CATERPILLAR

ENGINE COURSE BOOK

CATERPILLAR ENGINE ELECTRONICS

COURSE DESCRIPTION

Title: Caterpillar Engine Electronics

Length: 4 1/2 Days

Prerequisite: None

Course Number: SEGQ4031

Content:

This Course is a basic introduction to Caterpillar electronic sensors and controls, and the related tooling and troubleshooting procedures. After successfully completing this class, students will be able to . . .

- **Use diagnostic tooling**
- **Use Caterpillar schematics**
- **Recall the 25 components of electronic engines and how they work**
- **Use the Electronic Troubleshooting Guide**
- **Successfully troubleshoot Caterpillar electronic engines**

Audience:

Students attending will be asked to bring approved safety glasses and wear only rigid shoes. (no canvas shoes or open toe shoes) Students should also bring a calculator.

This is a one week class, designed for Caterpillar dealer employees, customers, and Caterpillar employees. Attendees are usually some mixture of supervisors, engineers, and technicians.

Caterpillar Engine Electronics

Schedule

Day	Sec.	Subject	Time	
Monday	1	Introduction & Scope/Goals of the Class	8:00	9:30
		Break	9:30	9:45
	2	Engine Performance Factors	9:45	10:30
	3	Fuel Systems Overview	10:30	11:00
		Lunch	11:00	11:45
		Fuel Systems Overview	11:45	12:30
	4	Engine Nomenclature	12:30	1:00
	5	Electronic Engine History	1:00	2:15
		Break	2:15	2:30
	6	Digital Multimeter Lab	2:30	3:30
	7	Quiz (Review)	3:30	4:00
Tuesday	8	Electronic Control Modules	8:00	9:30
		Break	9:30	9:45
	9	Harnesses and Connectors	9:45	10:30
	10	Harnesses and Connectors Lab	10:30	11:00
		Lunch	11:00	11:45
	11	Electronic Sensors	11:45	2:15
		Break	2:15	2:30
		Electronic Sensors	2:30	3:30
	12	Quiz (Review)	3:30	4:00
Wednesday	13	Electronic Component Summary	8:00	9:30
		Break	9:30	9:45
	14	Electronic Technician Lab	9:45	11:00
		Lunch	11:00	11:45
	15	Open / Short Exploration Lab	11:45	2:15

		Break	2:15	2:30
		Open / Short Exploration Lab	2:30	3:15
		Lab Feedback (teams share results)	3:15	4:00
Thursday	16	Troubleshooting / Scenarios	8:00	9:15
		Break	9:15	9:30
		Troubleshooting / Scenarios	9:30	11:00
		Lunch	11:00	11:45
	17	Troubleshooting Lab (Broken Engines)	11:45	2:15
		Break	2:15	2:30
		Troubleshooting Lab (Broken Engines)	2:30	4:00
Friday		Troubleshooting Lab (Broken Engines)	8:00	9:15
		Break	9:15	9:30
		Troubleshooting Lab (Broken Engines)	9:30	10:15
	18	Final Test / Class Evaluation	10:15	11:00

Caterpillar Engine Electronics

Student Literature List

Description	Literature Number
Student Binder	SENR3470
Course Registration	Photocopy
Glossary of Terms	LEXQ9297
Course Schedule Sheet	Photocopy
List of Relevant Caterpillar Literature	Photocopy
Engine Performance Reference	LEXT1044
Lab Sheet - Digital Multimeter	Photocopy
Fuel System Quiz	Photocopy
Lab Sheet - Deutsch Connectors	Photocopy
Sure Seal Connector (Special Instructions)	SMHS7531
Deutsch HD & DT Connectors (Tool Manual)	SEHS9615
Proper Welding Techniques	SEBD6700
3176 Pocket Pal	LEXT3069
Sensors 3176B, 3406E, C-10, C-12	LEXT1724
Sensors C-10, C-12, 3406E, C-15, C-16	LEXT1725
Sensors 3116, 3126 HEUI	LEXT1722
Sensors Diesel Truck Electronics	LEXT1723
Operating Tips	NEEG2502
Cat Truck Engine Diagnostic Codes	NEEG2501
Cat Marine / Industrial Engine Diagnostic Codes	NEEG2490
ECM / Sensor Quiz	Photocopy
Lab Sheet - Unbroken Engines	Photocopy
Lab Sheet - Electronic Technician	Photocopy
Lab Assignment - Broken Engines	Photocopy
Final Exam	Photocopy
Course Evaluation Sheet	Photocopy

Caterpillar Engine Electronics

Hardware List

Every day:

- Whiteboard & markers
- Smartboard & projector

Monday:

- 7000 Series Fuel Nozzle
- 3116 MUI Injector
- 3176 Injector cutaway
- 3176B Injector cutaway
- 3406E Injector cutaway
- HEUI Injector cutaway
- HEUI Pump cutaway
- IAPCV cutaway
- Beaker of fuel with Thermal Hydrometer
- Electrical Components Group

Tuesday:

- 3176 Fat ECM
- PEEC ECM
- ADEM II ECM
- ADEM III (ADEM 2000) ECM
- Connector Kits - HD, DT, Sure Seal
- Red Extraction Tool (1 per student)
- HD Lab Kit (1 per student)
- DT Lab Kit (1 per student)
- Pin Crimper pliers (1 per student)
- Stripper pliers (1 per student)

- Wire - 14 AWG approx. 12" long (1 per student)

Sensors:

- Inlet Air Temperature
- Fuel or Coolant Temperature (1 active, 1 passive)
- Pressure Sensor - boost
- Pressure Sensor - oil
- Pressure Sensor - Atmospheric
- Pressure Sensor - HEUI oil
- Speed/Timing - brass bodied 3176
- Speed/Timing - 3406E
- Speed/Timing - 3126B passive
- Speed/Timing - C15
- Throttle Position - "Can Type"
- Throttle Position - 12v unpainted (pedal mounted)
- Throttle Position - 12v painted (pedal mounted)
- Throttle Position - "Speed Brick"
- Rack Position - 3512 PEEC
- Rack Position - 3406 PEEC
- Timing Position - 3406 PEEC
- BTM

Datalink Adapters:

- ATA (7X1686)
- GMC (7X1714)
- International (7X1403)
- J1939 (157-4829)

Additional Tooling:

- Fluke 87 Multimeter with probes
- Fluke 123 Industrial Scopemeter with probes

- 3 - wire HD Breakout Tee
- Spoons
- Simulator with Throttle Position Sensor

Caterpillar Engine Electronics

Lesson Plan 1 - Introduction & Scope/Goals of the Class

Objectives:

- The instructor will complete all administrative duties required for class start up.
- The instructor will explain the course objectives and course schedule to the students and answer any questions concerning them.
- The instructor will explain course safety procedures.
- The instructor will introduce himself and the training facility.
- The students will introduce themselves.

Literature Needed:

Registration Sheet	Copy
Course Schedule	Copy

Hardware Needed:

None

Time Required:

1.5 Hours

Tasks Required by Instructor to Meet Objectives:

1. Fill out registration forms.
2. Explain course objectives and schedule.
3. Explain course safety procedures.
4. Introduce self and students.

Caterpillar Engine Electronics

Lesson Plan 2 - Engine Performance Factors

Objectives:

- The student will gain an understanding of engine manufacturing test conditions by completing a sample problem.

