MAK 411E Experimental Methods in Mechanical Engineering

# AUTOMOTIVE LABORATORY MANUAL

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# I. VEHICLE TECHNOLOGY LABORATORY

## Part 1. Determination of the center of gravity location:

The location of center of gravity (CG) is necessary for

- Calculating the climbing ability (Gradability)
- Acceleration performance
- Designing brake systems and springing
- Vibration considerations
- Handling and rollover considerations
- Driving stability investigations
- Determining mass moment of inertia etc.

Low center of gravity is always desirable, as they are associated with fewer driving dynamic problems and increased vehicle performance during cornering and braking, but in practice the design options are relatively restricted.

The position of center of gravity is highly dependent on the loading; when the vehicle is loaded the CG changes in both longitudinal and vertical axis. The body lowers when it is loaded, i.e. its center of gravity drops. The center of gravity of the passengers and the luggage is usually higher than that of the body so the end results a higher overall center of gravity.

The first step in calculating the individual wheel loads in steady state cornering, accelerating, or braking conditions is to determine the CG location. Therefore, in Part 1, the location of CG will be determined experimentally, and using this data, braking performance of this vehicle will be analyzed in Part 2

**Instruments:**

A simple crane, a frame to lift the axle of the test vehicle, a load cell connected between the frame and the crane, amplifier (bridge), voltmeter, and a straight ruler.

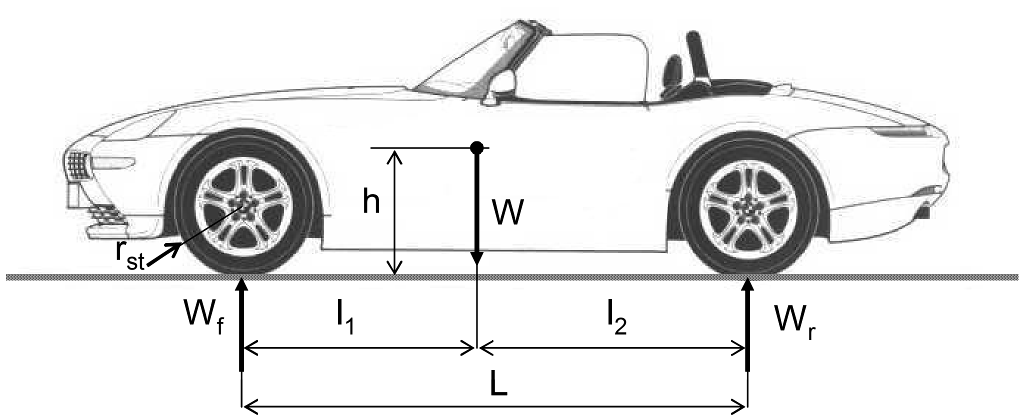



**Figure 1 Location of vehicle's center of gravity.**

Mathematical observation of the measurement is as follows: Using known front and rear axle loads, location of the center of gravity along the longitudinal axis ($l_1$ and $l_2$) can be easily calculated.

From Figure 1, total weight is

$$W = W_f + W_r \tag{1}$$

and where

$$L = l_1 + l_2 \tag{2}$$

Taking moment at rear tire contact point:

$$W.l_2 = W_f.L$$

Thus,

$$l_2 = \frac{W_f}{W} L \qquad \text{and} \qquad l_1 = L - l_2 \tag{3}$$

In Figure 2, taking moment at the center of the rear axle

$$W_f'.L.Cos\alpha + W.Sin\alpha.h' - W.Cos\alpha.l_2 = 0 \tag{4}$$

where

$$\sin\alpha = \frac{H}{L} \tag{5}$$

and calculating h′, height of the center of gravity is

$$h = h' + r_{st} \tag{6}$$

where $r_{st}$ is the static radius of the tires.

