Lab 1: GOVERNED ENGINE TESTS

OBJECTIVE:

During this laboratory period you will run an engine test similar to the power-take off portion of a Nebraska Tractor Test. Certain additional information not normally included in a Nebraska Test will also be developed. Parameters of interest are engine torque, horsepower, RPM, fuel and air consumption.

1) To observe the manner in which a governed engine reacts to changes in load.
2) To determine horsepower and torque at various loading of a governed engine.
3) To observe the effect of load on fuel consumption efficiency.
4) To observe volumetric efficiencies under varying loads.

PROCEDURE:

A. The class should organize so as to have all members participate in some phase of the test: operation, data collection, or data analysis.

B. Before starting the engine, confirm that the dynamometer control knobs and switches are in the following positions:

i. Controller power sw. -	"off"
ii. Dynamometer power sw. -	"off"
iii. Performance monitor sw. -	"load"
iv. Load control pot -	"fully counter-clockwise"*
v. Load switch:	
1. Man./Ext. -	Out (Man.)
2. Torque/Current -	Out (Torque)
vi. RPM control pot -	"fully clockwise"*
vii. RPM switches:	
1. RPM/Load -	Out (RPM)
2. Man./Ext. -	Out (Man.)

viii. Be certain controls are unlocked before attempting settings.

With the exception of the controller and dynamometer power switch and RPM control pot, all switches are in a position for completing the test.

C. Start the engine and run until thoroughly warmed. To hasten warming:

i. Engage dynamometer with engine clutch.
ii. Open throttle to about 1500 rpm.
iii. Turn on controller power and dynamometer power switches (yellow lamps on). Red "excitation" lamp may glow.
iv. Place the RPM/Load switch in the "OUT" (Load) position. Turn load pot clockwise to load engine slightly. **DO NOT OVERLOAD!**
v. Leave the load on until engine operating temperature reaches approximately 160° F. Turn load pot fully anti-clockwise to unload the engine. Place the RPM/Load switch in the "IN" (RPM) position.

D. When engine is warm, you are ready to begin a test.

i. Be certain load knob is returned to full counter-clockwise position.
ii. Open throttle all the way (w.o.t.). Record values of engine load (lbs), RPM, fuel flow (gph), and air flow (cfm) on the accompanying data sheet. These values represent the first run under load due to the method of connecting engine dynamometer and controls.

Using the controller load pot, and beginning at the high engine speed and ending at approximately 1100 rpm, slowly decrease the load (cw pot rotation) on the engine in appropriate steps to obtain at least 10 sets of readings. The first five of these readings should be between highest and rated speed. (Rated speed is that speed at which the governor has the throttle plate in the carburetor -- or injection delivery valve in the case of diesels -- in the fully open position.) The remaining five runs should be equally spaced over the difference of the rated speed and approximately 1100 rpm.

iii. Repeat steps 2 & 3 with throttle settings of 80% of w.o.t. and 60% of w.o.t.
iv. When load tests are complete, remove load (cw rpm pot rotation) from the dynamometer and reduce the engine speed to approximately 750 rpm (idle). Note and record the value of air consumption.
v. De-clutch the dynamometer. Let idle for one minute. Shut off engine.

EQUIPMENT: Governed engine, dynamometer which indicates load and speed, fuel and air flow measurements equipment and a stopwatch.

THEORY:

$$P_b = \frac{2pi\,FR\,N}{33{,}000}$$

Where (English Units)
P_b = brake power, Hp
T = torque, ft - lbs
F = net dynamometer load, lbs.
R = length of dynamometer reaction arm, ft.
N = dynamometer speed, rpm
$2pi$ = constant, number of radians in 360^o of rotation
33,000 = constant, 1 Hp = 33000 ft - lb / min

$$P_b = \frac{2pi\,FR\,N}{60{,}000}$$

Where (Metric Units)
P_b = brake power, kW
T = torque, N.m
F = net dynamometer load, N.
R = length of dynamometer reaction arm, m.
N = dynamometer speed, rpm
$2pi$ = constant, number of radians in 360^o of rotation

One measure of fuel efficiency is **specific fuel consumption**, the quantity of fuel required per unit of work done. This is expressed as **kg of fuel/ (kW-hr)** or **lbs of fuel/ (hp-hr)**, and is calculated by dividing the fuel consumption, kg/hr or lbs/hr by the power.