Literature Needed:

Engine Performance Reference	LEXT1044
PowerPoint Slides	

Hardware Needed:

Beaker of fuel and thermo-hydrometer

Projector and smartboard

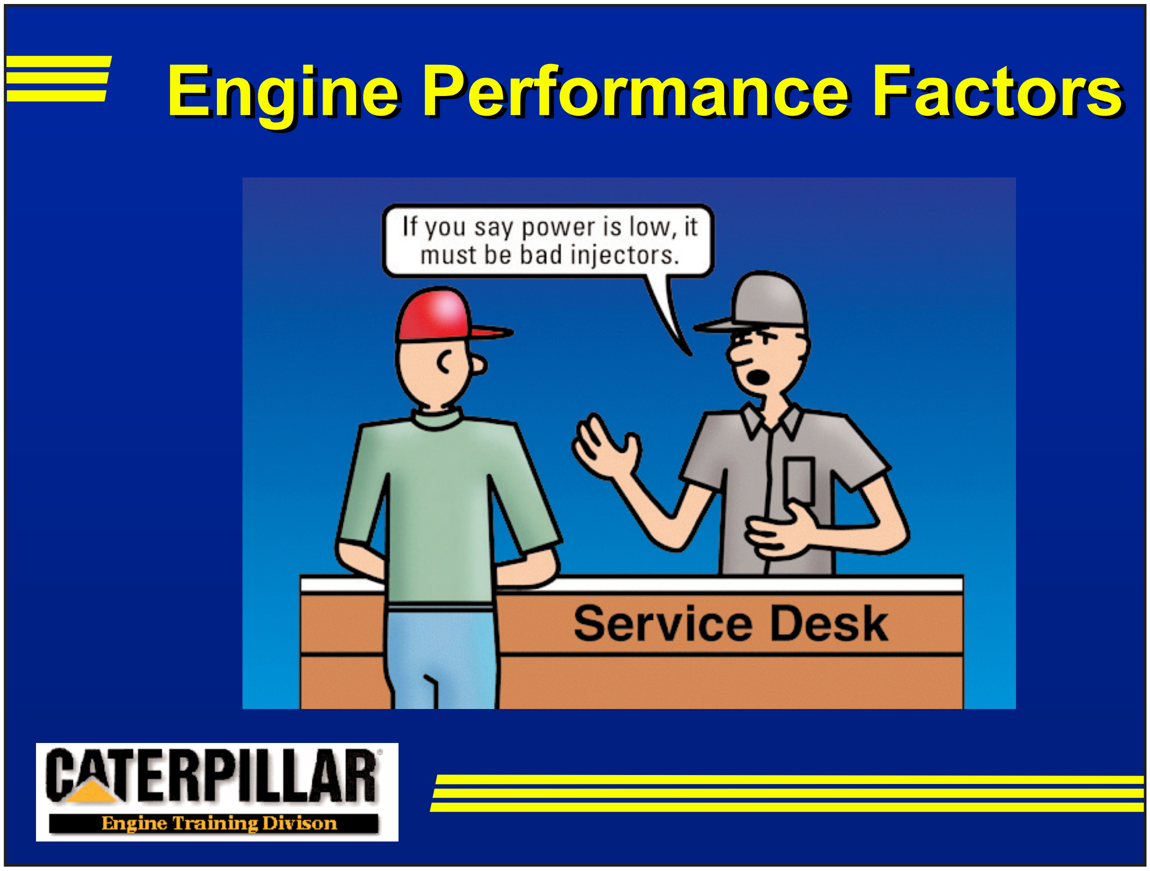
Calculator

Time Required:

.75 Hours

Tasks Required by Instructor to Meet Objectives:

1. Demonstrate fuel density measurement by using thermo-hydrometer and fuel sample.
2. Complete sample problem with students.
3. Answer any questions.



Slide # 1

• **HP tol = ± 3%**

Performance Tolerances:

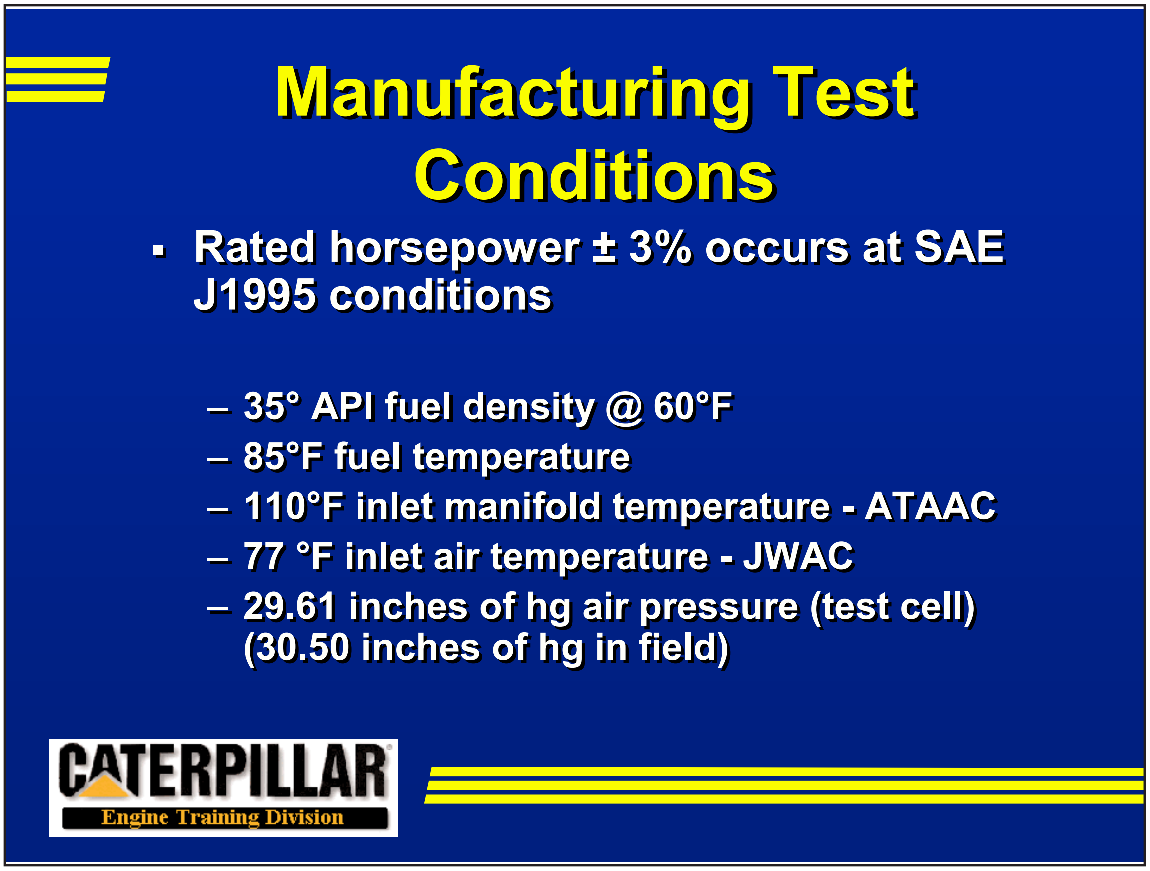
Caterpillar engines are guaranteed to produce their rated brake horsepower within a tolerance of +/-3%.

