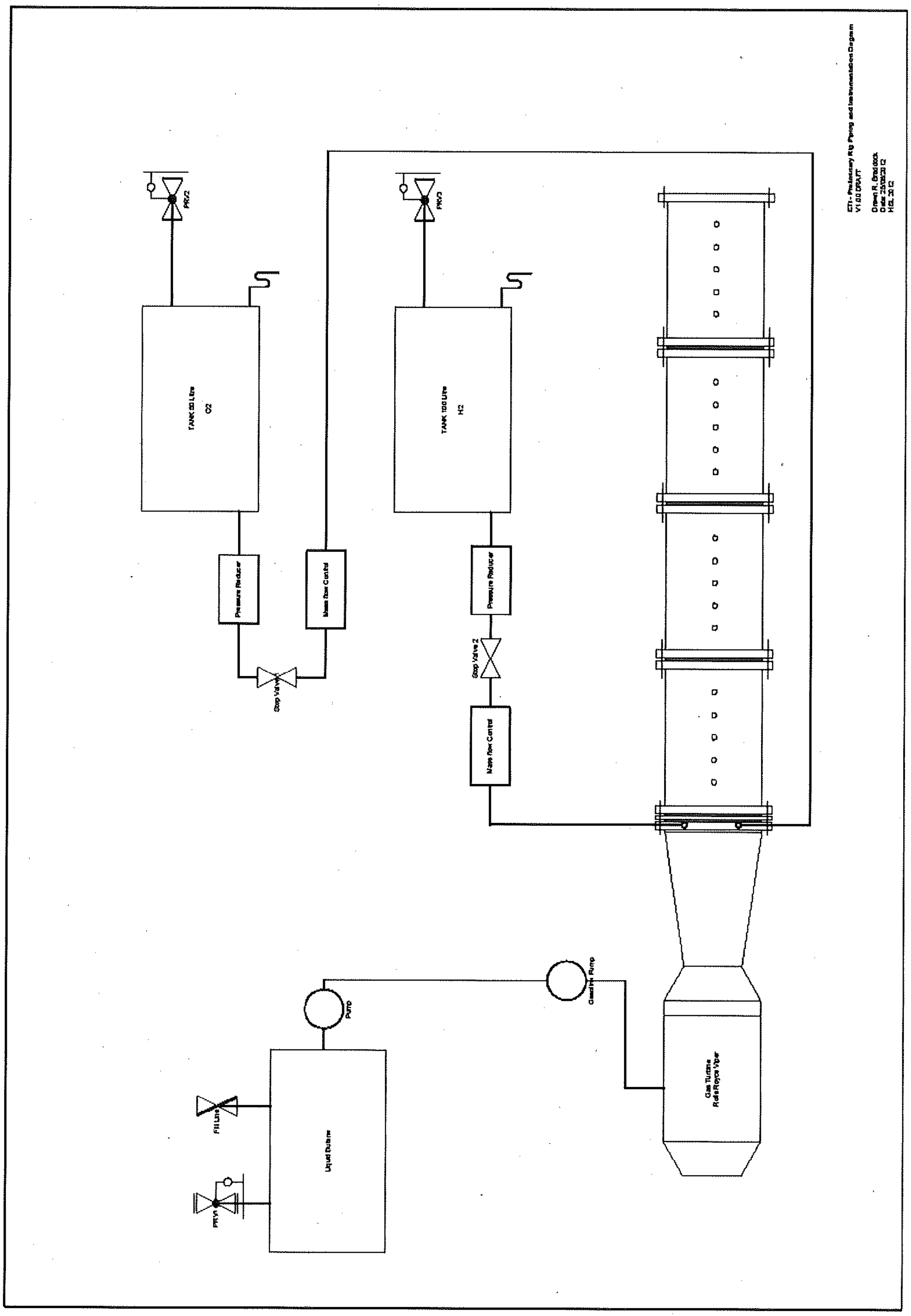

150 x 75 PFC
150 x 75 PFC
152 x 152 x30 UC
152 x 152 x 30 UC
R307
R307
M30
100 x 50 PFC
4 Fixed Castors
Blickle BO-G127K
4 Blickle Guide Rollers
FTH 50 x 15/12-12K
1370
914
1000
824
642
170
1218
714
639
804
494
2 Issued for Customer Approval 3/07/12 C.J.H.
1 Issued for Discussion Only 22/06/12 C.J.H.
Rev No Revision note Date Signature Checked
C.J.H.
22/08/12
Fabweld New Mills Ltd.
Cradle G.A.
J5543
2
1/1