$$BSFC = \frac{m_f}{P_b}$$

Where (English Units)
BSFC = brake specific fuel consumption, lb / (hp. hr)
m_f = fuel consumption, lb / hr
P_b = brake power, Hp

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Where (Metric Units)
BSFC = brake specific fuel consumption, kg / (kW. hr)
m_f = fuel consumption, kg / hr
P_b = brake power, kW

Another measure of fuel efficiency is **brake thermal efficiency**, e_{bt} which is brake power (P_b) divided by fuel equivalent power (P_{fe})

$$P_{fe} = \frac{m_f * HV * 778}{60 * 33{,}000}$$

Where (English Units)
P_{fe} = fuel equivalent power, Hp
m_f = fuel consumption, lb / hr
HV = heating value of fuel, BTU / lb
778 = conversion factor, 778 BTU per ft - lb work
33,000 = constant, 1 Hp = 33000 ft - lb / min

$$P_{fe} = \frac{m_f * HV * 778}{3{,}600}$$

Where (Metric Units)
P_{fe} = fuel equivalent power, kW
m_f = fuel consumption, kg / hr
HV = heating value of fuel, kJ / kg
3,600 = conversion factor, s / hr

Mixtures of air and fuel will burn only when they are mixed in correct proportion. This proportion of air and fuel is known as the "air-fuel ratio" and is determined on a weight (or mass) basis. The ratio can be determined by measuring air and fuel inputs for a given operating condition and substituting the proper values in the equation:

$$A/F = \frac{mass\ air\ (lb\ air)}{mass\ fuel\ (lb\ fuel)} \qquad A/F = \frac{mass\ air\ (kg\ air)}{mass\ fuel\ (kg\ fuel)}$$

If measurements are on the rate basis, i.e. lb/min or kg/min, then one may substitute as follows:

$$A/F = \frac{mass\ air\ (lb/\min air)}{mass\ fuel\ (lb/\min fuel)} \qquad A/F = \frac{mass\ air\ (kg/\min air)}{mass\ fuel\ (kg/\min fuel)}$$

Volumetric efficiency or Delivery Ratio (V.E.) represents the percentage of piston displacement filled with gasses during say, an intake stroke, and there is a distinct relation between it and the engine cylinder's mean effective pressure (M.E.P.) and hence, power output. V.E. is the ratio of actual volume to the theoretical volume of intake.

$$\text{Delivery Ratio} = \frac{m_a}{m_{at}} = \frac{actual\ mass\ flowrate\ of\ air\ (lb\ or\ kg/\min air)}{theoretical\ mass\ flowrate\ of\ air\ (llb\ or\ kg\ ambient\ air)}$$

Note the calculation of theoretical air flow requires knowledge of the number of engine revolutions per intake strokes. For a 4 str. cycle, there are 2 revolutions per intake stroke

$$m_{at} = \frac{DN}{rc} \frac{1}{12^3} \rho$$

Where (English Units)
m_{at} = *theoretical mass flowrate of air, lb/* min
D= *Engine Displacement*, in^3/*cycle*
rc= *revolutions per cycle, (4 stroke =2)*
$1/12^3$ = *Unit conversion factor* (ft^3/in^3)
ρ = *Ambient air density*, lb/ft^3

$$m_{at} = \frac{DN}{rc} \frac{1}{1000} \rho$$

Where (English Units)
m_{at} = *theoretical mass flowrate of air, kg/* min
D = *Engine Displacement, l/cycle*
rc = *revolutions per cycle, (4 stroke =2)*
$1/1000$ = *Unit conversion factor* (m^3 / *l*)
ρ = *Ambient air density*, kg/m^3

Finally, the effective pressure resulting from combustion can be determined. These represent average working pressures throughout the power stroke and are called **mean effective pressures**. These can be determined for 4-stroke engines, from the M.E.P. equation:

$$P = \frac{p_{mep}(L/12) A_p N_e \, n}{33*10^3 (rc)} = \frac{p_{mep}(D/12) N_e}{33*10^3 (rc)}$$