Question: Assume you have a 3406C engine, rated 425 hp at 2100 rpm, and it is running at full load. How low could its horsepower output be before you would suspect a problem with the engine?

Answer: We really can't say what the expected power should be unless we know the conditions in which the engine is operating.

97% X 425 hp = 412.25 hp.

However, the engine may be performing perfectly, yet producing less than 412 hp., depending on the ambient conditions.



Slide # 2

• SAE J1995

The engine is only guaranteed to make rated horsepower under conditions stated in SAE specification J1995.

This slide shows the manufacturing test conditions at which our engines are tested. It is not a Caterpillar specification, it is used by all major engine manufacturers.

Distribute a formula sheet to each student, and have them refer to the fuel density chart.

• Standard fuel

35°API @ 60°F is standard for the industry, not just for Caterpillar. Standard fuel weighs 7.076 pounds per gallon @ 60°F. Caterpillar sets horsepower in our manufacturing test cells, using 35°API @ 60°F fuel, heated to 85°F. It weighs 7.001 pounds per gallon, and has 18,392 BTU's per pound.

• Demo / practice use of thermo-hydrometer

Demonstrate fuel density measurement, using a thermo-hydrometer and a sample of fuel.

Use the formula sheet (pages that show the correction factors) to discuss standard conditions for fuel density, fuel temperature, inlet air temperature, and inlet air pressure.

Inlet air temperature:

Non-ATAAC: Standard is 77°F, measured after the air filter and before the turbocharger (if there is one).

ATAAC: Standard is 110°F measured in the air inlet manifold. You may need to bend a probe to fit the port on a 3406E.

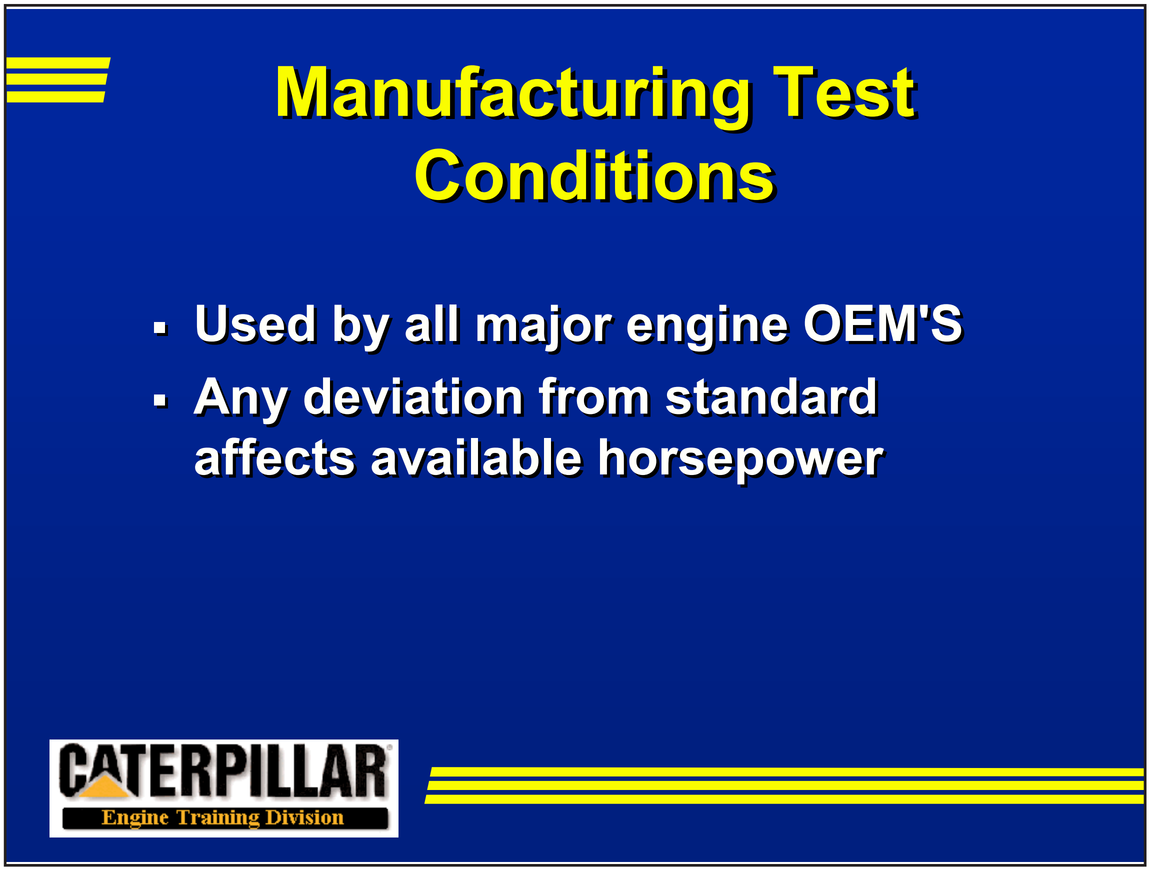
Ambient air pressure: 29.61”Hg is standard in a Caterpillar test cell, but 30.5”Hg is standard in the field. This takes into account the difference caused by air cleaner, relative humidity, and exhaust back pressure that are present in the field, but are not in the factory test cell.

In the test cell, we can control the humidity in the engine’s inlet air -- it doesn’t breathe test cell air.

The higher the relative humidity, the less oxygen present in the air to provide good combustion of the fuel.

The engine also does not have a muffler or air cleaner in the test cell.

Since we cannot control these factors in the field, we compensate by stating a higher norm for ambient barometric air pressure. As the actual ambient air pressure departs from this norm, we apply the correction factors found in the formula sheet.



Slide # 3

Operating conditions can either increase or decrease the engine's available horspower and torque.

- **> 1 reduce HP**

Correction factors greater than 1.000 will cause reduced power.