9 P&ID

P&ID for engine including control and instrumentation will be included here

P&ID for experimental instrumentation: pressure transducers, thermocouples and ionisation probes, will be included here

Figure 10 Draft P&ID of test rig



PTX/PMP 1400

Industrial Pressure Sensors

Druck

STANDARD SPECIFICATIONS

Operating Pressure Ranges
0 to 100, 250, 400, 600mbar,1, 1.6, 2.5, 4, 6, 10, 16, 25, 40, 60 bar gauge and absolute.
0 to 100, 160, 250, 400, 600 bar sealed gauge and absolute.
Barometric (PTX 1400 only) 800 to 1200mbar abs.

-1 to 1.6 bar gauge (compound)
-1 to 2.5 bar gauge (compound)
-1 to 4 bar gauge (compound)

Overpressure
The rated pressure range can be exceeded by the following without degrading performance:
1 bar for 100 and 250mbar ranges
2 bar for 400 and 600mbar ranges
2 x (180 bar max) for ranges 1 bar to 100 bar
2 x (500 bar max) for ranges 160 to 600 bar.

Pressure Media
Fluids compatible with a fully welded assembly of 316 stainless steel and Hastelloy C276.

Supply Voltage
PMP 1400: 9 to 30V d.c.
PTX 1400: 9 to 28V d.c. Min supply voltage that must appear across transmitter terminals is 9V and is given by Vmin= Vs - (0.02 x RL) where Vs = supply volts, RL = total loop ohms

Output Voltage
PMP 1400: 0 to 5V (3 wire pedestal configuration) (calibrated between 5-100% FS)
PTX 1400: 4-20mA (2 wire configuration)

Load Impedance (PMP version)
Greater than 100k ohms for quoted performance.

Zero Offset and Span Setting
Factory set to 0.5%, then 5% site adjustable by sealed, non-interacting potentiometers.

Long Term Stability
0.25% FS range per annum typical.

Accuracy
Combined Non-linearity, Hysteresis and Repeatability: 0.15% typical, 0.25% maximum Best Straight Line Definition.

Operating Temperature Range
-20° to 80°C.

Temperature Effects
Total Error Band 1.5% typical, 2% maximum, -20° to 80°C. For ranges below 400mbar values increase pro-rata with calibrated span.

Weight
200 grams nominal

Pressure Connection
G¼ female.

Electrical Connection
DIN 43650 plug supplied with mating socket.

Ingress Protection
Sealed to IP65

Voltage Spike Protection
Units will withstand 600V spike test to ENV 50142 without damage, applied between excitation lines and case.

Safety

EMC emissions	EN50081-1
EMC immunity	EN50082-1
Certification	CE marked

PED compliant CE Category 1 Pressure Accessory to Pressure Equipment Directive (PED) 97/23/EC. Note: 'Operating Pressure Range' is equivalent to maximum working pressure (Ps) as referred to in the PED.

PTX 1400 supplied Intrinsically Safe certified as standard, for use with barrier systems to Ex 97D 2059 EEx ia IIC T4 amb 80°C.

OPTIONS

(B) Screw-in male/male adaptors with bonded seal
G 1/4 male (P/N 190-040)
1/4 NPT male (P/N 190-038)
7/16 UNF male to MS 33656 (P/N 190-042)
M14 x 1.5 male (P/N 190-035)
G 1/2 (pressure gauge) (P/N 190-039)
All adaptors 316 stainless steel construction.
(C) Vented 6 core cable (5.7mm) (P/N 192-004)
Specify required length on order.
(D) Pressure snubber adaptor (DA0839-1-02)
Screw in adaptor providing a G 1/4 female thread. Protects against unwanted fast transient pressure spikes. Refer to Snubber Product Note for further detail.

