

Performance Test

MAXIMUM POWER PERFORMANCE TEST

Always complete a rough hand drafted graph of the results

Is the fuel delivery a straight line ?

Do the SFC and Torque mirror each other

Build up your own memory joggers

PERFORMANCE TESTING

Build up your own memory joggers

Treat test result with caution

Are these results are believable

Not possible re-test

Repeatability of tests

- In order to be able to repeat test results, in addition to knowing the build of the engine, it is necessary to correct the results back to a standard induction temperature and barometric pressure within the test cell
- There are various standards for N/A and turbo, diesel and gasoline applications

Swept volume [displacement] of a cylinder

$$V_h = \frac{\pi}{4} D^2 s$$

d = bore

s = stroke

Swept volume of engine

$$V_H = V_h * z$$

z = number of cylinders

Gasoline applications ~ Ignition timing

Determination of ignition timing at differing speed and load conditions

The test is conducted throughout a wide range of ignition advance positions in order to determine engine performance levels with differing load conditions

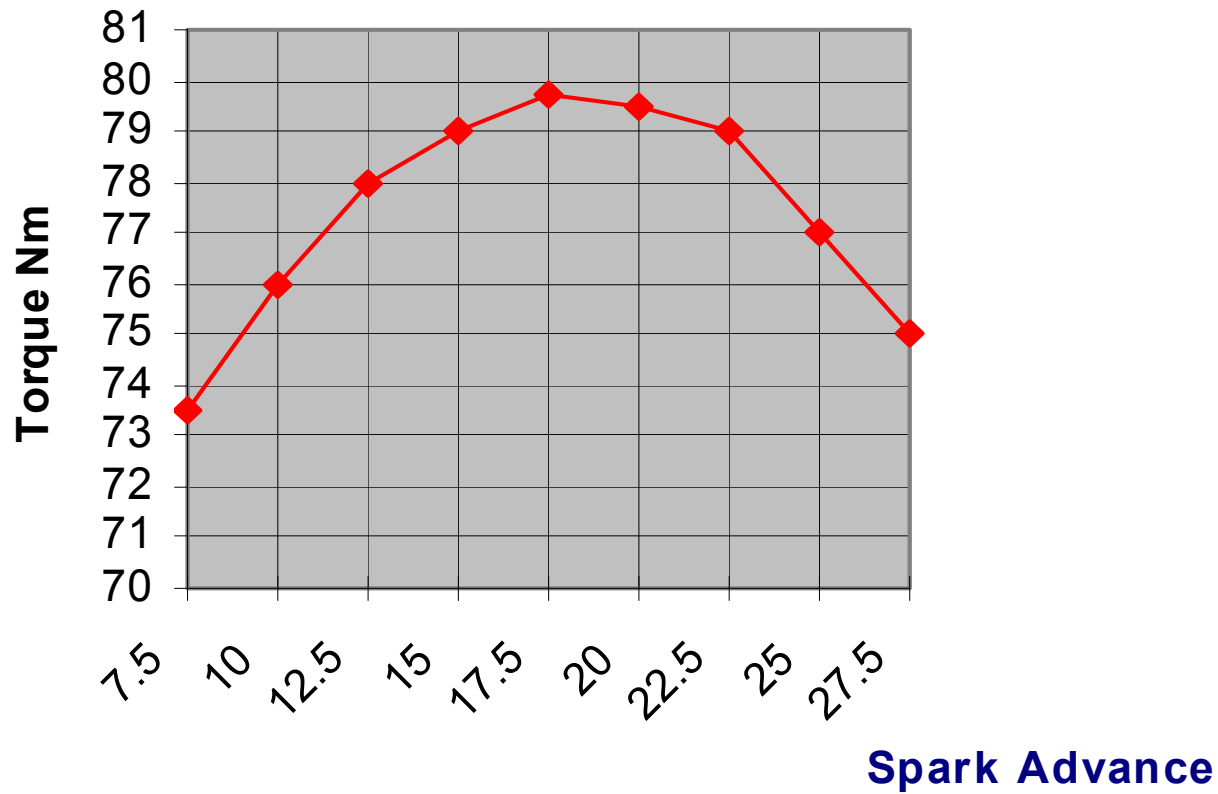
The test is conducted throughout a wide range of ignition advance positions in order to determine engine performance levels with full load advance

Fuel is set to L B T /M B T at the required test speed

Ignition Loop

Full Load Ignition Loop					
Engine running at 1500 rev/min					
Auto Fuel					
Coolant outlet temperature 90°C					
AIT 28°C		Exhaust back pressure 12 mmHg			
Manifold vacuum 16 mmHg					
Torque		Ignition			
Nm		Advance °			
68		5			
71.1		7			
72.7		9			
73.7		11			
74.7		13			
75.6		15			
75.8		17			
75.8		19			
75.3		21			
74.7		23			
74.3		25			
73.2		27			
71.9		29			

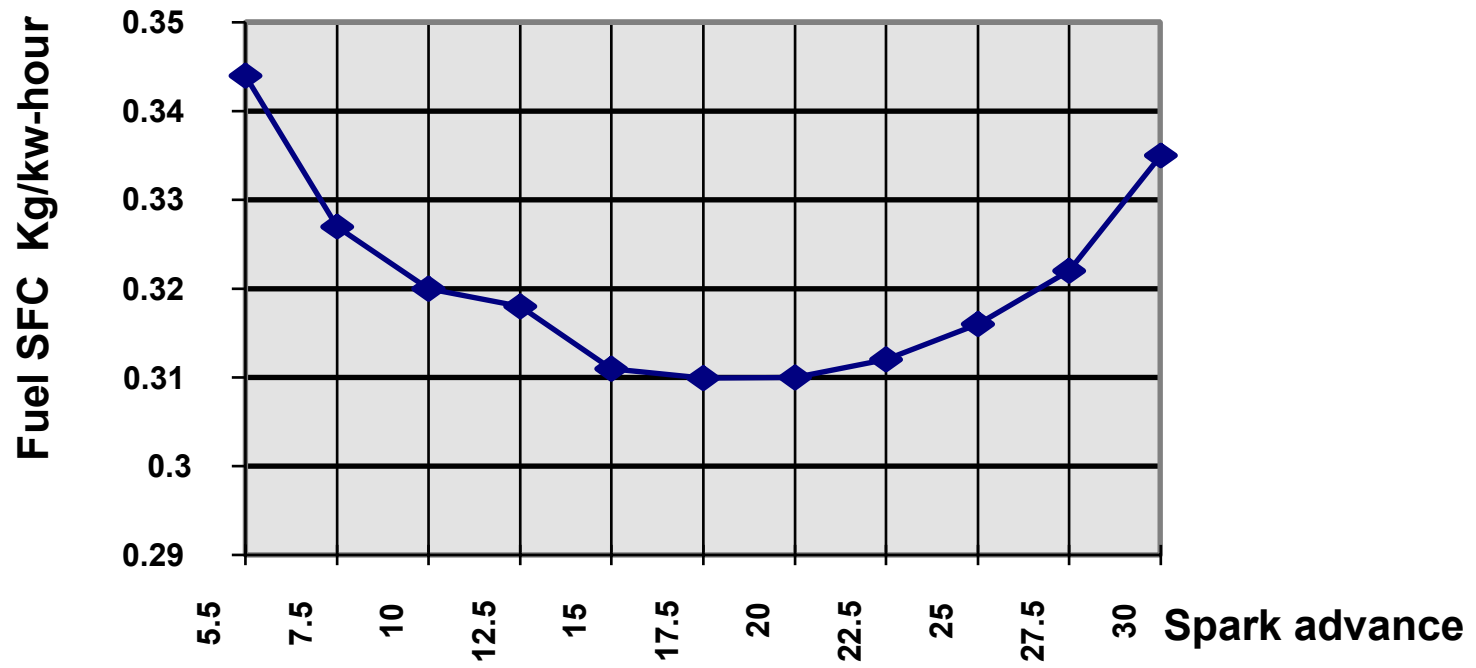
Full load 1500 rev/min ignition loop



Fuel Loop

Part Load Fuel Loop Readings		
Engine running at 3755 rev/min		
Producing 70.8 BMEP psi		
Manifold	Fuel flow	SFC
vacuum	kg/hour	kg/kW.hour
mmHg		
284	9.41	0.385
285	9.18	0.375
287	8.83	0.361
286	8.61	0.352
292	8.33	0.341
290	8.1	0.331
289	7.86	0.321
287	7.46	0.305
285	7.28	0.298
265	7.02	0.287
246	6.97	0.285
235	6.89	0.282
207	7.05	0.288
190	7.15	0.292
180	7.12	0.293
162	7.29	0.298

Full load ignition loop 1500 rev/min



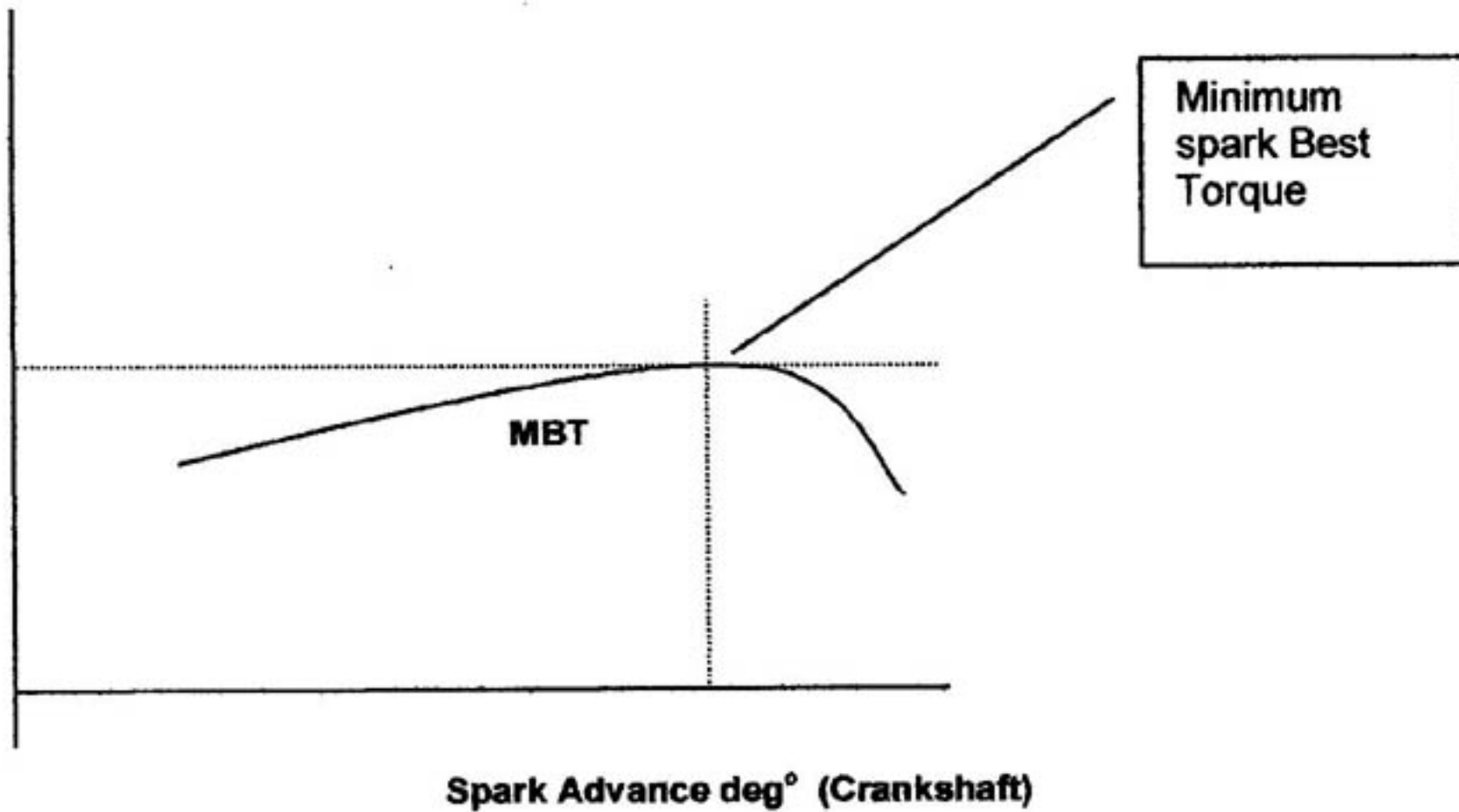
Determination of part load ignition timing

- These tests are conducted to establish the points of minimum specific fuel consumption relative to optimum spark advance.
- By running a series of loops throughout the speed range, and maintaining specified BMEP figures, a final part load ignition curve can be established