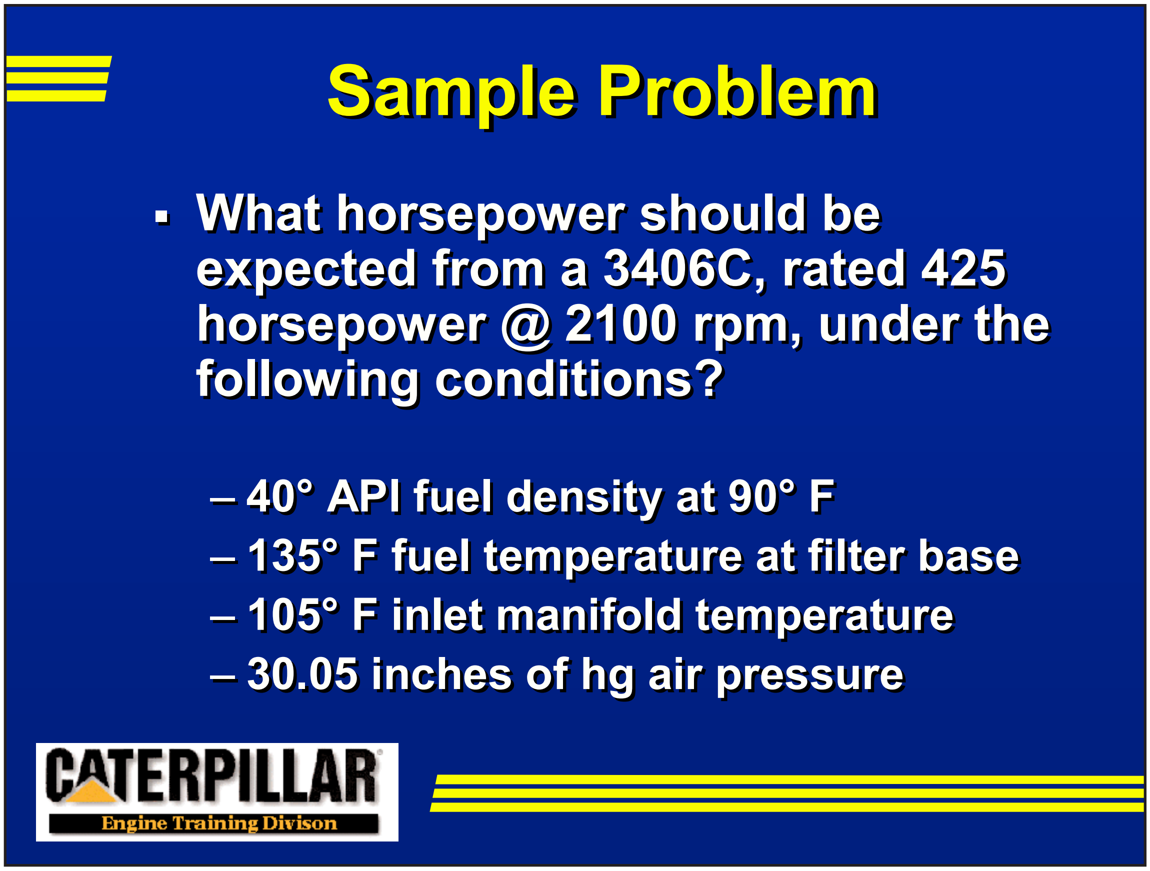
- **< 1 improve HP**

Correction factors less than 1.000 will improve horsepower.

- **15 HP Rule of Thumb**

Rule of thumb: operator will notice horsepower variation of 15 or more horsepower.

Answer any questions, then go to the next slide to work a practice problem.

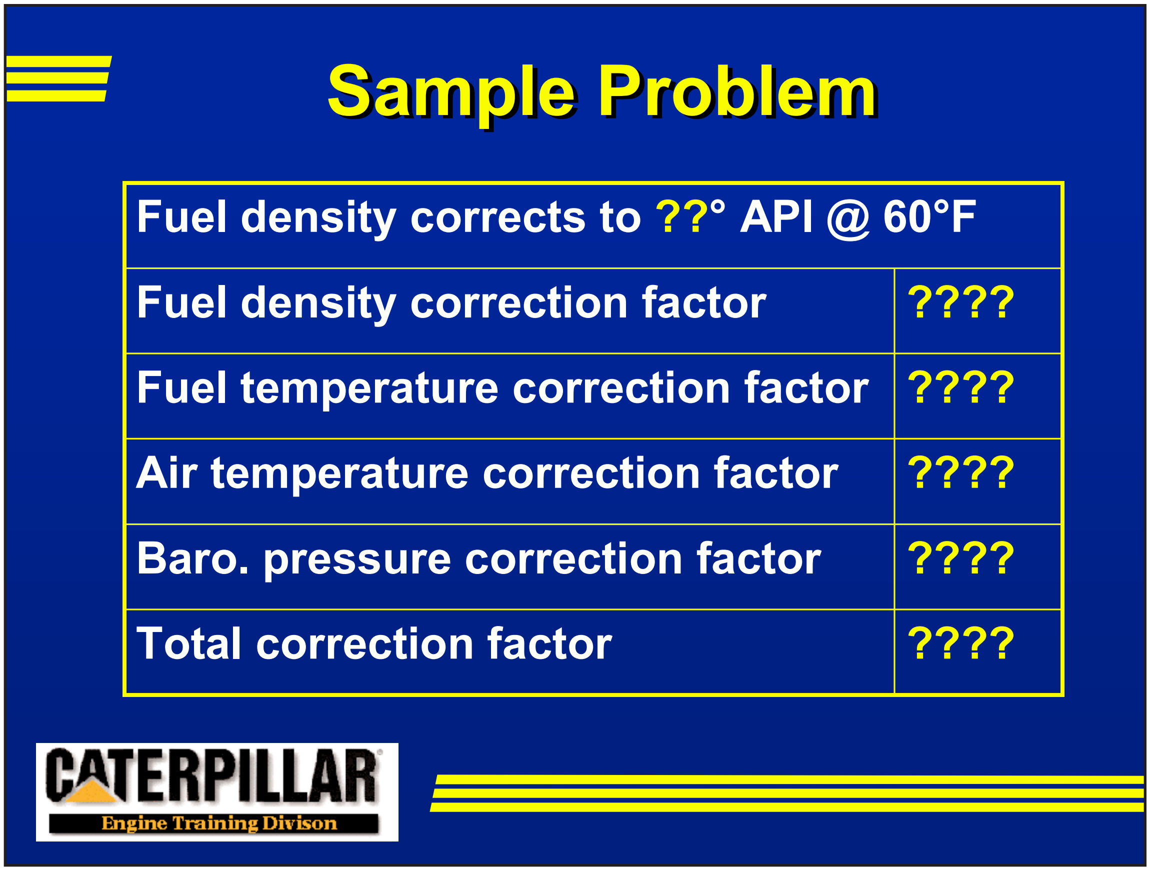


Slide # 4

• HP under conditions

Help the students as needed to find the information on the formula sheets (LEXT1044).

The following slides build a table that shows the answers one by one so that the students can check their work.