ORDERING INFORMATION

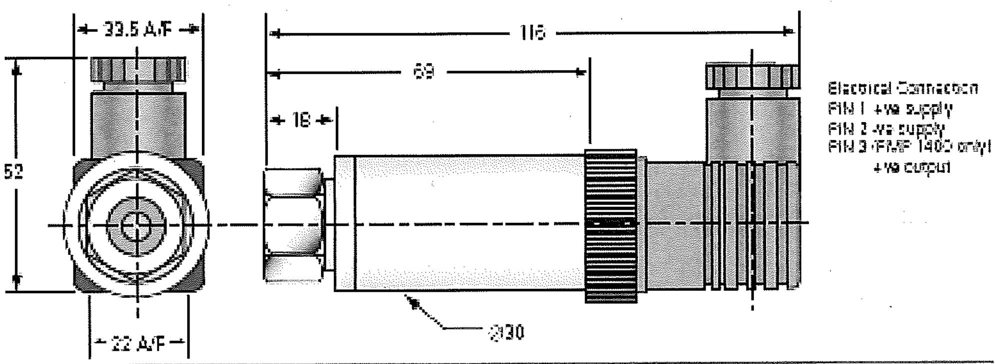
Please state the following:
(1) Type number PTX 1400 or PMP 1400
(2) Operating pressure range
(3) Gauge or absolute
(4) Options - As above. Order as separate line items (supplied unfitted).

RELATED PRODUCTS

Druck manufactures a comprehensive range of pressure sensors, indicators, controllers and calibrators. Product datasheets available.

Continuing development sometimes necessitates specification changes without notice.

INSTALLATION DRAWINGS - Dimensions in mm



Agent:

michael smith engineers limited

Head Office: Oaks Road Woking Surrey GU21 6PH Telephone: 01483 771871 Facsimile: 01483 723110
Web Site : www.michael-smith-engineers.co.uk

HYDRA-CELL DIAPHRAGM PUMP QUOTATION REF: HYP/AD5488/R3

Attention:	Mr Anthony Haynes	Date:	29th June 2012
	Reaction Engines Ltd	Tel:	01865 408 314 ext 369
	Building D5, Culham Science Centre,,	Fax:	01865 408 301
	Abingdon,Oxon	Email:	Anthony.Haynes@reactionengines.co.uk
	OX14 3DB	Enquiry ref:	

Application: Liquid Butane- engine feed pump.

Liquid	Butane	**Vapour pressure**	Assumed < suction pressure
Concentration		**Suction pressure**	4 Bar / Flooded
Temperature	Ambient	**Discharge pressure**	50 Barg
Density	0.6 g/cm³	**Capacity**	2.5 m³/hr
Solid Size	N/A	**NPSHA**	Assumed >NPSHR
Percentage solids	N/A	**Viscosity**	0.1 cP

We Offer:- ATEX rated equipment supply.

Qty	Description	Price Each
One	Hydra-Cell sealless diaphragm pump model G25SMCTHFECA mounted on a baseplate and direct coupled to 6 pole, 7.5 kW, 400 volt, three phase, 10-50 hertz, TEFC inverter rated motor with thermistors. The pump will give the required flow at the duty conditions stated at 629 rpm. At full motor speed, the pump is expected to achieve a flow of 50 l/min. NPSHR 5.5 metres	£5,931.00
	Optional Items:-	
One	Hydra Cell Oil level bowl complete with dual high and low level switches.	£546.00
One	Hydra Cell 16 oz oil level bowl sight glass part number A01-116-3400	£104.00
One	AC inverter control panel constructed in IP54 painted steel enclosure suitable for wall mounting for location in a none hazardous area. Enclosure supplied with door interlocked isolator, Lenze SMV31, 7.5kW 400 volt, three phase, 50 hertz, flux vector controlled AC inverter supplied in IP31 chassis style enclosure with integral mains filter and membrane key control pad. Unit is suitable for manual speed control or speed control from a 4 to 20 mA or 0 to 10 volt DC signal. The AC inverter control panel incorporates the following features:- Mains power, running and fault indicators. Remote / Off / Local pump run selector switch. Manual stop / start, fault reset push buttons. Local / Remote speed reference selector switch with manual speed potentiometer. Thermistor relay and control interlocks with the inverter running and fault signals. Twin dual channel intrinsically safe barrier relays interlocked with the inverter running and fault signals.	£2,713.00
One	Lenze SMV31 chassis mount 7.5kW 400 volt, three phase, IP31 AC inverter speed controller with integral filter, membrane key pad and remote panel mounted membrane key pad.	£730.00
One	Packing and carriage delivered UK mainland	Included