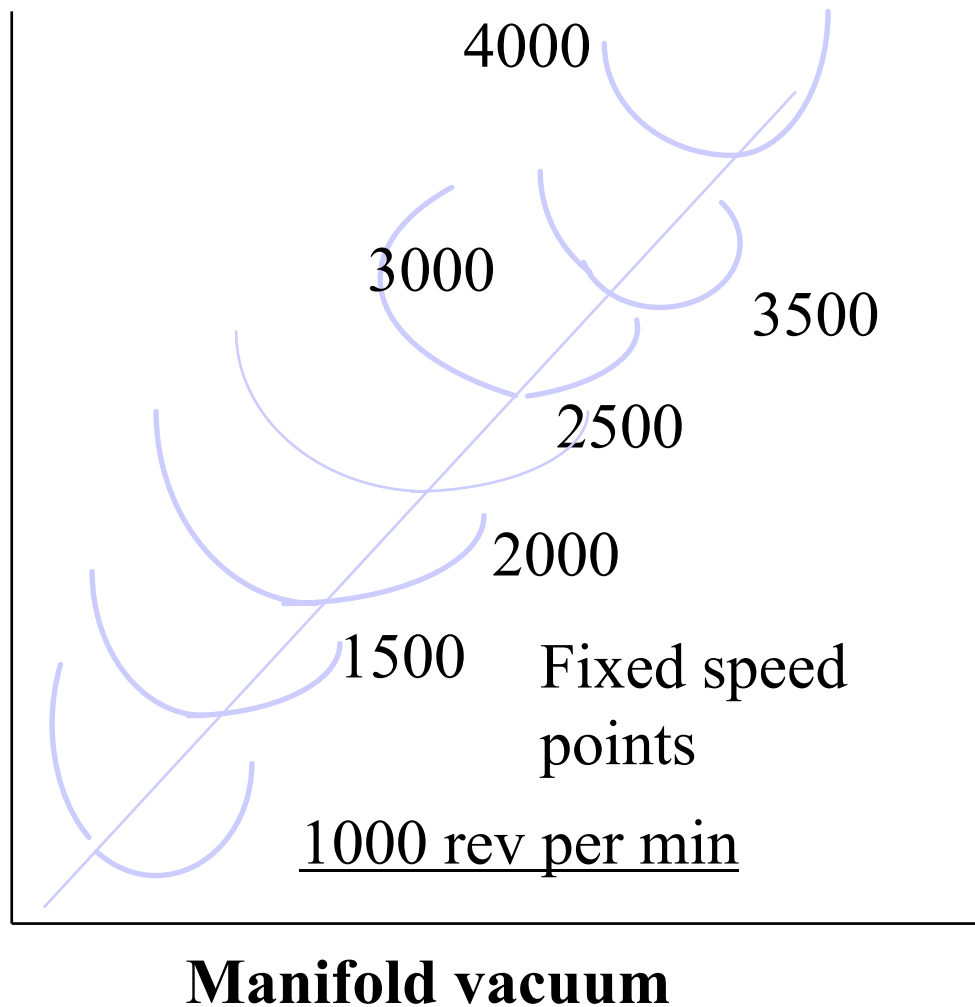
Determination of ignition timing ~ part load procedure

- Set throttle position as required/select dynamometer constant speed mode.
- Establish MBT at required speed/load
- Start loop, retard ignition by 14° /reset load with throttle
- Allow conditions to stabilize

Torque



**SFC
Fuel**



**Fuel loops constant
throttle setting**

Note: The minimum fuel/
maximum torque point
at each fixed speed, gives
a near straight line curve
for any given throttle
setting

Effect of spark change

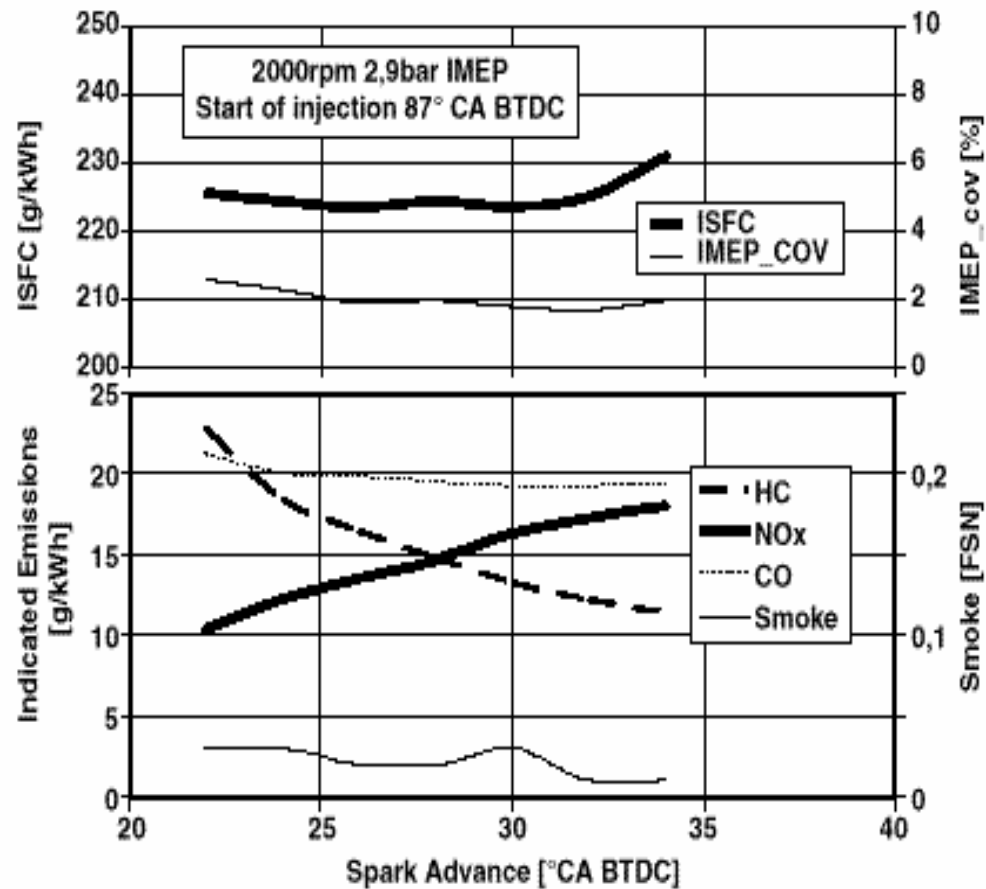


Fig. 6: Spark timing variation.

PERFORMANCE TESTING

- Air cleaner differential pressure
- Boost (if applicable) centre of inlet manifold
- EGR Vacuum/pressure
- EBP 75mm+/-10mm down stream of mating flange
- Fuel supply pressure, +ve.. : -ve..
- Intake manifold vacuum centre of manifold
- Oil Pressure ; Engine gallery take off position
- Temperature Thermocouples always as close to outlet/inlet as possible in a position where flow is unrestricted
- Fuel temperature, measure as close to the measuring head as possible

CALIBRATION

Instruments and test equipment must be calibrated at test facility specified calibration intervals and must have current laboratory calibration records.

Full tractability of all calibration records is a prerequisite of all professional engine test laboratories

PRESENTATION OF DATA

Data to be plotted against engine speed

- Corrected B.M.E.P. - kPa (psi)
- Corrected Torque - Nm (lb-ft)
- Corrected Power - kW (BHP)
- Fuel Flow - kg/hr (Lb/hr)
- SFC - g/kW-hr (Lb/HP-hr)
- Spark Advance/Injection point ° crankshaft
- Intake manifold vacuum - kPa (in. Hg)
- Exhaust back pressure - kPa (in.Hg)
- CO% (etc) at exhaust manifold flange

Engine Instrumentation accuracy

- Fuel flow $\pm 1\%$ of reading
- Pressure $\pm 0.5\%$ of full scale
- Speed ± 5 rev/min throughout range
- Injection/spark $\pm 0.5^\circ$ of reading
- Temperature $\pm 1.5^\circ \text{C}$ up to 150°C
- Temperature $\pm 3.5^\circ \text{C}$ between 150° and 1000°
- Torque $\pm 0.5\text{Nm}$ or $\pm 1\%$ of full scale
- Emissions $\pm 3\%$ of full scale

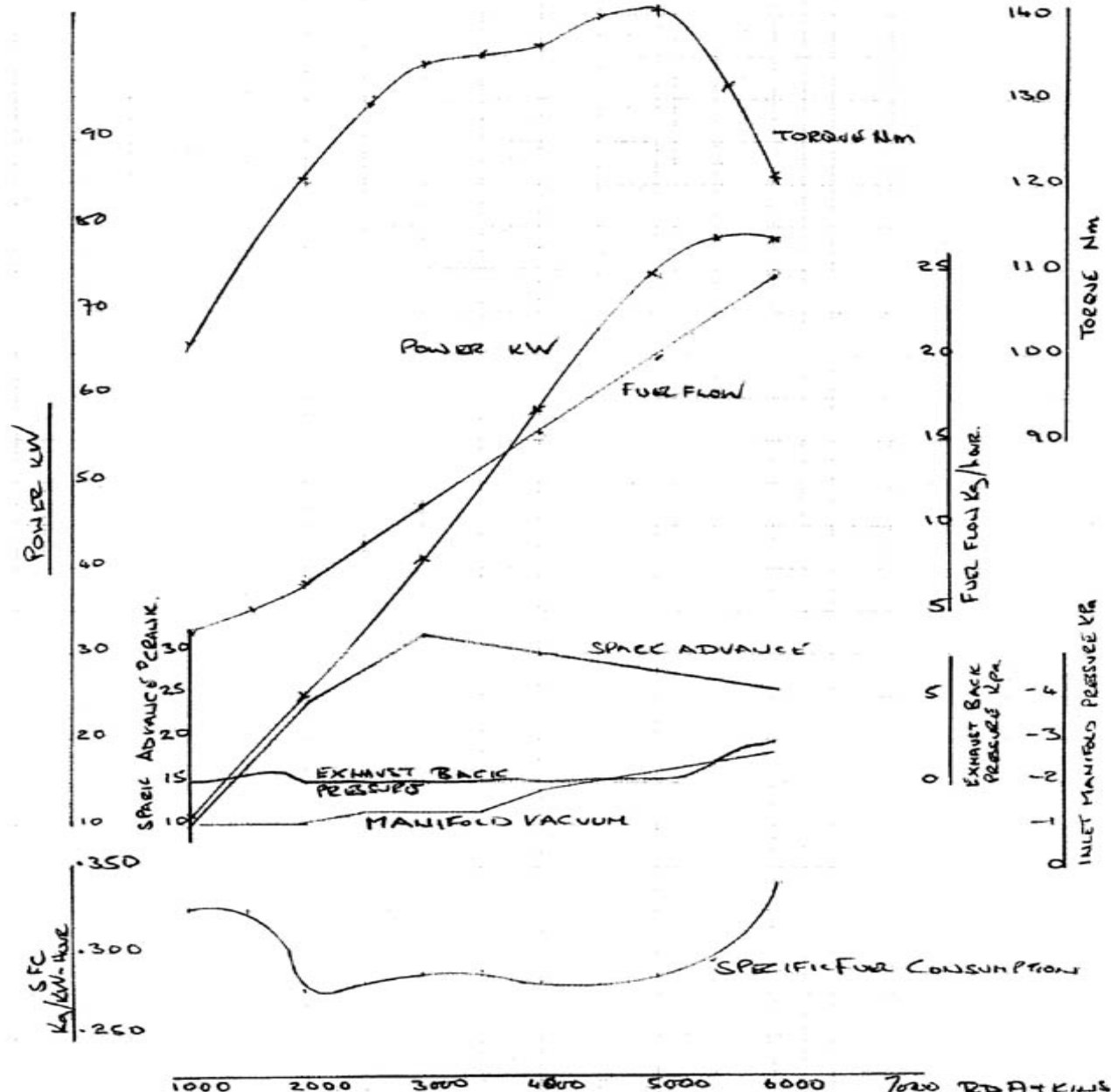
TAKING READINGS

- Allow engine to stabilize at each set point
- Oil and coolant temperatures to be held constant to pre-determined limits
- Allow a minimum of 5 minutes between each set of readings
- Instigate fuel and emission readings at the end of the stabilization period