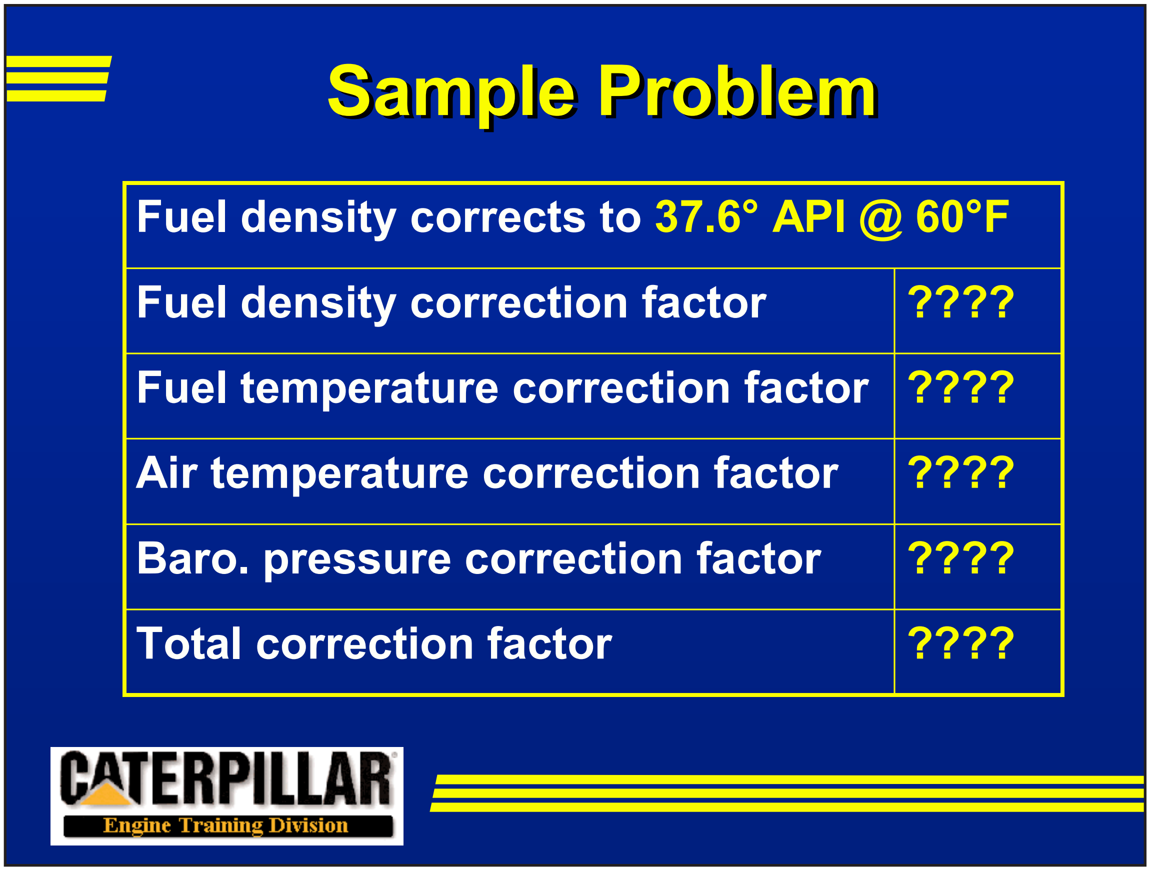
Slide # 5

Note to Instructor: If possible, demonstrate measuring API with a beaker of fuel.

First, correct the fuel density to 60°F.

The answer is 37.6° API at 60°F, as shown on the next slide. Since the API number is greater than 35, the fuel is less dense than standard.

There will be a reduction of power. The fuel density correction factor that we find in the table will be greater than 1.000.



Slide # 6

Now find the fuel density correction factor.

The factor is 1.011, as shown on the next slide. This correction factor means that there will be a 1.1% loss of power due to less than standard fuel density.

To find the % variation from standard, subtract the correction factor from 1.000, and multiply the result by 100%. In this case:

1.000 - 1.011 = -.011

-.011 x 100% = -1.1%

Sample Problem

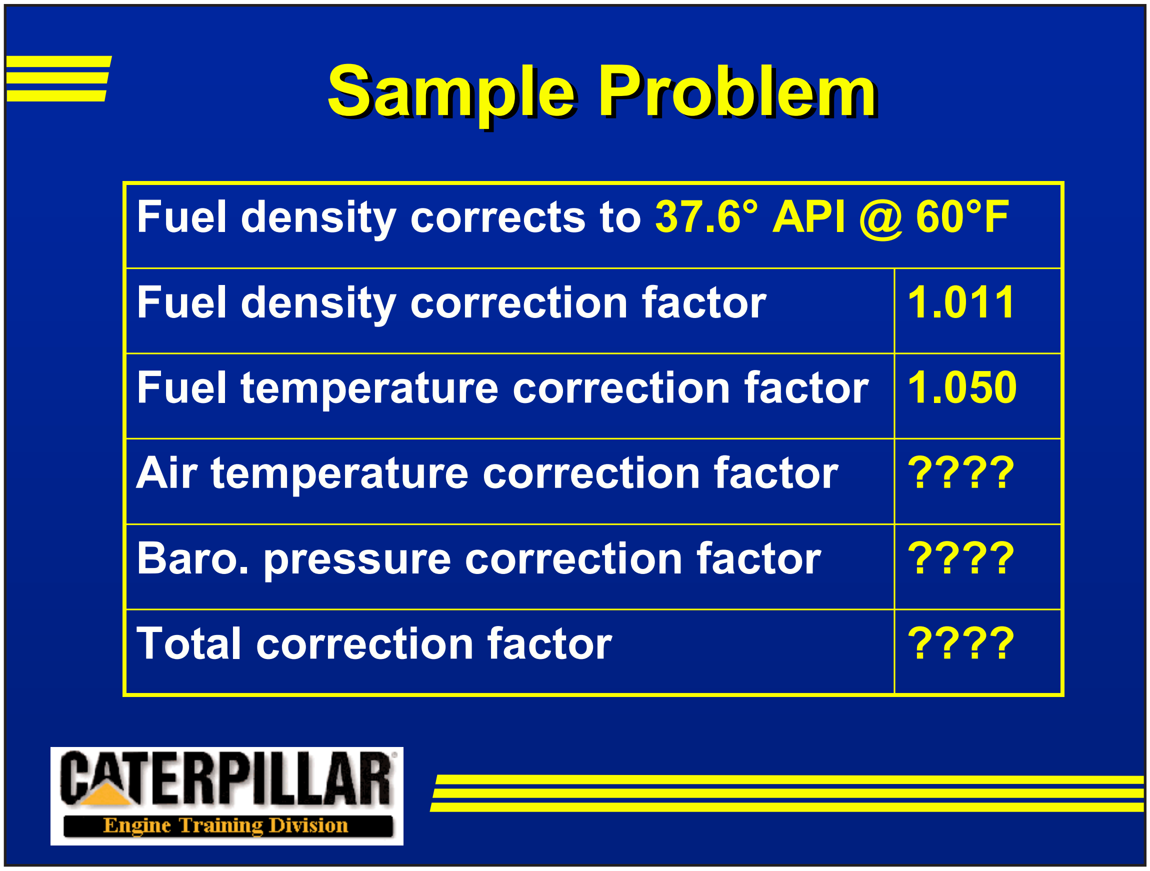
Fuel density corrects to 37.6° API @ 60°F	
Fuel density correction factor	1.011
Fuel temperature correction factor	????
Air temperature correction factor	????
Baro. pressure correction factor	????
Total correction factor	????

CATERPILLAR
Engine Training Division

Slide # 7

Now find the fuel temperature correction factor.

The factor is 1.050, as shown on the next slide.



Slide # 8

Now find the air temperature correction factor.

The factor is .997, as shown on the next slide.

This correction factor is very close to 1.000, because the air inlet temperature in this example (105°F) is very close to standard (110°F). Although the effect will be slight, the factor is less than 1.000 so there will be a positive effect on power.

To find the % variation from standard, subtract the correction factor from 1.000, and multiply the result by 100%. In this case:

1.000 - .997 = .003

.003 x 100 = +.3%

Sample Problem

Fuel density corrects to 37.6° API @ 60°F	
Fuel density correction factor	1.011
Fuel temperature correction factor	1.050
Air temperature correction factor	0.997
Baro. pressure correction factor	????
Total correction factor	????

CATERPILLAR
Engine Training Division

Slide # 9

Now find the barometric pressure correction factor.

The factor is 1.003, as shown on the next slide.