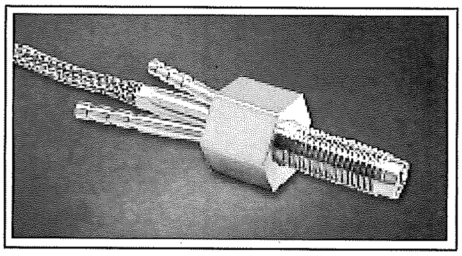
Hydra-Cell Diaphragm Pump - Woking

kulite®

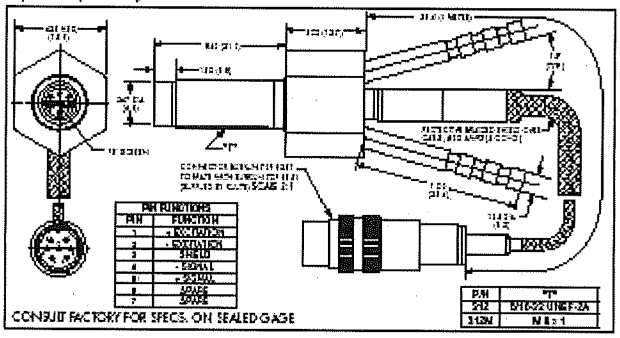
WATER/AIR COOLED IS® TRANSDUCER

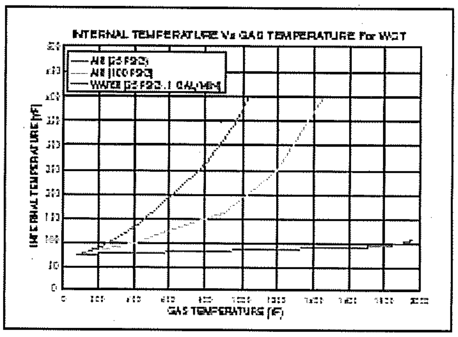
WCTV-312 (M)

- High Signal to Noise Ratio
- Patented Leadless Technology VIS®
- No Charge Amp Required
  No Special Cable Required
- Superior Thermal Protection
- Both Dynamic and Static Pressure Capabilities
- Extreme Temperature Capabilities Such As Required In Exhaust Systems



Kulite introduces a new small and compact Water Cooled Pressure Transducer for both dynamic and static pressure measurements in extreme temperature environments such as automotive and turbine exhaust systems. The WCTV-312 combines Kulite's patented Low Cost Leadless Silicon Technology and a Miniature Water Cooled Jacket to provide pressure measurement capabilities previously unavailable.





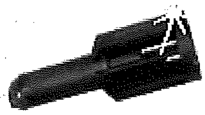
INPUT Pressure Range	1.7 25	7 100	17 250	35 500	70 BAR 1000 PSI
Operational Mode	Absolute, Sealed Gage				
Over Pressure	2 Times Rated Pressure				
Burst Pressure	3 Times Rated Pressure				
Pressure Media	Compatible With Exhaust Gases and Fluids and Any Media Compatible With SiO_2 and 15-5 PH Stainless Steel				
Rated Electrical Excitation	10 VDC/AC				
Maximum Electrical Excitation	15 VDC/AC				
Input Impedance	1000 Ohms (Min.)				
OUTPUT Output Impedance	1000 Ohms (Nom.)				
Full Scale Output (FSO)	100 mV (Nom.)				
Residual Unbalance	± 25 mV (Max.)				
Combined Non-Linearity, Hysteresis and Repeatability	± 0.1% FSO BFSL (Typ.), ± 0.5% FSO (Max.)				
Resolution	Infinitesimal				
Natural Frequency (KHz) (Typ.)	240	380	550	700	1000
Insulation Resistance	100 Megohm Min. @ 50 VDC				
ENVIRONMENTAL Water Flow Rate	.15 Gal/Min (Typ.)				
Operating Temperature Range	75°F to 2000°F (24°C to 1093°C)				
Steady Acceleration	10,000g. (Max.)				
Linear Vibration	10-2,000 Hz Sine, 100g. (Max.)				
PHYSICAL Electrical Connection	4 Conductor 32 AWG Teflon Shielded Cable 36" Long				
Weight	50 Grams (Approx.) Excluding Cable				
Pressure Sensing Principle	Fully Active Four Arm Wheatstone Bridge Dielectrically Isolated Silicon on Silicon Patented Leadless Technology				
Mounting Torque	80-120 Inch-Pounds (Max.)				