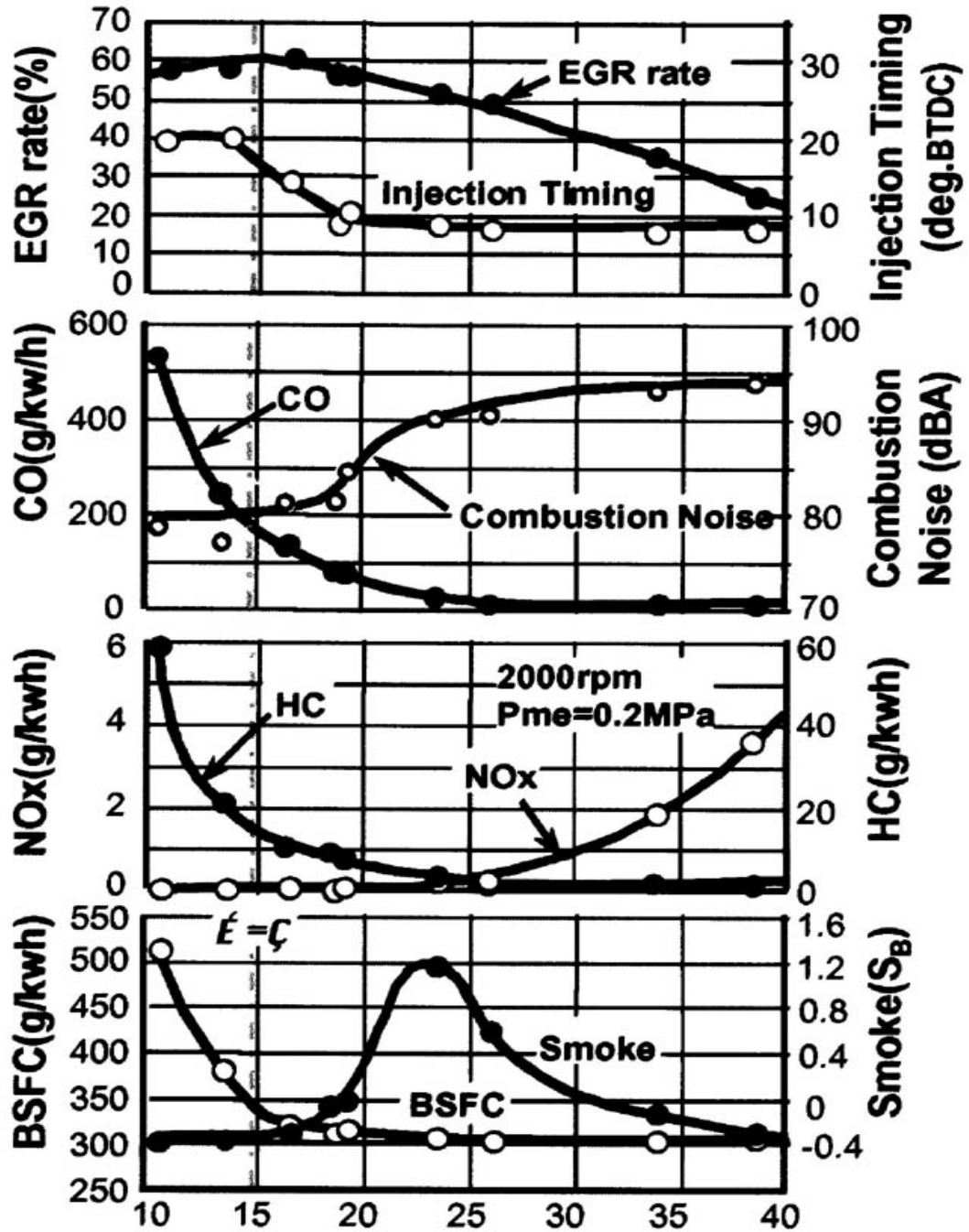
MAXIMUM POWER ~ PERFORMANCE TEST~ WOT PC

- # Always complete a rough hand drafted graph of the results.**
- # Is the fuel delivery a straight line ?**
- # Do the SFC and Torque curves mirror each other**
- # Build up your own key rules for further reference**

WOT PERFORMANCE CURVE.

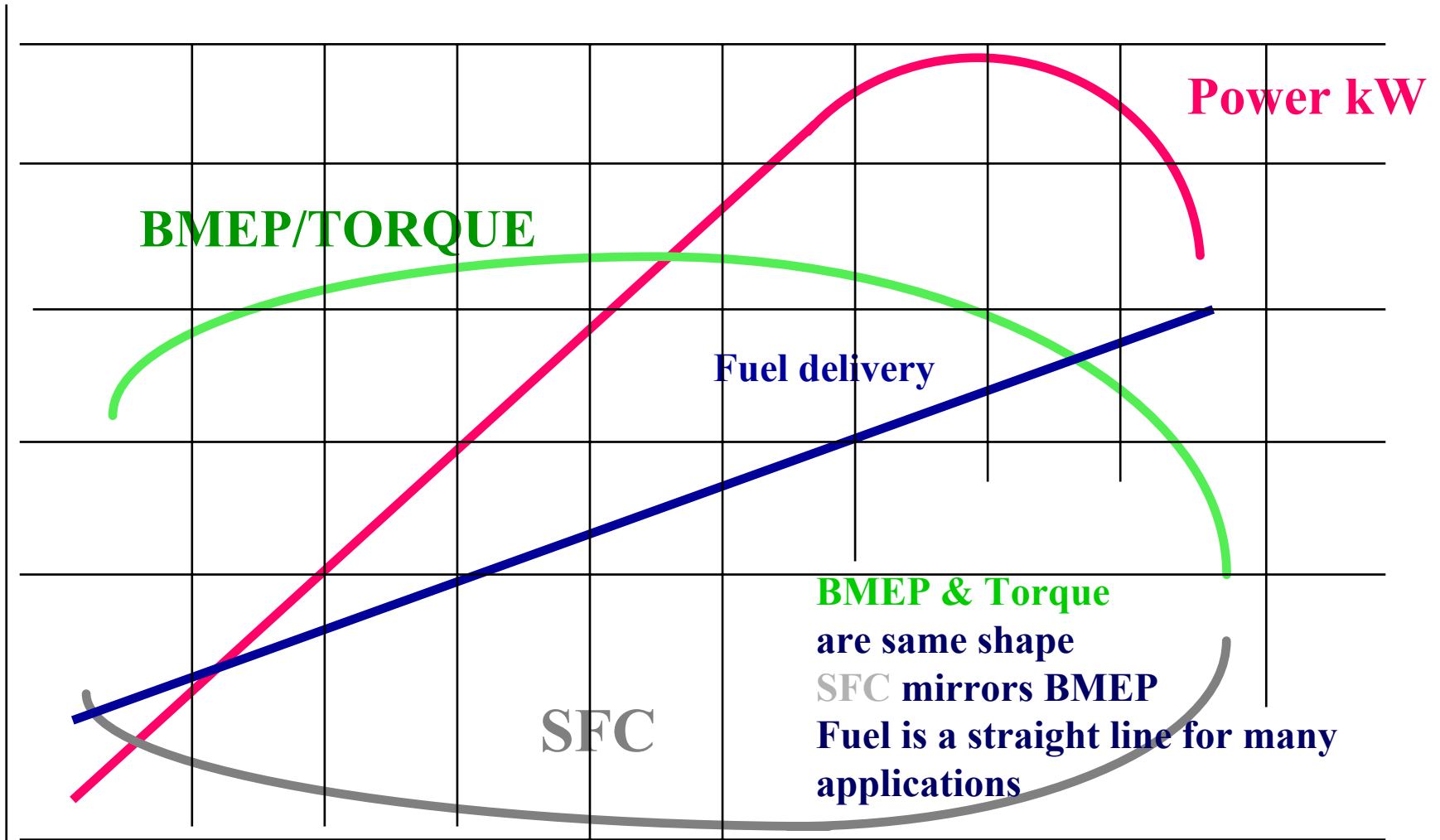


Wide
Open
Throttle
Power
Curve
WOT.PC



Changes to AFR and the effect on EGR; CO; NO_x; BSFC

TYPICAL POWER CURVE



Effects of air/fuel ratio/Gasoline engines

- Air fuel ratio; mass of air in charge to mass of fuel
- Stoichiometric ratio; the ratio where there is exactly sufficient O₂ present for complete combustion ; Ranges 14: to 15:1 ~ 14.7:1 is the accepted norm.
- Lambda excess air factor, the ratio of actual to stoichiometric air/fuel ratio. The range is from 0.6 (rich) to 1.5 (weak)
- Lambda ratio has a great influence on power, fuel consumption and emissions.

Testing terminology

- LBT Leanest fuel for best torque
- MBT Minimum spark for best torque
- MBT-L MBT Retarded to clear detonation
- TLA Top limit advance
- BLA Bottom limit advance
- OCT Oil consumption test
- Carbon Hours Engine running hours since last decarborisation

Measurement of mechanical losses

- Indicator diagram
- Motoring tests
- Morse tests
- Willans line
 - We will consider the last three

Morse Test

Run the engine under stable conditions

Ignition or fuel injection are then cut off, and quickest possible measurement made of power to run at the same speed.

Errors include

When the non firing cyl pressure is reduced there is drop of friction between piston and bore

Cylinder wall temperatures fall rapidly, increasing viscous drag

Pumping losses are changed

- The engine is run under steady conditions and ignition or injection cut off in each cylinder in turn (only use with multi cylinder engines)
- When cyl cut out, dyno load adjusted to restore engine speed. the reduction in power noted. This is assumed to be the indicated power contributed by the non firing cylinder
- The process is repeated for all cylinders and the sum of the reductions in power is taken to be a measure of the indicated power of the engine.
- With a 8 cylinder engine, 3 cylinders at once can be disabled giving more accurate results.

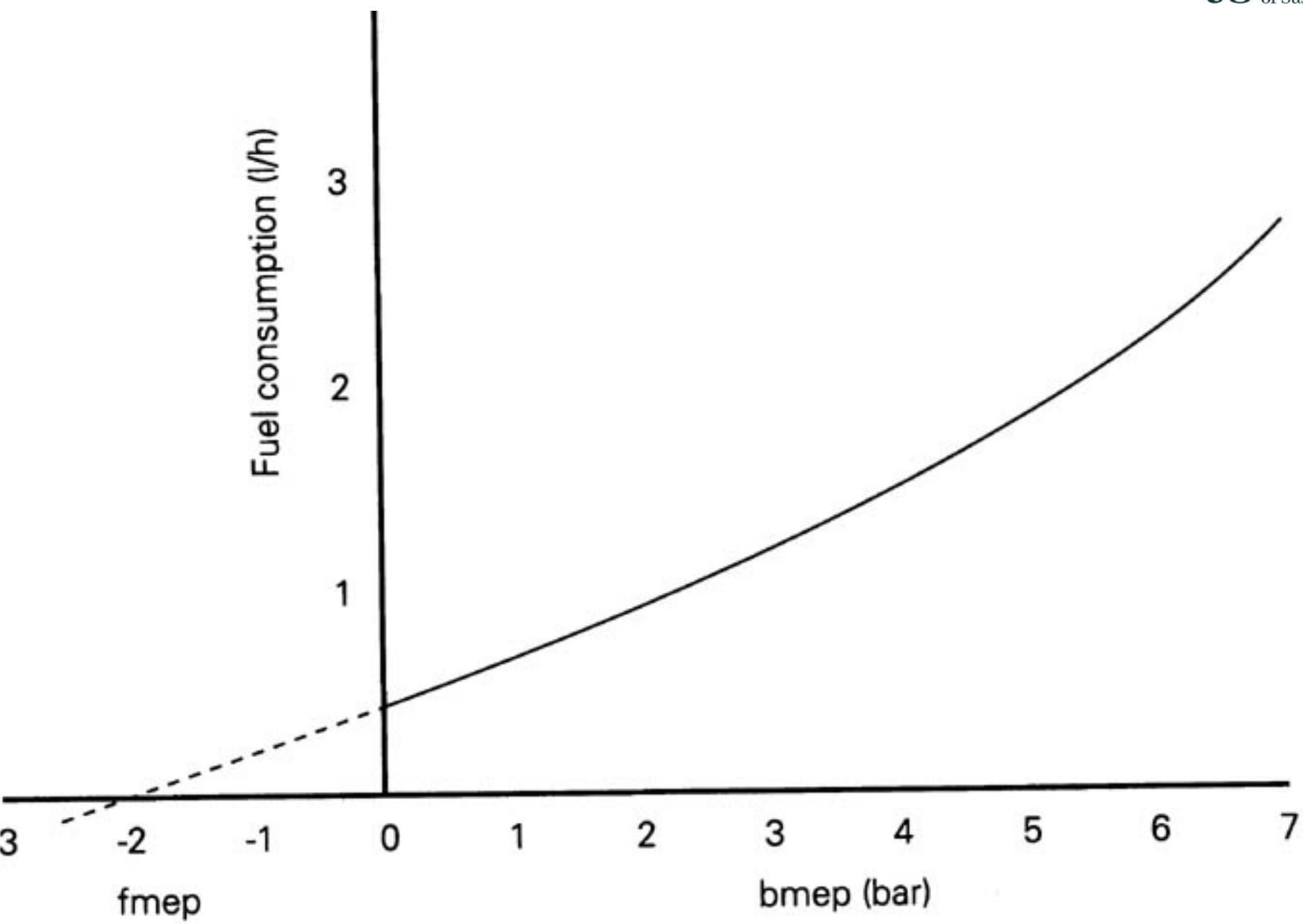
Morse Test

MECHANICAL EFFICIENCY BY MORSE TEST								
REV/MIN	TOTAL IND POWER kW	Cyl No 1 kW	Cyl No 2 kW	Cyl No 3 kW	Cyl No 4 kW	Brake powe kW	Friction Powe kW	Mechanic efficiency
1000	9.08	2.29	2.25	2.27	2.28	7.86	1.22	86
1500	16.15	3.86	4.19	4.27	3.82	13.32	2.83	82
2000	22.83	5.72	5.68	5.76	5.68	19.02	3.81	83
2500	28.12	7.12	6.91	6.99	7.09	24.50	3.61	87
3000	36.00	9.13	8.91	8.97	9.00	29.95	6.05	83
3500	42.40	10.77	10.48	10.52	10.63	35.18	7.22	82
4000	50.68	12.88	12.50	12.71	12.59	40.73	9.95	80
4500	58.05	14.70	14.37	14.56	14.42	44.43	13.62	76
5000	63.56	16.34	15.76	16.02	15.45	46.70	16.86	73
5500	69.74	18.00	17.25	17.42	17.08	48.98	20.76	70
6000	75.83	19.54	18.66	18.91	18.72	50.14	25.70	66
		<u>The average mechanical efficiency is 79.31%</u>						

The WILLAN'S Line Method

Applicable mainly for diesel engines

- The curve of fuel consumption rate against torque at constant speeds plots well as a straight line up to 75% of full power.
- Equal increases in fuel give equal increases in power (combustion efficiency being constant)
- At zero power, all fuel burned is expended in overcoming mechanical losses.
- Extrapolation of the Willan's line to zero fuel consumption gives a measure of friction losses in the engine



Diesel - Cetane Number ~ recap

Cetane number is the most important diesel fuel specification. It is an indication of the extent of ignition delay.