Where:
P = *Power, Hp*
p_{mep} = *Mean Effective Pressure, psi*
L_i = *Stroke Length, in*
A_p = *Piston Area*, in^2
D = *Engine Displacement*, in^3
N_e = *Engine Speed, rpm*
n = *Number cylinders*
rc = *revolution per cycle* (4 *stroke* = 2)

$$P = \frac{p_{mep}(L) A_p N_e \, n}{60*10^6 (rc)} = \frac{p_{mep}(D) N_e}{60*10^3 (rc)}$$

Where:
P = *Power, Hp*
p_{mep} = *Mean Effective Pressure, kPa*
L_i = *Stroke Length, cm*
A_p = *Piston Area*, cm^2
D = *Engine Displacement, l*
N_e = *Engine Speed, rpm*
n = *Number cylinders*
rc = *revolution per cycle* (4 *stroke* = 2)

FORMAL REPORT:

1) A formal report with Introduction, Objectives, Methods and Procedures, Results and Discussion section is required. All table and figures must be well organized, with adequate axis and labels, and captions for all figures and tables. The report must be typed, with all figures and tables computer generated, except sample calculations which can be neatly hand written and attached as an appendix.

2) For each set of data taken calculate and display in a captioned table in the report:
   a) Engine Brake Power and Torque.
   b) Brake Specific fuel consumption,
   c) Brake Thermal efficiency (%)
   d) Brake Mean effective pressures (psi, kPa)
   e) Air-fuel ratio (mass air/mass fuel)
   f) Volumetric efficiency (delivery ratio) for each run, including idle speed; where
      i. V.E. = Act. Vol. of air intake / Theor. Vol. of intake
   g) Show one complete set of sample calculations. Include your data sheets with your report.

3) Plot engine power, torque and spec. fuel consumption vs. engine rpm. Use good graphing techniques. Be sure to include a title block with graph title, tractor model, your name, class, and date. Show location of governed range, load control range, high idle speed, rated engine speed, and rated power on plots. (No load, or high idle, speed may be obtained by extrapolating the right hand portion of the hp and torque curves of Step 1 to an intersection with the abscissa, for the WOT test)

4) Discuss your results. Explain the relationship between power, torque and spec. fuel consumption.
   a) Explain why power and torque curves are shaped the way they are.
   b) Why do the curve shapes, differ in the governed range compared to the load control range?
   c) Why does the specific fuel consumption increase rapidly in the governed range?
   d) Does torque continue to rise somewhat in the load control range as engine RPM decreases?
      i. What aspect of engine performance does this characteristic describe?
   e) Do max. power and torque occur at the same point? – Discuss the reasoning behind your answer.
   f) What engine rpm would you select for a 45 hp output? Discuss this in general terms with regard to fuel efficiency, torque characteristics and overall operational efficiency.
   g) Discuss the relationship between vol. eff., engine rpm and the governor (fuel per injection). Hint: The optimum valve timing is different at different engine speeds and turbocharger boost depends on exhaust temperature and pressure.

5) Plot torque and mass of fuel per injection cycle versus rpm. Comment on the shape of the curves. How would you increase the torque reserve of an engine?

Possibly useful conversion factors

1 lb ≈ 4.4482 newtons	1 in = 2.54 cm
1 atm ≈ 101.3 kPa ≈ 14.696 psi	1 gal = 231 in^3

Name ______________________________
Date: ________________________

OBSERVED DATA - DYNAMOMETER TESTS

Engine:
Make & No. Cyls. ________________________
Bore & Stroke(in,cm)__4.2" 5" (106mm, 127mm)
Calculated Displacement (in^3,L) ______________________
Fuel Properties:
Type ___Diesel_________________
Weight ____6.9 lbs/gal (823 kg/m^3)
Heat Content__19350 BTU/lb, (45000 KJ/kg)

Dynamometer
Brake Arm Length___0.885ft (27 cm)

Air Properties:
Barometer __________________mm HG
Temp. ___________________________
Rel. Hum. ______________________%
Sp. Vol.__13.9 ft^3/lb, 0.868 m^3/lb)

Run #	Engine Speed (rpm)	Dynamometer Load (lbs)	Fuel Flow (lb/min)	Airflow meter (cm H_2O)	Air Flow (Cfm)= 55 *R	Air Flow (lb/min)
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