Note: Custom pressure ranges, accuracies and mechanical configurations available. Dimensions are in inches. Dimensions in parenthesis are in millimeters. Continuous development and refinement of our products may result in specification changes without notice - all dimensions nominal. (S)

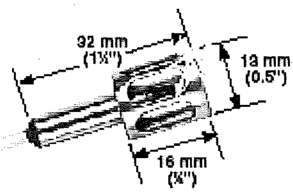
KULITE SEMICONDUCTOR PRODUCTS, INC. • One Willow Tree Road • Leonia, New Jersey 07605 • Tel: 201 461-0900 • Fax: 201 461-0990 • http://www.kulite.com

Air Temperature RTD Sensors

- For Monitoring of Air and Gas Streams; Mounts in Any Orientation
- Exposed Sensing Element Has Fast Response Times in Air
- Available with Stainless Steel or Plastic Housings
- High-Accuracy, 100 Ω, Class "A" DIN Platinum Element
- 3-Wire Construction for Connecting to Most Instruments
- Perfect for Air Temperature Monitoring and Control in Laboratories and Laminar Flow Benches

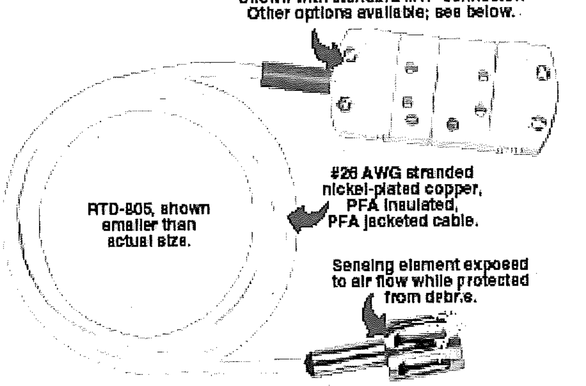


RTD-806 with plastic shield, shown actual size.



RTD-805 with stainless steel shield, shown actual size.

Shown with standard MTP connector. Other options available; see below.

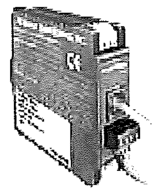


To Order *Visit omega.com/rtd-805_rtd-806 for Pricing and Details*			
Model Number	**Sensing Element**	**Cable**	**Max Temperature**
RTD-805	100 Ω Class "A" DIN	1 m (40") PFA insulated	230°C (450°F)
RTD-806	100 Ω Class "A" DIN	1 m (40") PFA insulated	230°C (450°F)

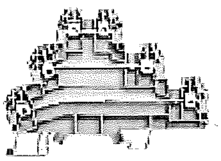
Terminations Available: Provided with a miniature connector standard. For heavy-duty connector add "-OTP" to model number for an additional cost. For audio connector add "-TA3F" to model number for an additional cost. For terminal lugs add "-LUG" to model number for an additional cost.

Ordering Examples: RTD-805-TA3F, 100 Ω class "A" SST housing with terminal lugs.

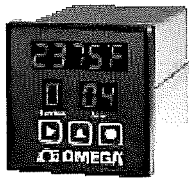
Popular Options Include:



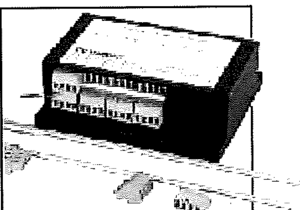
IDRN-RTD digital signal conditioner, visit omega.com/idrn-idrx



PUK-2T-10PK DIN rail terminal block, 10 pack, see omega.com/terminal-blocks



CN606RTD3 6-zone ⅛ DIN temperature monitor.



OM-CP-OCTRTD 8-channel data logger, visit omega.com/om-cp-octrtd

How are OMEGA's Model Numbers Constructed?

Termination Options: (Blank) – Miniature Connector (Standard)
OTP – Heavy-Duty Connector LUG – Copper Lugs
TA3F – Audio Connector:

Class "B" also available in economical 3-packs.

RTD — 805 — TA3F
RTD — 806 — LUG

Ordering Example: RTD-805-TA3F, RTD-806-SPRTX(M1).