The higher the cetane number the shorter the ignition delay, the smoother the combustion and the cleaner the exhaust

Cold starting is easier the higher the cetane number

Calorific value ~ recap

The calorific value of diesel fuel is lower than that of gasoline.

Diesel fuel ranges from 40MJ/kg to 43MJ/kg and is a function of fuel density

The higher the sulphur content the lower the calorific value, this has a big impact upon new emission regulations

CONFIDENCE

NEED TO REPEAT ALL PERFORMANCE TESTS

- In order to have statistical confidence in the results of any performance test, it is necessary to repeat the test at least twice, if possible three times

DESIGN LEVEL ONE STANDARD DVT TESTS

- ◆ Full load cycle test
- ◆ Thermal shock test
- ◆ Exhaust manifold crack tests
- ◆ Valve wear cycle tests
- ◆ General usage cycle test
- ◆ Critical speed tests

DESIGN LEVEL TWO STANDARD DVT TESTS

TESTS AS PER DESIGN LEVEL ONE

- THE NUMBER OF TESTS AND THE DURATION OF EACH TEST INCREASED.
- IN FIELD DURABILITY TESTS START

OFF TOOL VALIDATION COST SAVINGS

- ◆ Intelligent interpretation of tests
- ◆ Ensure that all tests produced to the highest standards
- ◆ Produce significant savings in the period between design concept and production sign off

VALUE FOR MONEY

To achieve the maximum value from any DVT work, the measurement and assessment of critical components pre and post test is a prerequisite.

This assessment would include the measurement of wear, rating of component condition and analysis of fluids and lubricant.

This data enables the engineer to undertake predictive analysis of wear rates [Re Bath Tub !] and thus to increase his confidence level in the validity of the test results and thus reduce the total number of tests to be undertaken

OIL ANALYSIS

- To gain information with regard to the integrity of the engine under test, it is recommended that 125 cc samples of engine oil are taken at agreed intervals and the following analysis performed :
- | | | |
|---------------------------|------------------|-----------------------------------|
| Fuel Dilution | Reference | ASTM D 3524 |
| Soot Content | Reference | IFP 303/03 |
| Viscosity | Reference | ASTM D 445 (N40° C 100° C) |
| Metal Content | Reference | ASTM D 4951/5185 |
| Sulphur Content | Reference | IP 244/ICP |
| Base No. (Acidity) | Reference | ASTM D 664/2896. |

Engine Application

- Objective is to establish the probability of a given product reaching its design life which in turn may be dictated by legislation
- Bench tests must replicate and accelerate in service life conditions
- A typical representative test cycle for all engine applications is not possible
- Specialist tests have been developed to test engines over the 4 most important operating conditions

Your place in the equation

- **Get the maximum value out of each test**
- **The importance of the technicians place within the automotive industry cannot be too highly stressed.**
- **It is the fine attention too detail that makes the difference between a successful new model and a dead duck**

Your responsibility

- **Accuracy and Attention to detail must become a way of life for you**
- **You are a professional and are on the ladder to becoming a chartered engineer**
- **You must do all in your power to ensure that the results you produce are correct ~ this is not as simple as it sounds**

Quality in Engine Testing

- **Quality is important to both the customer and the supplier, without it the two are unlikely to meet again**
- **In engine testing, quality has a huge significance**
- **There are three considerations when defining ‘Quality’**
 - **The product meets the clients needs**
 - **The product is produced at the agreed cost**
 - **The goals are achieved in the agreed time**

The principle considerations for test technicians and engineers alike is that the engine test must have the following attributes:

1. Accuracy.
2. . Consistency
3. . Repeatability
4. Quality Workmanship

The customer must get what it is paying for, and everyone involved in the provision of this must understand what the customer is expecting to get.

Most 'Quality Accreditation' audits examine the whole operation to establish that all involved are aware of their role in meeting the standards

Quality Standards

Within the Test Industry the Quality Standards that are applicable in other industries have a 'Stay in Business' implication for Test Laboratories.

For all Quality Standards a company is accredited to, the accredited bodies i.e. BSI, LQRA or UKAS will ensure compliance by visiting them as follows: -

- a) Surveillance visits every 6 months, this will involve the body auditing parts of the Quality System in rotation.
- b) Re-Certification every 3 years, this will involve the body auditing every part of the Quality System.

BS EN ISO9000 Series

- The ISO 9000 series sets out the methods that can be implemented in an organisation to ensure customers' requirements are fully met. Not only does a fully documented quality management system ensure the customers' requirements are met, but the organisation's requirements will also be met, both internally and externally and at an optimum cost. This is the result of efficient utilisation of the available resources - material, human and technological.
- This Quality Standard covers the whole operation of the company, which includes methods and procedures that a company commits to follow in order to Assure Quality of their service or product that they are supplying to customers.

BS EN ISO9000 Series

The ISO standard is endorsed by Lloyd's Register Quality Assurance (LRQA) or by British Standard Institute (BSI) and is a national standard. The standard covers things like,

- i. Customer initial contact through to invoicing procedures**
- ii. Service or product tracking through the company procedures**
- iii. Service or product 'Quality Control' procedures**
- iv. Quality Auditing systems**
- v. Customer concern, follow up procedures etc., etc.**

When a company is accredited to BS EN ISO 9000 it is for the entire engine test operation.

UKAS (EN 4501)

The United Kingdom Accreditation Service (UKAS) is recognised by the UK Government as the body responsible for the assessment and accreditation of organisations performing testing. UKAS was formed in 1995 as a company limited by guarantee by the merger of the National Measurement Accreditation Service (NAMAS) and the National Accreditation Council for Certification Bodies.

Testing organisations that comply with the requirements of the NAMAS Accreditation Standard and regulations are granted NAMAS Accreditation by UKAS and are entitled to use the NAMAS logo.

The United Kingdom Accreditation Service is the body providing accreditation for companies operating in the engine testing industry, primarily testing engines, fuels, oils, additives and the components by measurement and sampling.

UKAS (EN 4501) [cont.]

What does it mean for Test Technicians?

Test Laboratories are of necessity ‘quality environments’, as all the work carried out is required to be traceable to a baseline of a known standard, for example,

- i. **Test Procedures** are generally developed to a recognised Industry Standard and where the test results are required to have UKAS Accreditation, then a UKAS Accredited Test Procedure must be followed. This test procedure will be the same in any company wishing to offer that service to a customer seeking UKAS Accredited results.
- ii. **Calibrated equipment** must be used to reduce the risk of introducing faulty data and information into the test results through inaccurate measurements or physical activities like torque down procedures.

UKAS (EN 4501) [cont.]

Documentation and records must be meticulously kept to record the stages and results of tests. These records provide trace-ability and are the basis of customer reports and the documentation will vary depending upon the test. In ‘meeting the clients needs’ the passage of information up and down the links within the test team is vital, and it begins for the technician with the test instructions. The technician must understand the clients objectives for the test, and how the engineer is proposing to achieve them, and therefore his / her role in the project.

UKAS (EN 4501) [cont.]

Total Preventative Maintenance (TPM) procedures will prevent the introduction of faults into tests, and help to minimise the causes of unnecessary down-time. Downtime being periods when the test has been stopped or interrupted for unforeseen reasons, (not adjustments or component changes written into the test procedures).

‘Downtime’ can cost the company as much as £1,000 per day for accredited tests in test bed income, as well as customer inconvenience. Often a five-minute task will prevent escalation into major causes of down time.

That is the essence of (TPM).

UKAS (EN 4501) [cont.]

- **Training of technicians** towards a high basic standard is required to service the needs of the test industry, which is regularly operating at or near the cutting edge of engine development.

This training together with an enhanced interest in the developments within the industry will provide the basis of a good technician / engineer.

UKAS (EN 4501) [cont.]

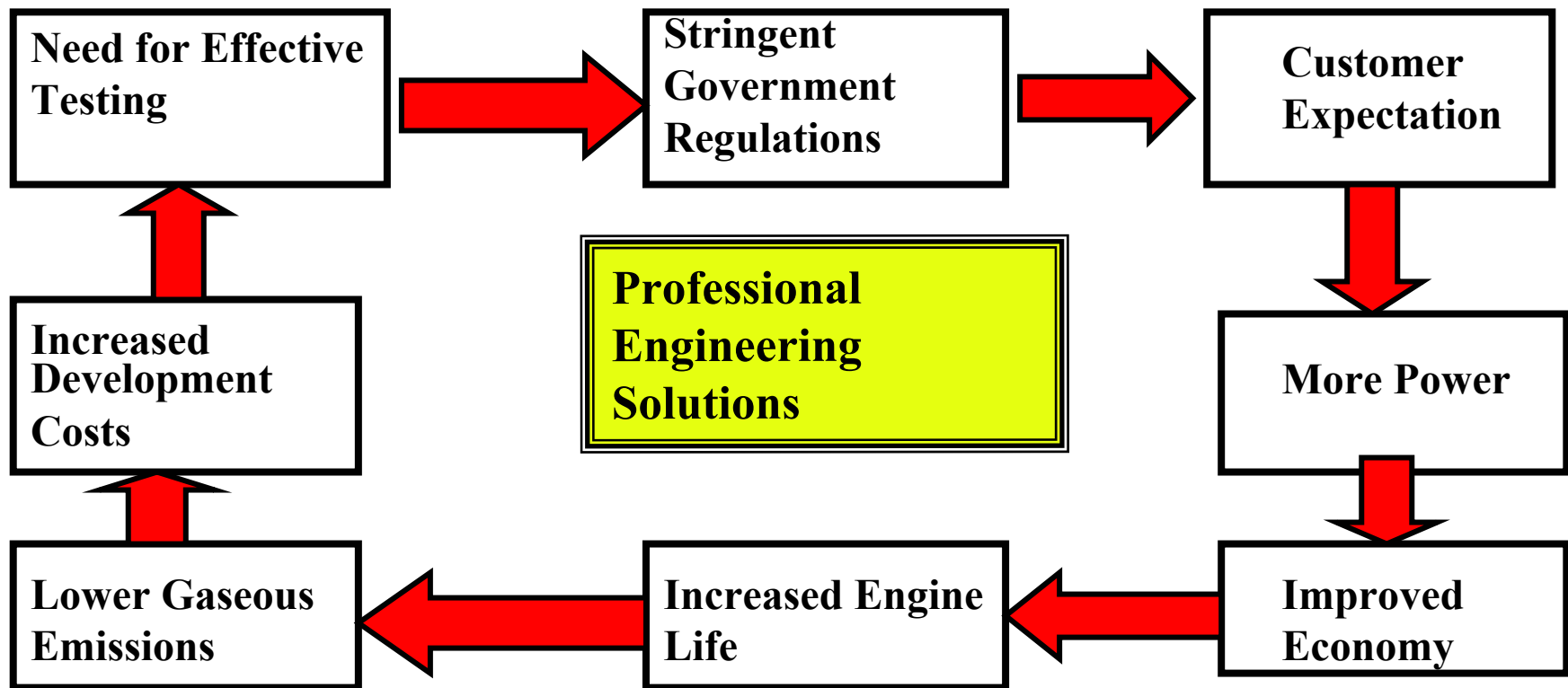
- **Work practices and fitting skills** are required to be of the highest standard in a highly competitive industry 'Right First Time' and forward thinking should be the absolute baseline for an engine test / build technicians work.
- **Witness Reports** are frequently generated by assessments conducted as part of the UKAS Accreditation 'rules' to continuously **monitor the competence of those technicians** who will carry out UKAS Accredited Test Procedures.
- *The assessments should be looking at key skill areas within the test procedures (component replacement skills), test control equipment operation and use, and underpinning knowledge of the test aims and outcomes. An awareness of the Rating function will always add value to the technicians engine testing knowledge.*

Note

A worthwhile edict for all employees in the engine test industry to always bear in mind is this, :-

It takes years of hard work to build a good reputation, BUT it only takes seconds to destroy it!

The pressures that we engineers endure, they underline the need for effective testing



CALIBRATION

- **Calibration is all, regardless of the objectives of the test in question, all key items must be calibrated.**
- **Failure to calibrate, makes the test worthless a waste of valuable time and money !**

Calibration definitions

- **Operational range**
 - The widest possible range of values (min to max) anticipated for any given parameter for the duration of the test.
- **Parameters**
 - All items with the potential of effecting the reported value. e.g. sensor, cable, signal conditioning etc
- **Calibration range**
 - The range max to min over which the instrument should be calibrated
- **Full Scale Deflection FSD**
 - The maximum value running back and through zero
- **Limits of Error(LOE)**
 - The maximum +/- error acceptable within the calibration standard

Calibration definitions

- **Accuracy of measurement**
 - The closeness of the agreement between the result of a measurement and the true value of the measurement
- **Uncertainty of measurement**
 - Results of the evaluation aimed at characterising the range within which a true value of measurement is estimated to lie
- **Traceability**
 - The property of a result of a measurement whereby it can be related to approximate measurement standards (National or International) through an unbroken chain of comparison.

Repeatability is KING !

In order to repeat any given test at some time in the future, it is essential that all variables are noted, for example:

- Engine build specification**
- Ignition and injection timing**
- Type of fuel, oil and coolant**
- Position of sensors on the engine and within the cell**

Replicate test results

- It will be impossible to replicate tests at some time in the future if one does not have full records of engine build, cam timing, ignition and injection timing, compression ratio, fuel, oil and coolant used.
- The more data, the better you sleep at night!