Sample Problem

Fuel density corrects to 37.6° API @ 60°F	
Fuel density correction factor	1.011
Fuel temperature correction factor	1.050
Air temperature correction factor	0.997
Baro. pressure correction factor	1.003
Total correction factor	????

CATERPILLAR
Engine Training Division

Slide # 10

With all the correction factors calculated, the next step is to multiply them times each other to arrive at the total correction factor:

1.011 x 1.050 x .997 x 1.003 = 1.062

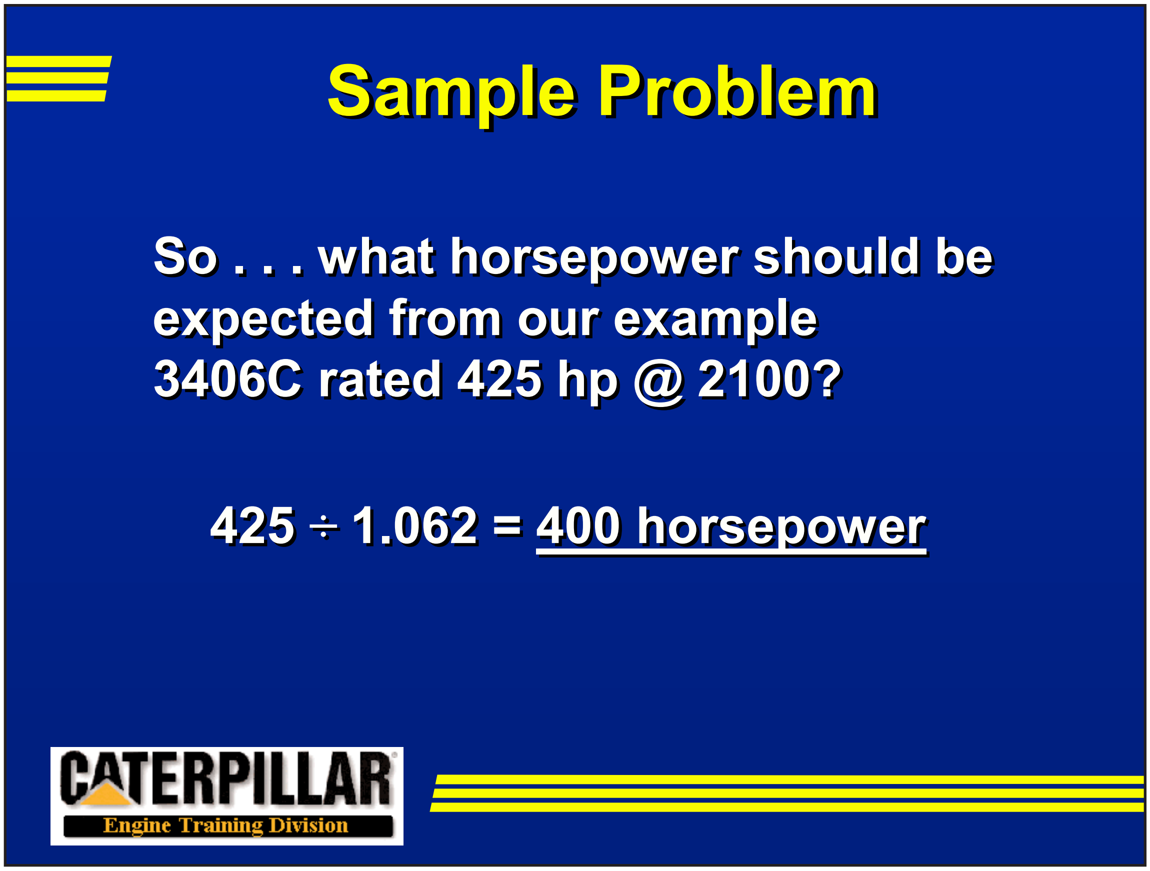
Sample Problem

Fuel density corrects to 37.6° API @ 60°F	
Fuel density correction factor	1.011
Fuel temperature correction factor	1.050
Air temperature correction factor	0.997
Baro. pressure correction factor	1.003
Total correction factor	1.062

CATERPILLAR
Engine Training Division

Slide # 11

The total correction factor shows that performance will be reduced by 6.2%. The main reason is the high fuel temperature. The expected horsepower under these operating conditions can be calculated by dividing the rated horsepower by the total correction factor (see next slide).



Slide # 12

• Below 15 HP rule

As seen, the expected horsepower is 400. This would more than likely cause a performance complaint. Generally, a loss of 15 horsepower or more can be felt by the operator.

• Importance of considering ALL aspects - fuel/air

So, even though it is an electronic engine it is important to take other non-electronic factors such as, fuel and air into consideration when troubleshooting.

• Instructor note

Students who work on oil field "fraccing rig" applications will be famaliar with measuring the hydraulic horsepower. This will be calculated as:

Hydraulic Horsepower = (Barrels per Minute) x (PSI) ÷ 40.8

Hydraulic horsepower depends upon the engine's brake horsepower minus a 5 to 10% loss in the transmission that drives the pump. Hot fuel (along with other performance factors) affects the output of any diesel engine. If the hydraulic horsepower is too low, it may be due to fuel temperature. Fuel return-to-tank rates have an impact on fuel temperature, especially with hot ambient conditions and partially filled tanks.

Here are some return rates:

	Cycle to head	Burn rate	Return
3176B	90 Gal/hour	10 Gal/hour	80 + Gal/hour
3512	250 Gal/hour	109 Gal/hour	141 + Gal/hour
3406E	70 Gal/hour	18 Gal/hour	52 + Gal/hour

Less than 1/2 full tank, with high return rate leads to hotter fuel. As heat goes up, fuel expands and becomes less dense (less weight per unit volume).

Remedies: use fuel coolers, use dual tanks, keep tank(s) full, make sure that the cooling fan from an engine is not blowing hot air onto a fuel tank.

Tomorrow, in our discussion of fuel temperature sensors on electronically controlled engines, we will talk about how some engines can compensate for elevated fuel temperature.

Electronics Class

Questions so far?

CATERPILLAR
Engine Training Divison

Slide # 13

Caterpillar Engine Electronics

Lesson Plan 3 - Fuel Systems Overview

Objectives:

- The student will be able to recall the four types of fuel systems and their importance.