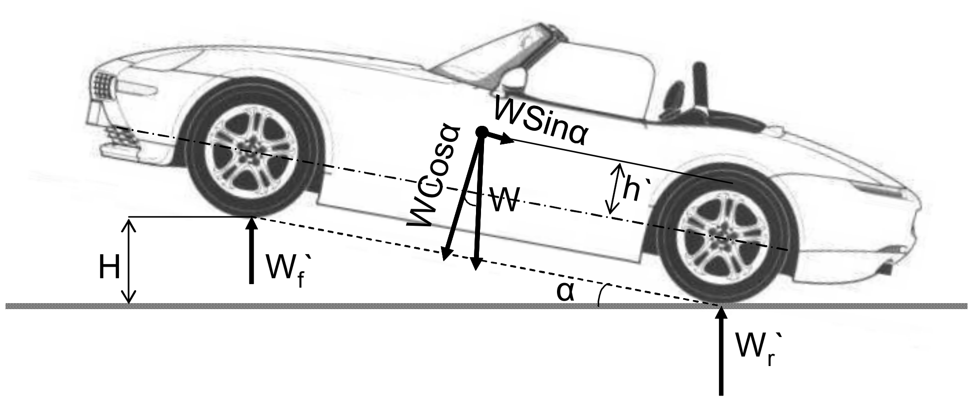



**Figure 2 Determination of center of gravity height.**

**Procedure:**

1) Properly inflate all tires on the test vehicle. To eliminate tire springing during the measurement, it is recommended that the tire pressure on both axles be increased to 3.0 to 3.5 bar.
2) In order to eliminate the springing effect. Both axles must be prevented from compressing or rebounding before the vehicle is raised. A locking device must be used to adjust the amount of compression in the suspension springs when the vehicle is loaded. (Welding an old set of shock absorbers is an easy solution)
3) Measure and record the tire static radius (both front and rear).
4) Measure and record the front and rear tire track width.
5) Measure and record the wheel base length.
6) Record the vehicle fuel load and other weight variables. Any load that could shift must be secured; fuel tank should be empty or full. The vehicle should be in on-road condition, i.e. tools, spare wheel etc.
7) Place the load sensor between the frame and the crane and calibrate the load sensor for normal load.
8) Lift the frame and balance the amplifier when only the frame's load acting on the sensor.

   *Note: Please take extreme caution not to damage the cables by stepping on them, running over them with the vehicle or the frame or in any way mistreating them. Electric cranes should be operated by the laboratory staff only! Never attempt to use the remote control by yourself.*

9) Place the front axle of the test vehicle on the frame.
10) Lift the front end of the vehicle "just enough" to separate the contact between the tires and the ground. Record the front axle load. The rear wheels must be rolling freely. Brakes must be released and gear box must be in neutral.
11) Lift the front axle of the vehicle using the crane (30-50 cm recommended). Record the new front axle load and the distance between the wheel hub center and the ground.
12) Subtract the static tire radius to calculate H.
13) Move the rear axle of the vehicle into the frame. Repeat the step 9 for the rear axle.
14) Reconfigure the vehicle with the test personnel in the vehicle. (If instructed)

**Requirements:**

1) Derive the necessary equations and determine the location of CG along the longitudinal and vertical plane.
2) Discuss the effects of CG location on acceleration, climbing, stopping distance, springing, handling and rollover performance of a vehicle briefly.
3) Prepare a short design section for the report, which identifies the projected weight distribution for your design vehicle. Discuss the effects of power plant, drive axle, driver, passenger, trunk and fuel tank weights and their locations.
4) Answer the questions that may be assigned by your laboratory instructor.

**Part 2. Determination of brake force distribution:**

Braking performance of motor vehicles is one of the most important characteristics that affect vehicle safety. In order to stop the vehicle in shortest distance, brakes should be applied by means of all wheels. The vehicle's center of gravity and the specified distribution of braking force to the front and rear axles determine the amount of braking force which can be applied before the wheels lock at any specific level of adhesion between tire and road surface. Forces acting on a braking vehicle are illustrated in Figure 3. It is well known that the preferred design is to bring both axles up to the lockup point simultaneously. However, it is not possible over the complete range of operating conditions to which a vehicle will be exposed. Lock-up reduces the brake force on an axle, and results in some loss of ability to control the vehicle.

The distribution of braking forces on the front and rear axle is accomplished through brake proportioning. The braking-force-distribution is used to illustrate this relationship. In Figure 4, the coordinate axes show the braking force at front and rear axles relative to weight. The intersection of the straight lines, representing equal adhesion coefficients, at front and rear axles form the parabola describing "ideal" braking force distribution. Lines representing constant braking complete the diagram. If no braking-force proportioning device is provided, then the distribution of the braking force as installed in the unit also forms a straight line. The slope is the ratio of the braking forces at front and at rear axles as determined by the dimensions of brakes. The wheels always lock on the front as long as the installed braking distribution remains below the ideal distribution (Stable braking). The point at which the front wheels lock is found at the intersection of installed distribution and the lines representing the respective coefficient of adhesion. When the rear tires lock up, the vehicle will loose directional stability. The lock up of front tires will cause a loss of directional control, and the driver will no longer be able to exercise effective steering.