C-105

11 References

Benson, T., 2009, *Five Hole Probe – Flow Direction*, http://www.grc.nasa.gov/WWW/k-12/airplane/tunp5h.html [Accessed: 2/7/12], National Aeronautics and Space Administration, USA.

Fw: J5543 ETI Test Rig

John Gummer to Keith Moodie 10/07/2012 10:47

John Gummer
Project Manager Specialist
Major Hazards Unit
Health & Safety Laboratory, Harpur Hill, Buxton, Derbyshire, SK17 9JN
☎ +44 1298 21 8145
✉ john.gummer@hsl.gov.uk | www.hsl.gov.uk

----- Forwarded by John Gummer/STAFF/HSL on 10/07/2012 10:45 -----

From:	"Fabweld New Mills Ltd" <fabweldnewmills@tiscali.co.uk>
To:	<John.Gummer@hsl.gov.uk>
Date:	10/07/2012 10:39
Subject:	J5543 ETI Test Rig

Hi John !

Attached please find the following drawings:-

1) Test Rig On Slab G.A. (Method 2).
This design resulted from our discussions regarding the use of the "Tunnel" sections and our assessment of the advantages of using a new structural steel building over the test rig instead.
2) Tube G.A.
This is virtually complete as a manufacturing drawing, but will not get passed the notified body until we can add the welding details for all attachments. We also have calculations for the tubes & flanges.
3) Flange Machining Drawing.
This is a finalised drawing which will be used by the machinist to finish machine the forgings. The matching bore diameter needs to be confirmed when the pipes have been cut and measured so we need to cut the pipes before the forgings arrive.
4) Flange Welding Detail.
Finished drawing produced only for the main flange to pipe set up and weld preps.
5) Transition Piece.
Subject to dimensional changes at the inlet end when these become available from Scitek (Annulus diameters and method of mating to the gas turbine). Also Scitek have commented on the 10 degree to 4 degree junction and its effect on gas flow -- we are waiting to know if this needs modification or streamlining.
6) Turbulence Flange M/C Detail.
Subject to your approval, this is a finished machining drawing (bore diameter to be matched to tube flanges).
7) Sacrificial Section.
Concept drawing on hold for the time being awaiting assessment by Keith Moodie et al. We are also considering different types of sleeve for this and doing some calculations, but the final decision on which way to go must depend on your technical competence in this field.
8) Sacrificial Section Flange Machining.
On hold until the design is finalised. Also requires determination of the bore diameter.

9) Cradle G.A.
Subject to your approval, a virtually finished drawing.
10) Anchor Frame (Upper).
This will support the transition section and will sit on a sub-frame, yet to be drawn, which bolts to the concrete. This is the "fixed" point for the whole system and will be subject to calculation to resist a thrust load at the tube center line of 50 tonnes.
11) Standard Instrument Connection.
As requested by Scitek. Suitable for manufacture if approved.
12) Nameplate.
Mandatory on each of the tube sections subject to Nobo approval.

We trust that these drawings will assist you in visualising the system as a whole and that we have understood how you want it to operate. There will be more drawings to do, G.A.'s and detail, so the sooner we get overall approval and a purchase order the better. At the moment we are working with no authorisation whatsoever either technically or commercially and some duplication of work has already taken place. We are holding of on any further detail drawings and calculations until we van be sure that what we are doing is in accordance with your requirements.

Note that there are a number of areas where we could be starting to manufacture, or at least purchase materials and this would fit nicely into our present workshop schedule.

Best Regards,

Chris.

Fabweld New Mills Ltd
Unit 3 Canal Foundry
Albion Road
New Mills
High Peak
SK22 3EZ

Tel: 01663 746156 Fax: 01663 747960
Email: fabweldnewmills@tiscali.co.uk
Website: www.fabweld.co.uk

Contacts: Neville Oliver, Lou Lomas, Chris Horseman.

General Fabrications, Pipework, Tanks & Vessels, Access Platforms
Road Tanker Loading Platforms, Ladders & Stairways, Process Plant Modifications,
Installation & Maintenance, Lead Lined X-Ray and Radioactive Materials Storage Cabinets,
Lead Lined Access Doors, manual and powered for radiography containments.

600 flange weld details-paper.pdf Anchor Frame (Upper)-Layout1.pdf Flange Machine Detail-paper.pdf