Calibration Equipment Identification

Where possible all critical equipment shall be tagged or labelled with a serial number, frequency of calibration and calibration status shown on the tag or label.

Calibration for all elements critical to the utility of the test should always be traceable to National Standards. The frequency of calibration should be determined by a scientific approach paying due attention to the past behaviour of the measurement system used. Evidence of calibration should be readily discerned on all measurement equipment. Wherever possible the calibration of each parameter should be performed with reference to the whole measurement system. Calibration should include all instrumentation between the physical quantity being measured and the point at which data is logged for use with the test report. For example, calibration of a temperature sensor would require the sensor to be placed in a temperature- controlled bath and the measurement recorded employing the instrumentation used during test.

Definitions

Operational Range; -

The widest possible range of values (difference between the maximum and minimum values), anticipated to be seen for any given parameter throughout the duration of the test.

Parameter / measuring chain; -

All items of hardware or virtual with the potential to affect the reported value in engineering units. For example; -sensor, cable, signal conditioning and display / logging resolution.

Parameter Calibration Range; -

The maximum recommended range over which each specific parameter should be calibrated.

Definitions (cont.)

Calibration Range; -

The range (minimum to maximum), over which each specific parameter / measuring chain is calibrated should exceed the operating range.

Full Scale Deflection (FSD); -The maximum single sided values for each measuring chain having a calibrated range intercepting at or through zero.

Limits of Error (LOE); -

The maximum +/- error acceptable with reference to the calibration transfer standard. The defined 'Limits of Error' excluding uncertainty errors associated with the calibration transfer standard and method of calibration.

Definitions (cont.)

Accuracy of Measurement; -

The closeness of the agreement between the result of a measurement and the true value of the measurement.

Uncertainty of Measurement; -

Results of the evaluation aimed at characterising the range within which a true value of measurement is estimated to lie, generally with a given likelihood.

Trace ability; -

The property of the result of a measurement whereby it can be related to appropriate measurement standards, (generally international or national), through an unbroken chain of comparison.

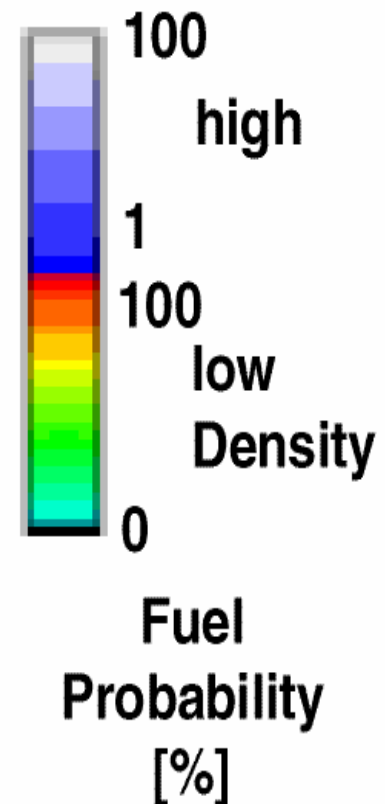
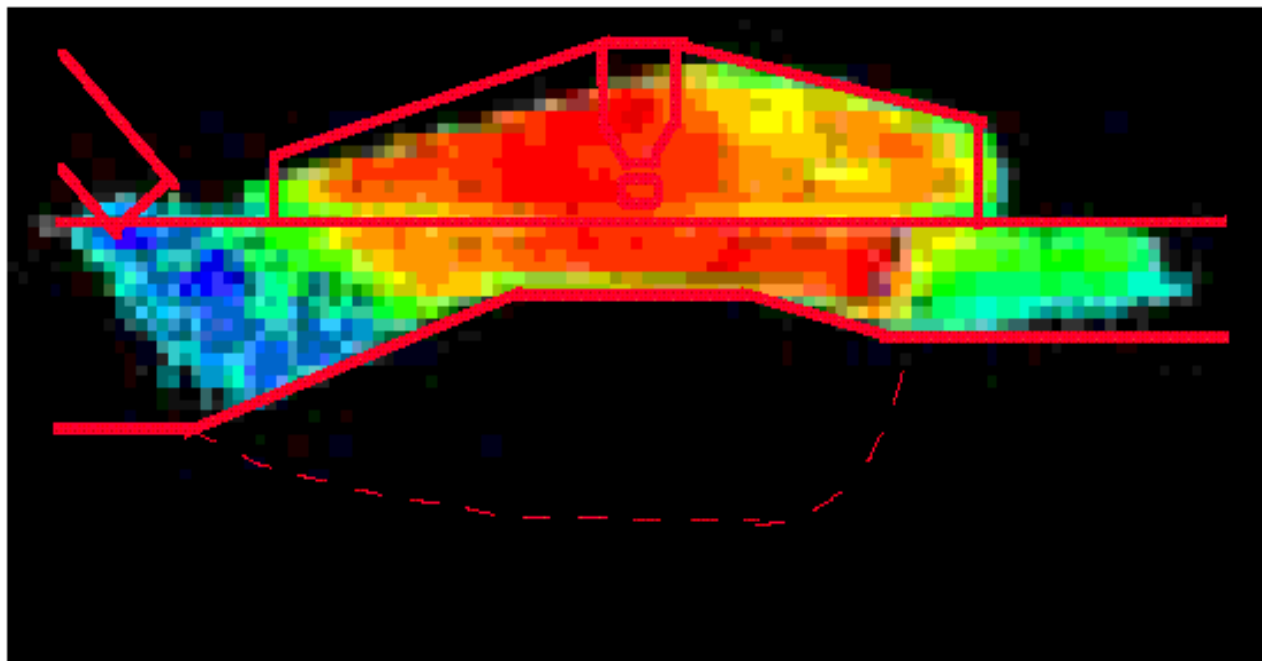
Calibration Personnel and Equipment

All personnel carrying out calibration should be adequately trained, and regularly reviewed to assess their competence with the calibration equipment and procedures.

All the channels defined as a critical calibration parameter must be calibrated using equipment that is fit for that purpose, and traceable to National Standards. Equipment records must be kept detailing the history of all Calibration Standards used.

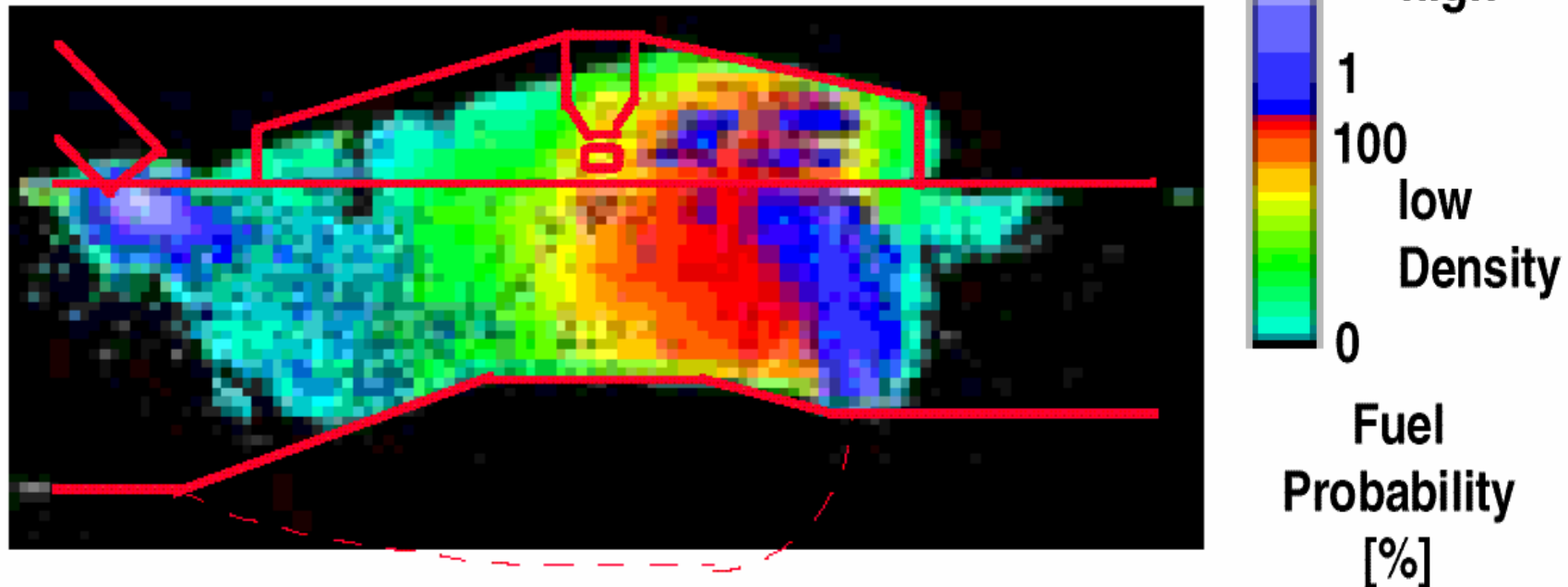
PERFORMANCE TESTING

35° CA BTDC



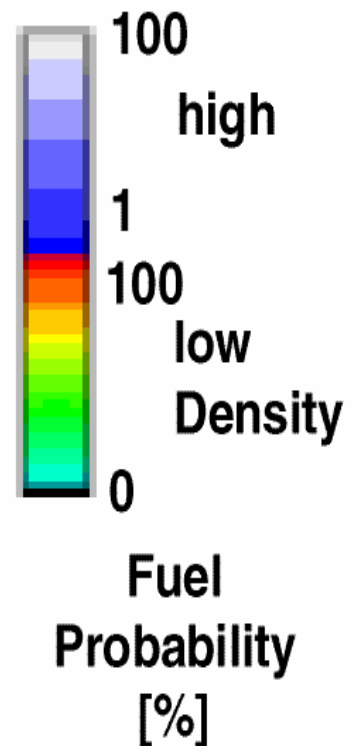
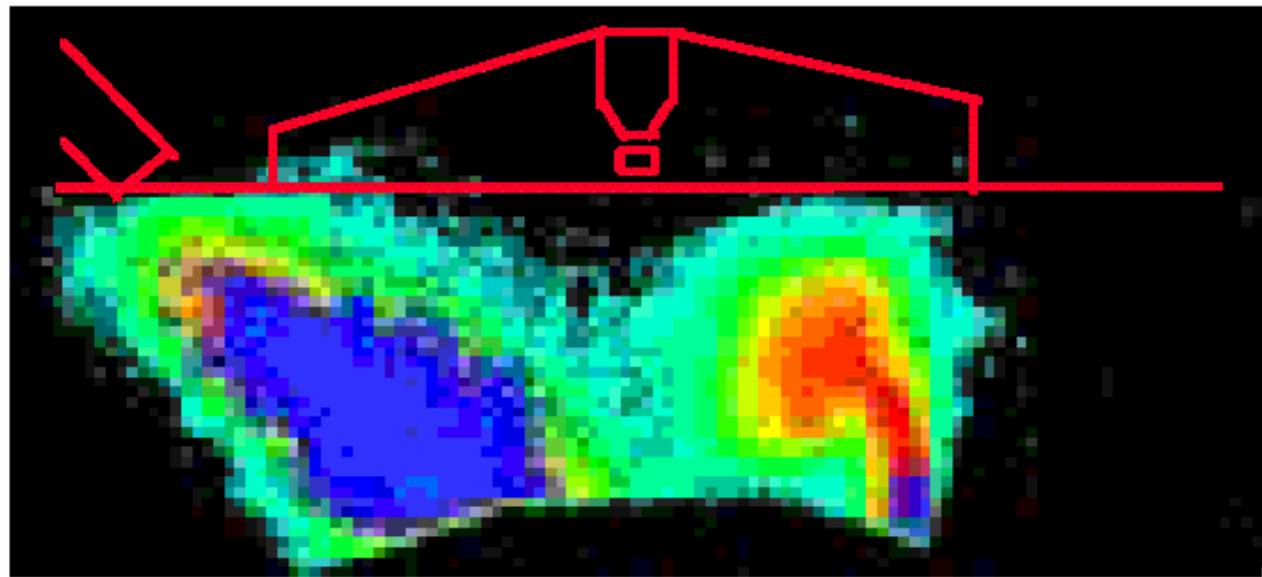
PERFORMANCE TESTING