Braking-force proportioning device is used to adjust the apportionment of the braking force between front and rear axles as determined by the brakes' particular dimensions in order to achieve a closer approximation to the ideal distribution.

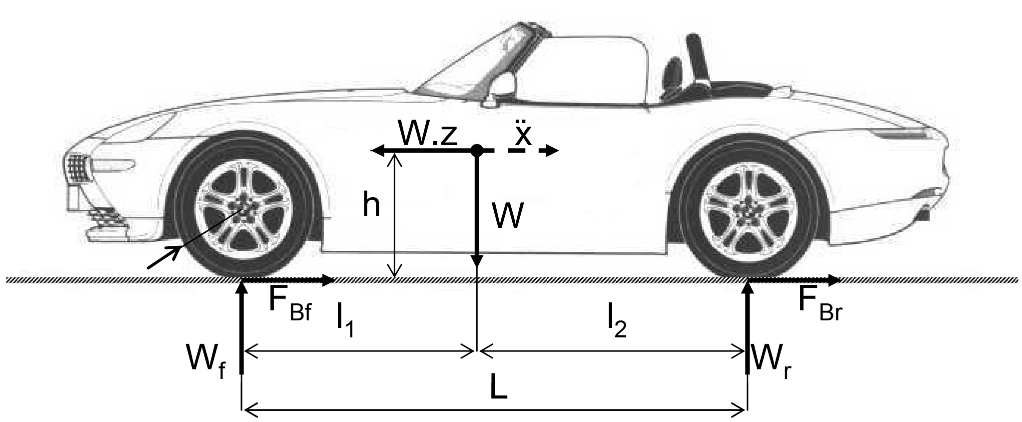



**Figure 3 Forces acting on a vehicle during braking.**

The distribution of the braking forces between the front and a rear axle is a function of the design of the brake system when no wheels are locked. For a conventional brake system, the distribution of the braking forces is primarily dependent on the hydraulic or pneumatic pressures, brake geometry and brake cylinder areas in the front and rear brakes. Proportion of the front brake forces to total brake force is represented by $K_{bf}$ where $F_{Bf}$ and $F_{br}$ are front and rear braking forces respectively.

$$K_{Bf} = \frac{F_{Bf}}{F_{Bf} + F_{Br}} \tag{7}$$

During braking, a dynamic load transfer from the rear axle to the front axle occurs such that the load on an axle is the static plus the dynamic load transfer. Neglecting, the road resistances, from Figure 3, front and rear axle loads can be calculated as:

$$W_f = \frac{W}{L}(l_2 + z.h) \quad \text{and} \quad W_r = \frac{W}{L}(l_1 - z.h) \tag{8}$$

where z is non-dimensional deceleration

$$z = -\ddot{x} / g \tag{9}$$

From the force balance in longitudinal axis

$$F_{Bf} + F_{Br} = W.z \tag{10}$$

Thus

$$\frac{F_{Bf}}{W} + \frac{F_{Br}}{W} = z \tag{11}$$

Adhesion coefficients for the front and rear axle is given by:

$$\mu_{front}(z) = \frac{F_{Bf}(z)}{W_f(z)} \quad \text{and} \quad \mu_{rear}(z) = \frac{F_{Br}(z)}{W_r(z)} \tag{12}$$

Then, on each axle maximum braking force is given by:

$$F_{Bf\,\max} = \mu_P.W_f \quad \text{and} \quad F_{Br\,\max} = \mu_P.W_r \tag{13}$$

where $\mu_P$ is the peak coefficient of friction.