Literature Needed:

PowerPoint Slides

Hardware Needed:

Plunger and barrel (wood mockup if available)

Mechanical Unit Injector (Cut away if available)

Electronic Unit Injector (Cut away if available)

Hydraulic Electronic Unit Injector (Cut away if available)

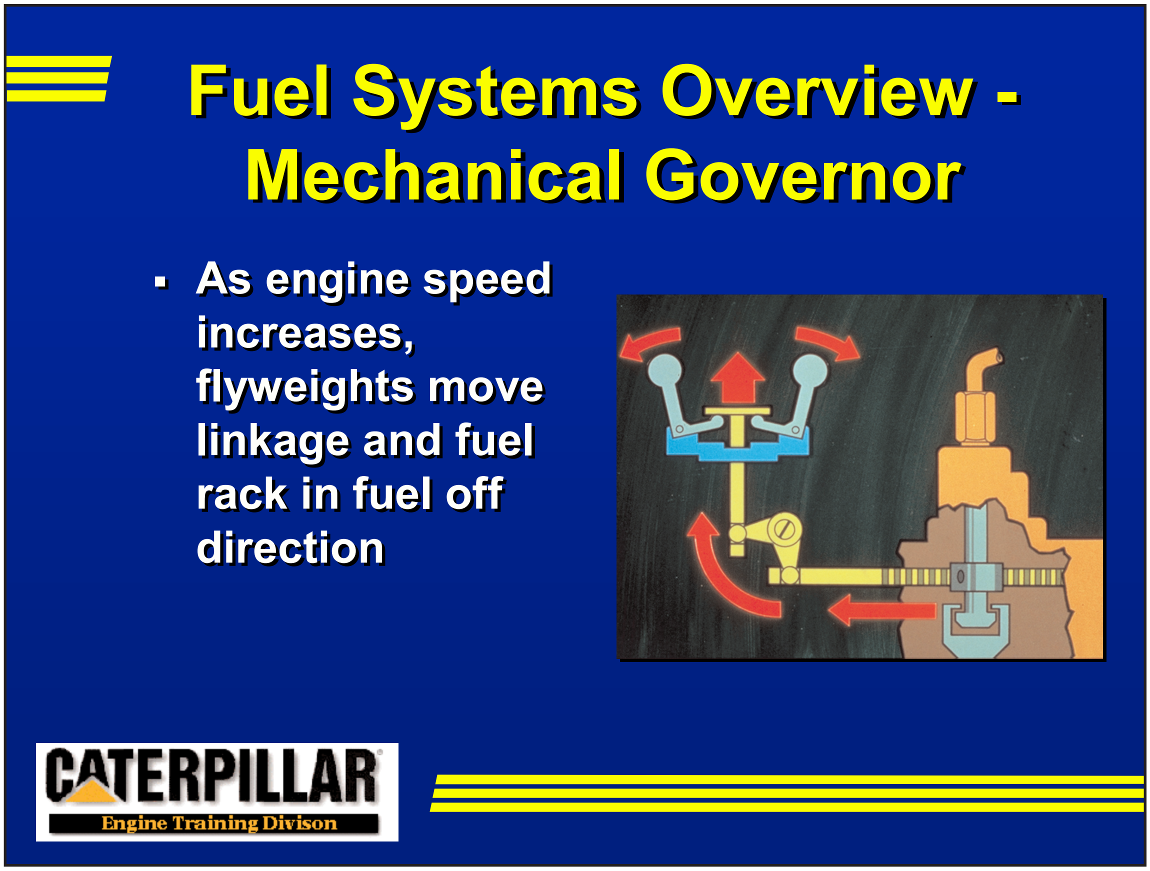
Projector and smartboard

Time Required:

.75 Hours

Tasks Required by Instructor to Meet Objectives:

1. Present the slides on fuel systems
2. llustrate the operation of a plunger and barrel with the wood mockup.
3. Pass around the injectors as they are discussed.
4. Answer any questions

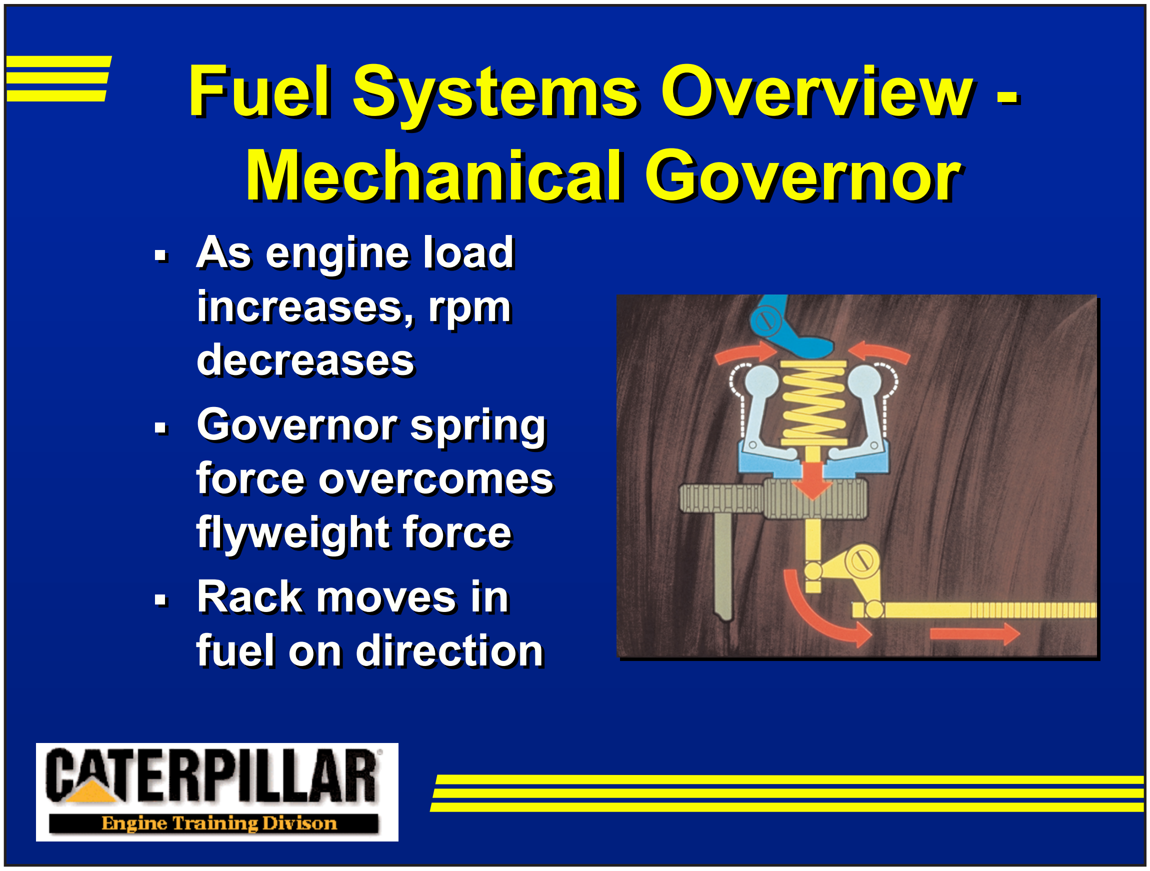


Slide # 14

• **Engine speed increases, flyweights move out, rack moves in off direction.**

When PEEC was introduced in 1987, it utilized most of the mechanical fuel system. This is an illustration of how the mechnical governor system functions.