50° CA BTDC



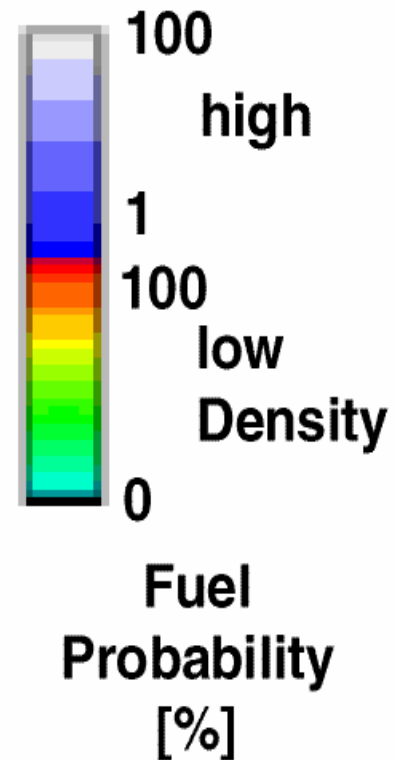
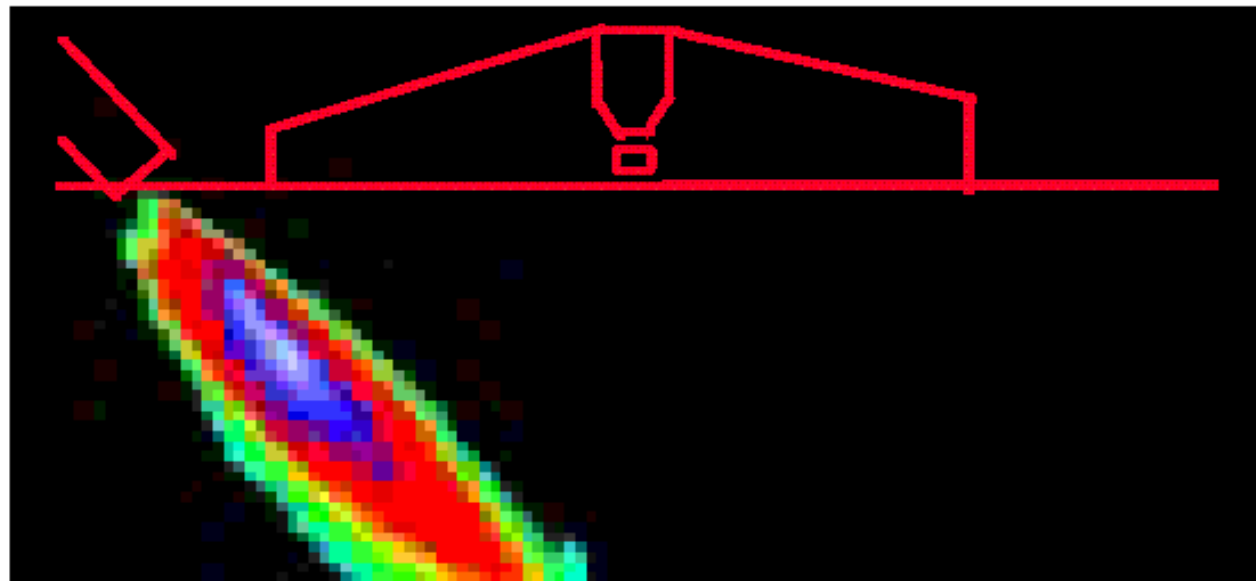
PERFORMANCE TESTING