In order to satisfy stability criterion, adhesion coefficient at rear axle must be smaller than the adhesion coefficient at front axle.

$$\mu_{rear} < \mu_{front} \tag{14}$$

Maximum deceleration and stability criterion is satisfied where

$$\mu_{front} = \mu_{rear} \tag{15}$$

Thus

$$\left(\frac{F_{Bf}}{W_f}\right)_{ideal} = \left(\frac{F_{Br}}{W_r}\right)_{ideal} \tag{16}$$

Solving Equation 11 and Equation 16 simultaneously, ideal brake force distribution curve can be calculated.

$$\left(\frac{F_{Bf}}{W}\right)_{ideal} = z\left(\frac{l_2}{L} + z\frac{h}{L}\right) \tag{17}$$

and

$$\left(\frac{F_{Br}}{W}\right)_{ideal} = z\left(\frac{l_1}{L} - z\frac{h}{L}\right) \tag{18}$$

According to EC regulations, for passenger cars, rear tires should not lock up between decelerations of 0.15 g and 0.8 g and 5 % tolerance is allowed between 0.3 g and 0.45 g. Also, in order to satisfy the stopping distance requirements, installed braking force distribution should be above the curve determined by:

$$\frac{F_{Bf}}{W} = \frac{z + 0.07}{0.85}\left(\frac{l_2}{L} + z\frac{h}{L}\right) \quad \text{where; } (z = 0.15 \ldots\ z = 0.61) \tag{19}$$

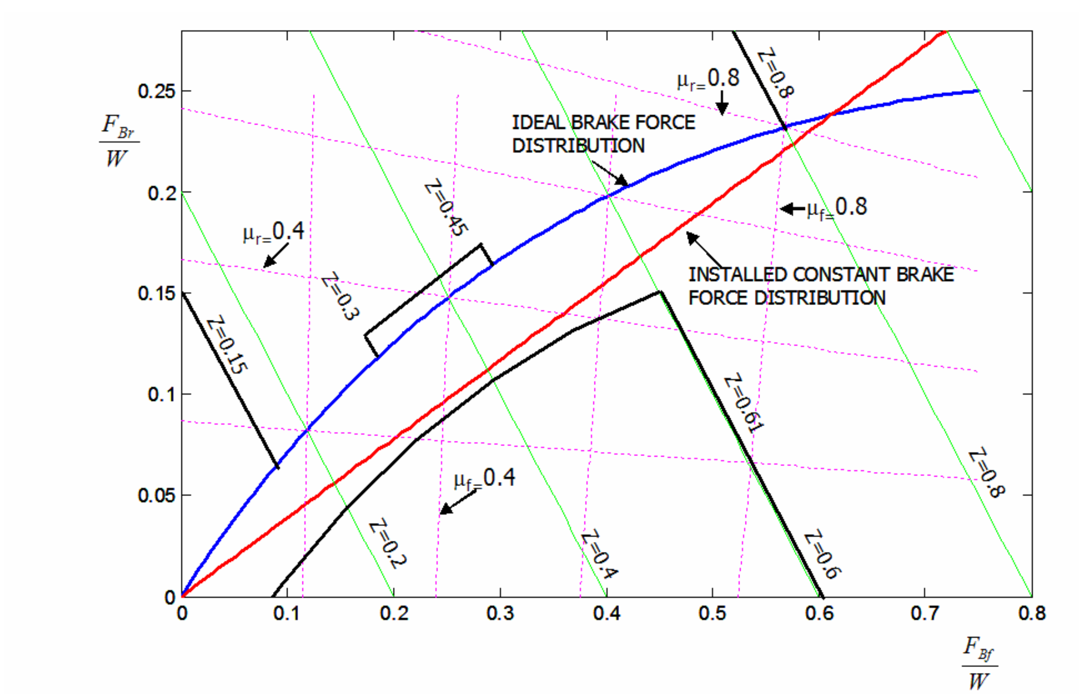
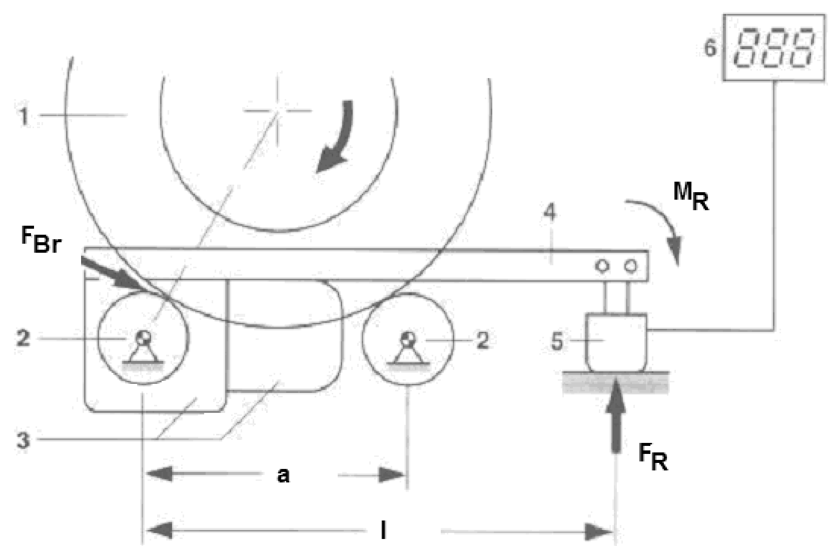