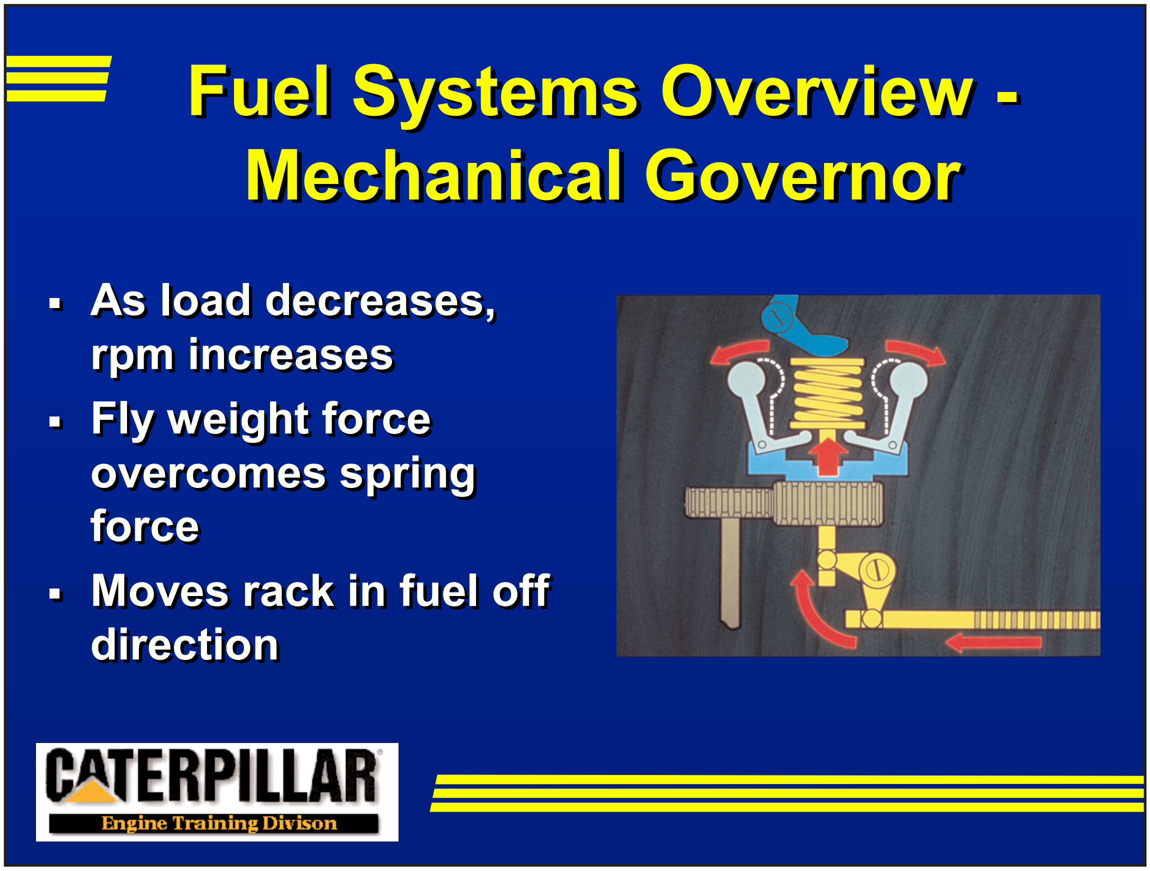
The governor controls the amount of fuel needed by the engine to maintain a desired rpm. Below the top red arrows are the governor flyweights. When the engine speed increases, centrigical force moves the flyweights out. In return, through a pivot lever, the rack linkage moves (bar just above bottom red arrow) in the fuel off direction.



Slide # 15

• **Load increases, rpm decreases, govenor spring moves rack in fuel on direction**

On the contrary, when engine load increases, rpm decreases. As engine speed slows, the flyweights also spin more slowly. With less rotational speed, the flyweight centrifugal force is decreased. The governor spring force overcomes the flyweight centrifugal force, and moves the rack in the fuel-on direction.



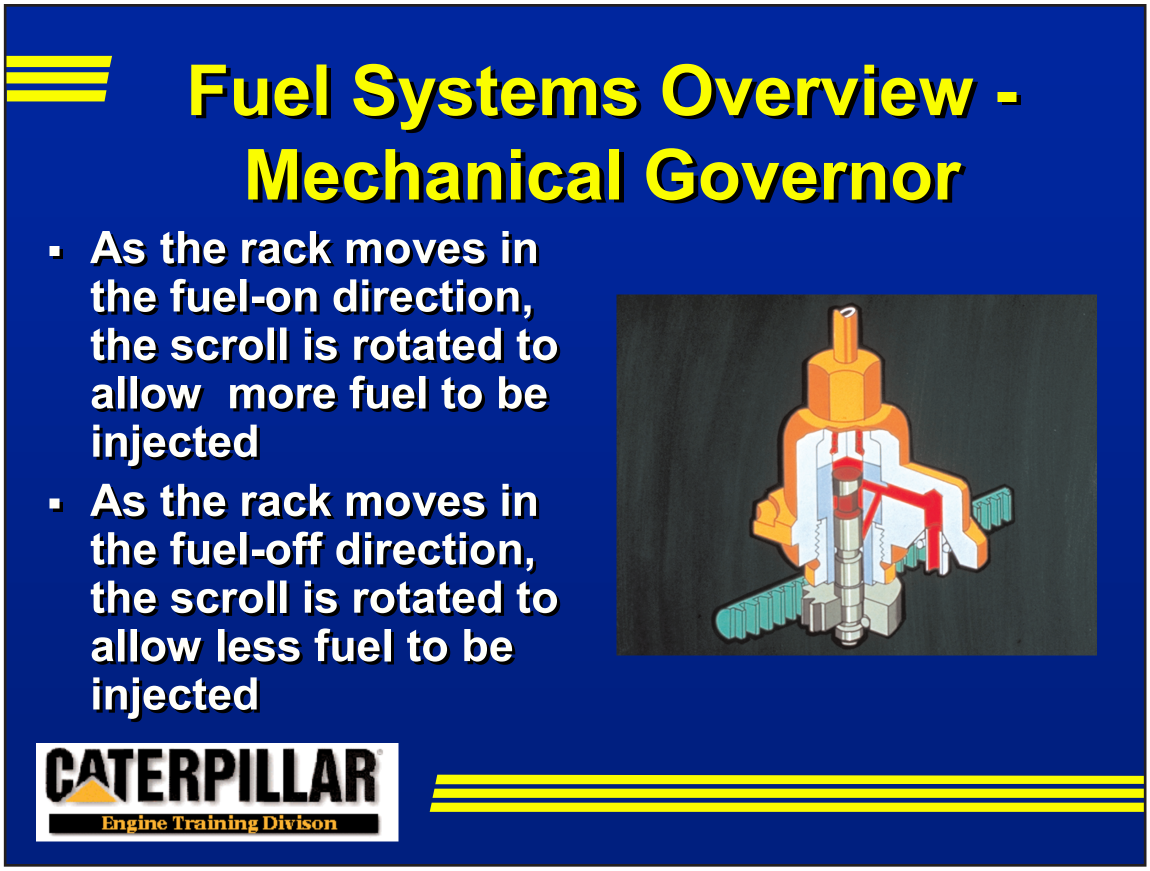
Slide # 16

- **Load decreases, rpm increases, flyweight force overcomes spring, rack moves in fuel off direction**

Once again, as engine load decreases, rpm increases. The spring force is overtaken by the centrigical force of the flyweights, and moves the rack in the fuel off direction.

- **Gov spring force = more fuel**
- **Force of flyweights = reduction of fuel,**
- **Force balanced = engine runs constant rpm**

The force of the governor spring always pushes to give more fuel to the engine. The centrifugal (rotating) force of the flyweights always pushes to get a reduction of fuel to the engine. When these two forces are in balance (equal), the engine runs at a constant rpm.



Slide # 17

• **Instructor note**

Read the caption. Point out the scroll. If a wood mock-up is available, use it to illustrate how the plunger and scroll move to determine the amount of fuel delivered.