60° CA BTDC



PERFORMANCE TESTING

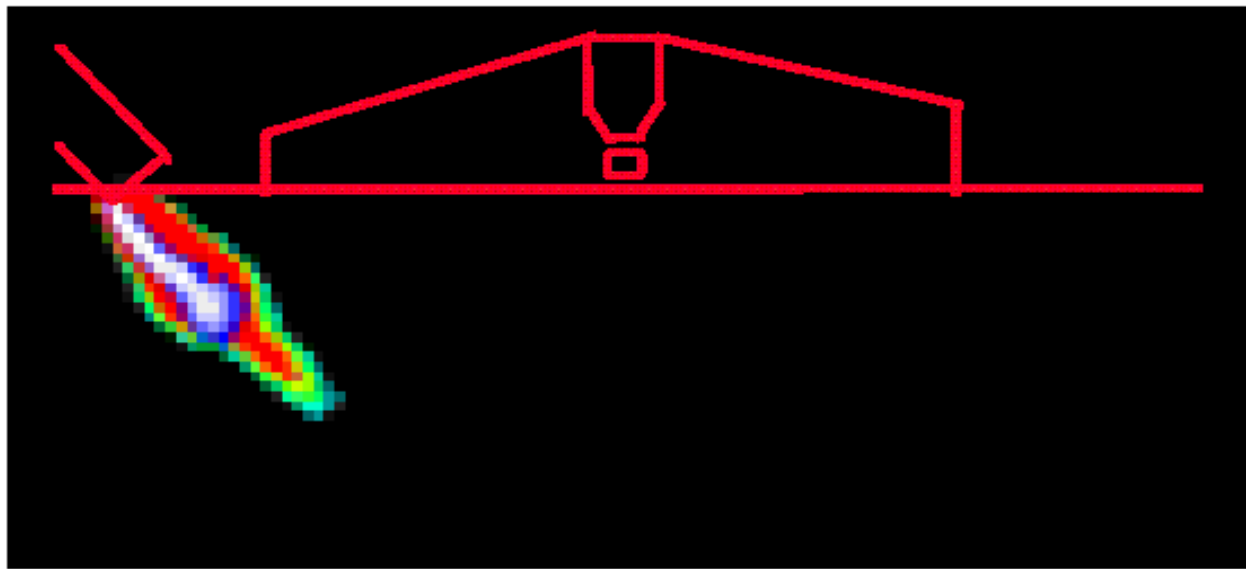
67° CA BTDC



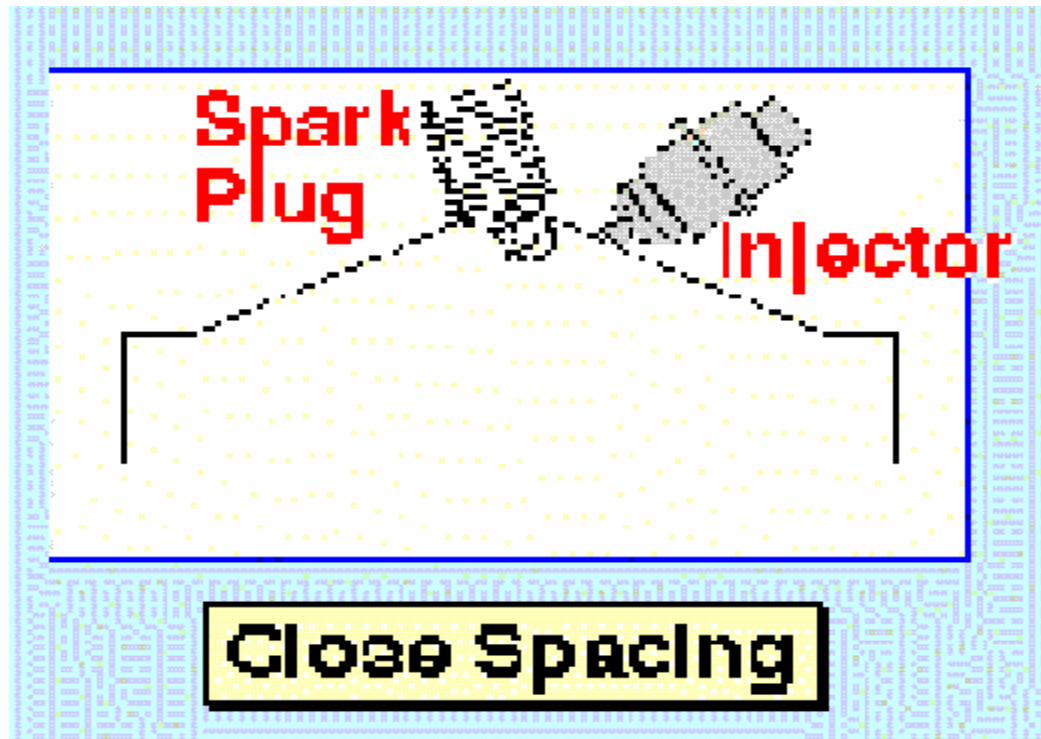
PERFORMANCE TESTING

Statistical evaluation of charge stratification at part load

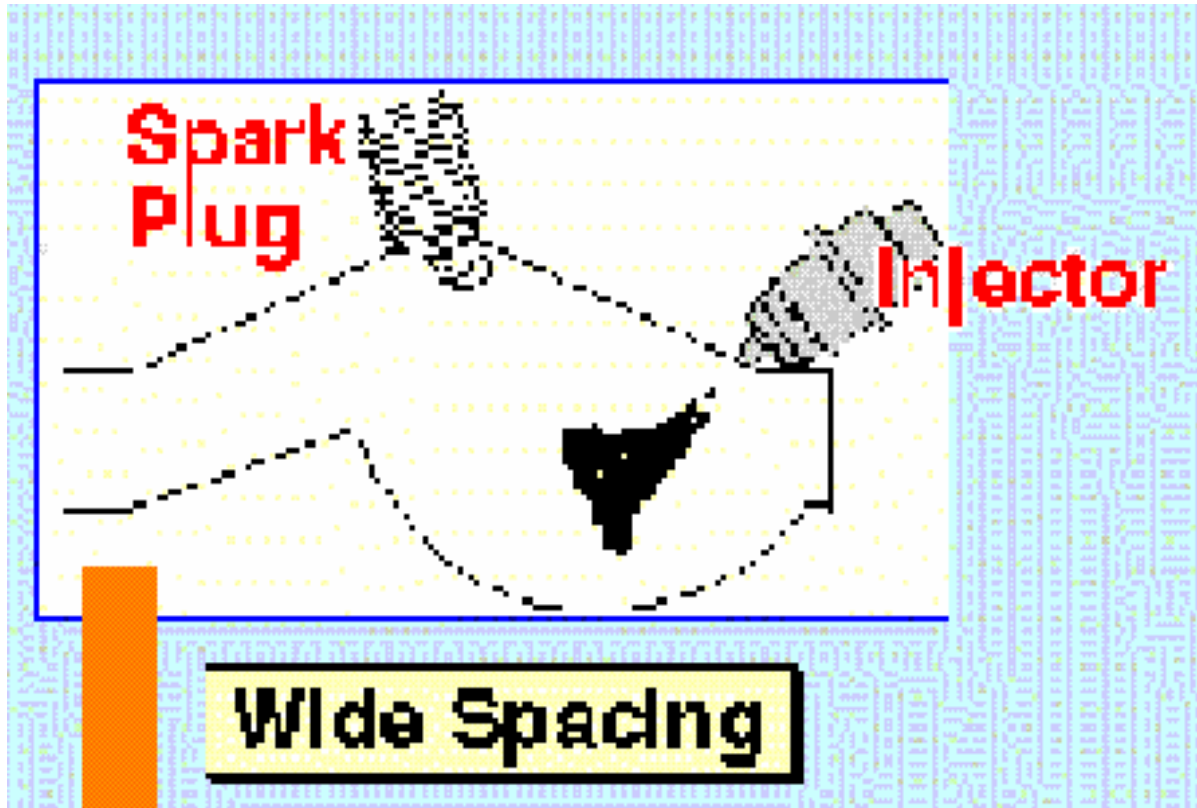
77° CA BTDC



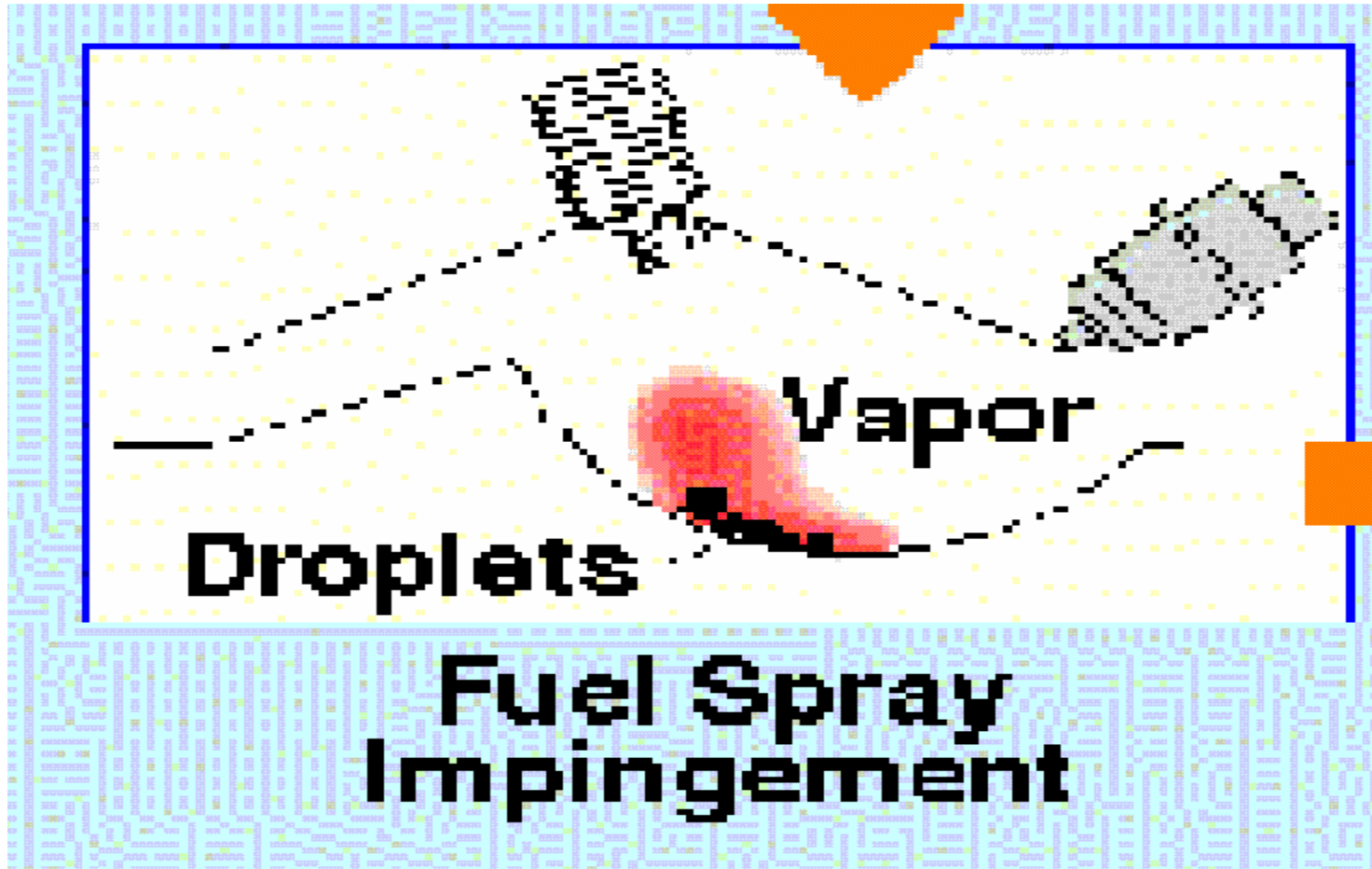
PERFORMANCE TESTING



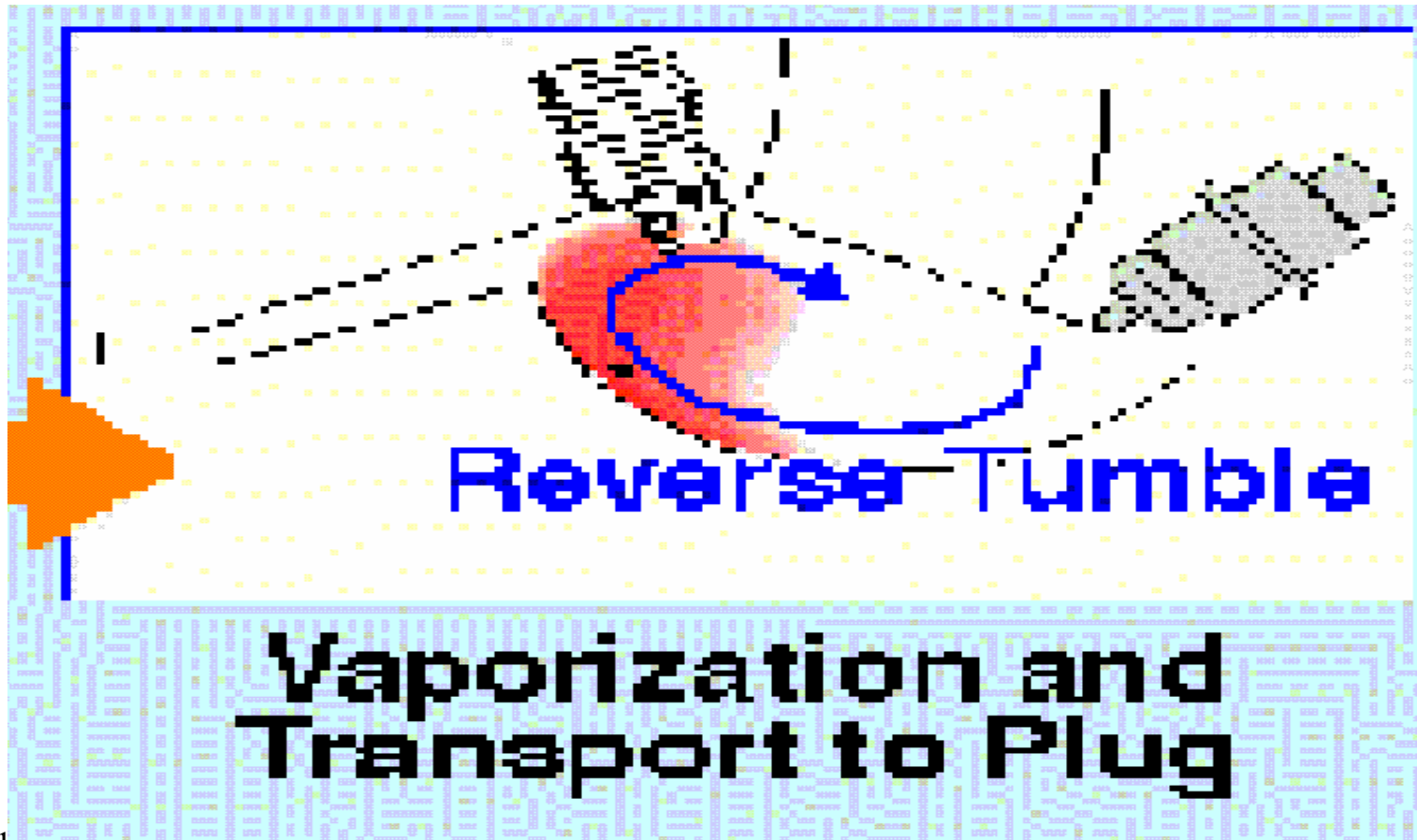
PERFORMANCE TESTING



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PERFORMANCE TESTING

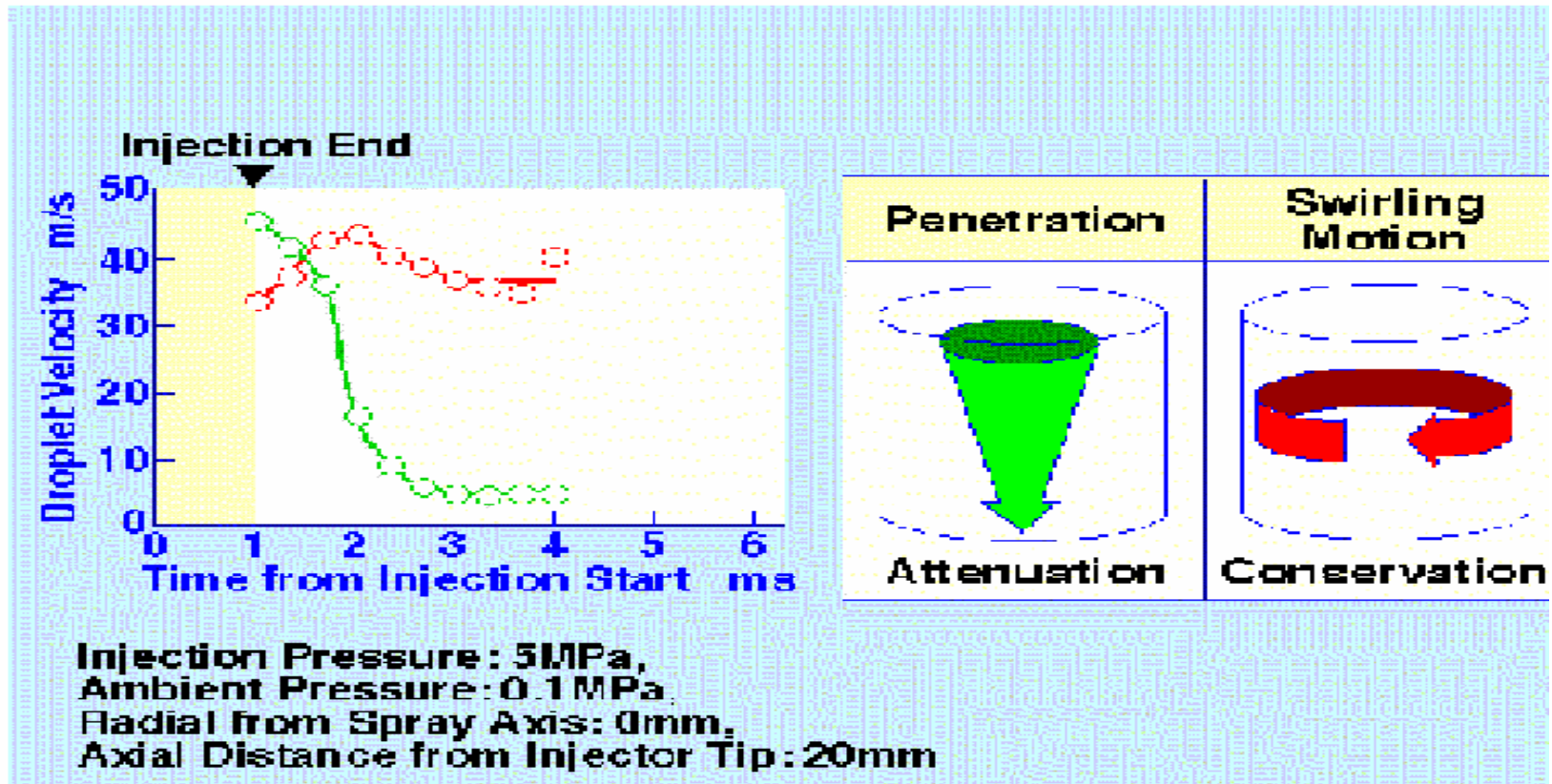


Fig. 3: Penetrating and swirling motions of fuel spray

PERFORMANCE TESTING

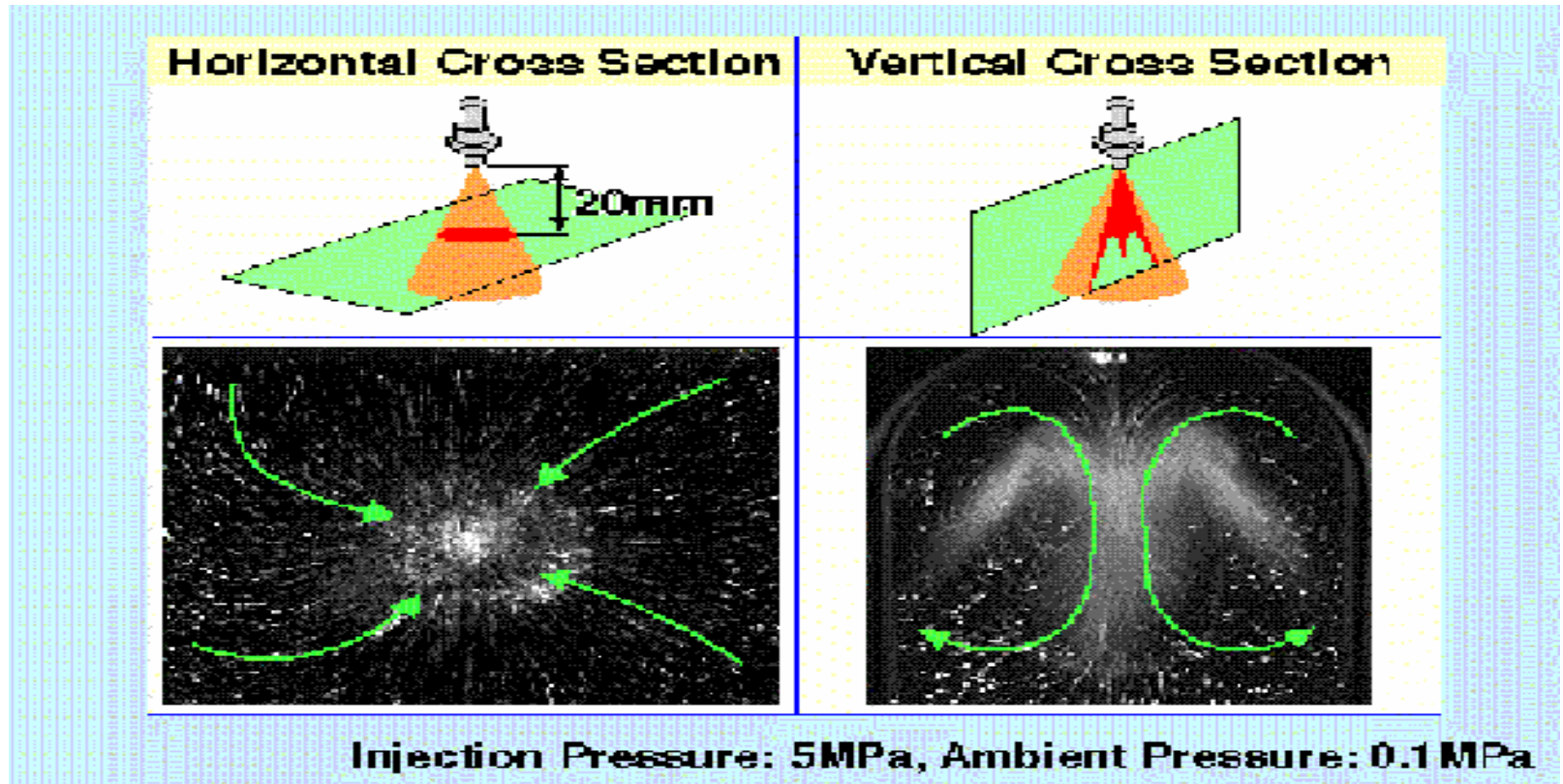
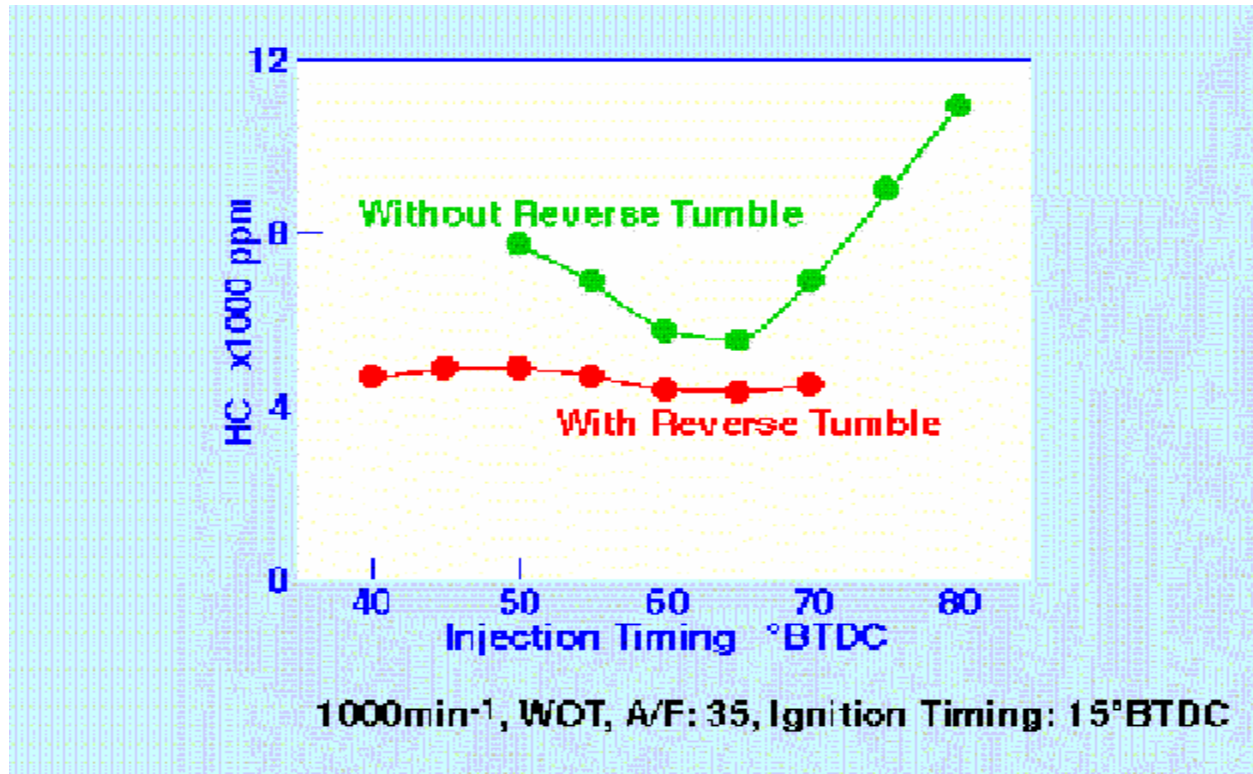