**Figure 4 Brake force distribution diagram and EC regulations.**

**Instruments:**

Brake test stand: The brake test stand's, in Figure 5, main components are two mutually independent roller sets, for the left and right sides of the vehicle respectively. A stable frame supports the roller sets[2], which assume the form of drive roller and a secondary roller in a parallel layout, while a drive chain provides the positive dynamic connection between the two rollers. An AC motor[3] powers the drive roller through a gear set with an upward conversion ratio. The electric motors set the rollers in motion and maintain a constant rotational speed against the considerable opposing forces that occur when the vehicle's brakes are applied. The suspended drive unit with torque lever[4] transmits the braking forces to the load sensing device[5]. The load device, incorporated within the hydraulic system, acts directly upon a gage. The gage, whose scale is calibrated in Newton, provides an analog display of braking force. Should the applied braking force start to exceed the available traction between tires and the test rollers, the wheel will respond by starting to slip and then lock. Tire slip, however, makes it impossible to perform useful measurements of braking force. An automatic override device recognizes this kind of slip and switches off the test unit. The display, meanwhile, continues to show the maximum braking force achieved before the override device was activated.

A brake pedal force measurement system is used to measure the applied pedal force. This system consists of a pedal force sensor and a hand held digital display.




***1- Vehicle tire, 2- Roller set with spacing a, 3- Motor with gear set, 4- Torque lever with length l, 5- Measurement sensor, 6- Display.***

**Figure 5 Operation principle of brake test stand.**

**Procedure:**

1. Place the font axle of the test vehicle on the brake test stand. Exercise extreme caution not to tip off the vehicle from the stand. Make sure there is no student around the test stand. The vehicle should be aligned on the test stand.
2. Attach the brake pedal sensor to the brake pedal of the test vehicle.
3. Activate the rollers. The drive rollers may be activated either by remote control or with an integral automatic on/off switch.

   *Caution: Small steering wheel movements may rotate the vehicle dangerously. Rollers should be activated only by the driver. The vehicle should be in the driver's possession at all times. Never leave the vehicle unattended when the rollers are running! In case of emergency, rollers must be deactivated by pressing the red "STOP" button. Never walk on the test stand. Shoes, pants, long skirts, shoe laces can be trapped between the rollers and may cause serious injuries even when they are not activated!*

4. Apply the brakes gradually and record the left and the right brake forces at constant pedal forces e.i. 10, 20, 30…N.
5. Repeat the same procedure for the rear axle for same pedal force levels.

**Requirements:**

1. Interpolating your measurements plot the brake pedal force vs. brake force diagrams (front and rear). Show your experimental data on the plot.
2. Assuming constant brake force distribution (no brake-proportioning device installed) Calculate the constant brake force distribution ($K_{bf}$) for the test vehicle.
3. Using the CG location calculated in Part 1, plot the axle load vs. deceleration diagrams.
4. Derive the necessary equations, and plot the ideal brake force distribution diagram. Show the constant deceleration lines and the constant brake force distribution on this diagram.
5. If you believe that this vehicle's brake system does not satisfy EC standards, recommend a new brake force distribution.
6. Answer the questions that may be assigned by your laboratory instructor.

   *Note: The reports are formal reports and must present all data, design and analysis professionally.*

**References:**


1. Wong, J.Y. *"Theory of Ground Vehicles"*; John Wiley & Sons, Inc. 3rd Edition, 2001.
2. Gillespie, T.D., *"Fundamentals of Vehicle Dynamics",* SAE, 1994.
3. Göktan, A. et al., *"Taşıt Frenleri",* Allied Signal Automotive, 1995.
4. Bosh, *"Automotive Handbook",* SAE, 1993.