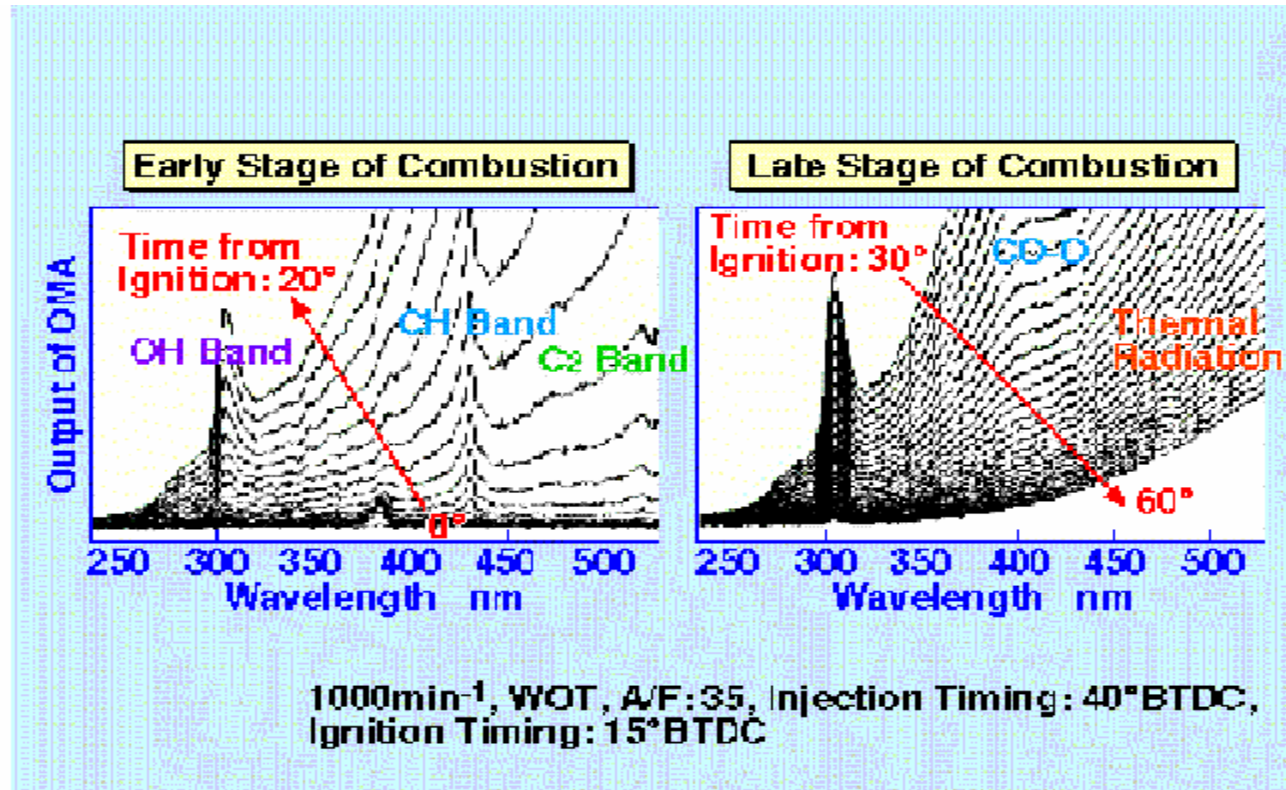
Fig. 4: Ambient air motions induced by fuel spray motion

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Influences of reverse tumble and injection timing on HC emission

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|. 8: Temporal variation in spectrum distribution of flame radiation

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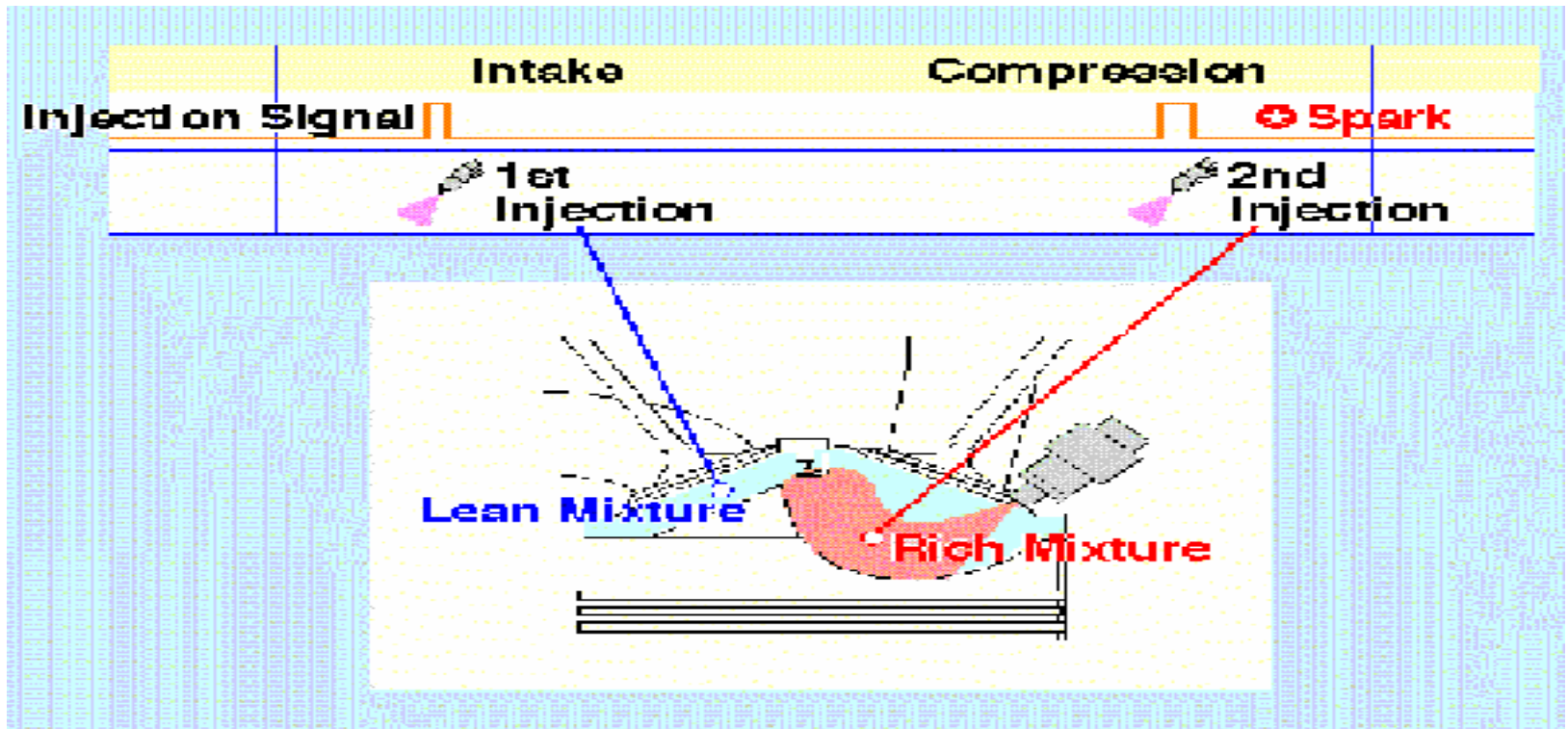


Fig. 10: Procedure of two-stage mixing

PERFORMANCE TESTING

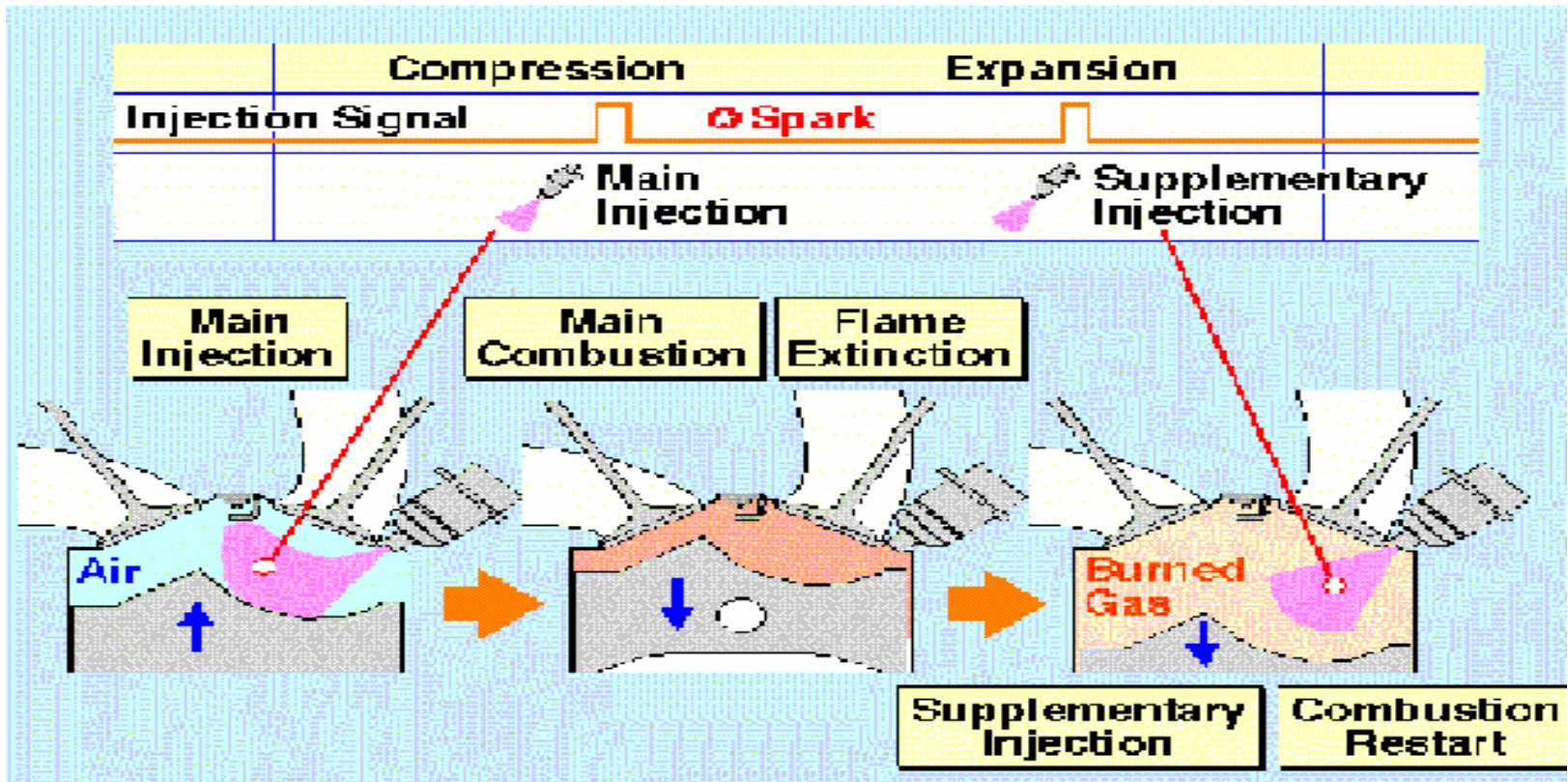


Fig. 12: Procedure to realize two-stage combustion

Preferred method of showing valve timing