**APPENDIX**

**Table 1. Measurement of brake forces.**

| Brake Pedal Force | Front-Left Brake Force | Font-Right Brake Force | Front-Total Brake Force | Rear-Left Brake Force | Rear-Right Brake Force | Rear-Total Brake Force | Brake Force Distribution |
|---|---|---|---|---|---|---|---|
| $Fp$ (N) | $F_{Bf}$ (N) | $F_{Bf}$ (N) | $F_{Bf}$ (N) | $F_{Br}$ (N) | $F_{Br}$ (N) | $F_{Br}$ (N) | $K_{Bf}$ |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

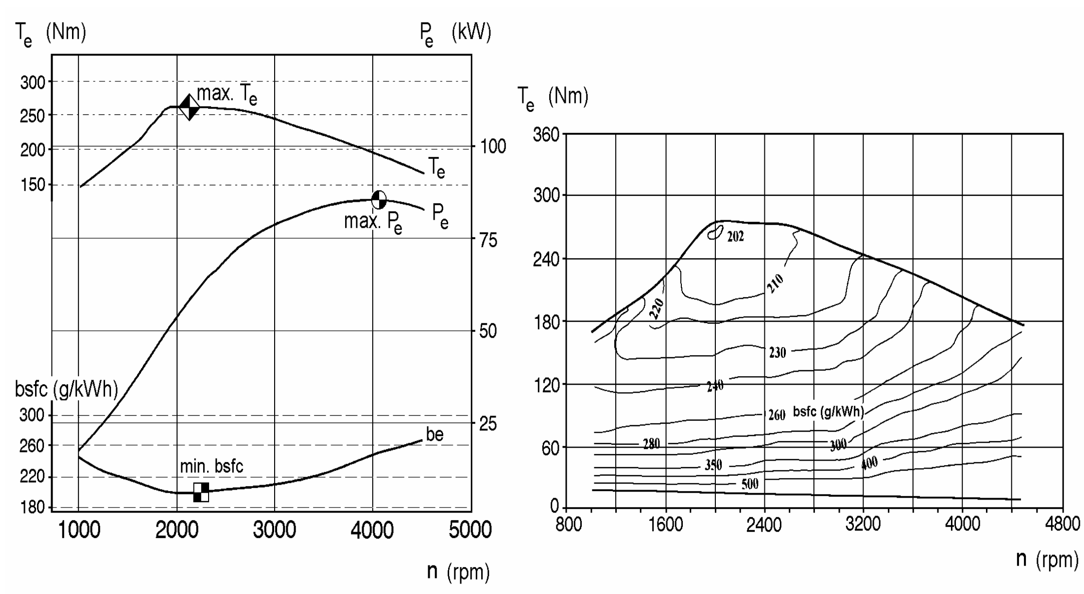
| | |
|---|---|
| Wheelbase (m) | |
| Track width front/rear (m) | / |
| Front axle load (N) | |
| Front axle load lifted (N) | |
| Hub center height lifted (m) | |
| Rear axle load (N) | |
| Static radius front/rear (m) | / |

## II. INTERNAL COMBUSTION ENGINES LABORATORY

**<u>Determination of the performance and heat balance characteristics of a diesel engine:</u>**

**Introduction:**

The practical engine characteristics of interest are power ($P_e$), torque ($T_e$), and specific fuel consumption (*bsfc*). The relative importance of these parameters varies over an engine's operating speed and load range. The maximum brake power and the break mean effective pressure (*BMEP*) define an engine's full potential (Figure 1). The maximum brake torque and *BMEP*, over the full speed range, indicates the ability of the designer to obtain a high air flow through the engine over the full speed range (volumetric efficiency $\eta_v$) and use that air effectively (relative air/fuel ratio λ and heat balance). Then, over the complete operating range, and most especially those parts of that range including partial load where the engine will operate for long periods of time, engine fuel consumption and engine emissions are important (Figure 1).




(a) (b)

**Figure 1. Characteristic graphs of a diesel engine.**
**a - Full load engine characteristic**
**b - Part load bsfc map (engine map)**

Internal combustion engine tests are usually carried out by an engine dynamometer. The test engine is mounted on a test bed and the output shaft of the engine is connected to the dynamometer rotor. Figure 2 illustrates the operating principle of such dynamometer. The rotor may be coupled electromagnetically, hydraulically, or by mechanical friction to a stator, which is supported on low friction bearings (Figure 3). The stator is balanced by the rotor stationary. The torque is exerted on the stator with the rotor rotation is measured over lever arm by balancing the stator with weights, springs, or pneumatic means.

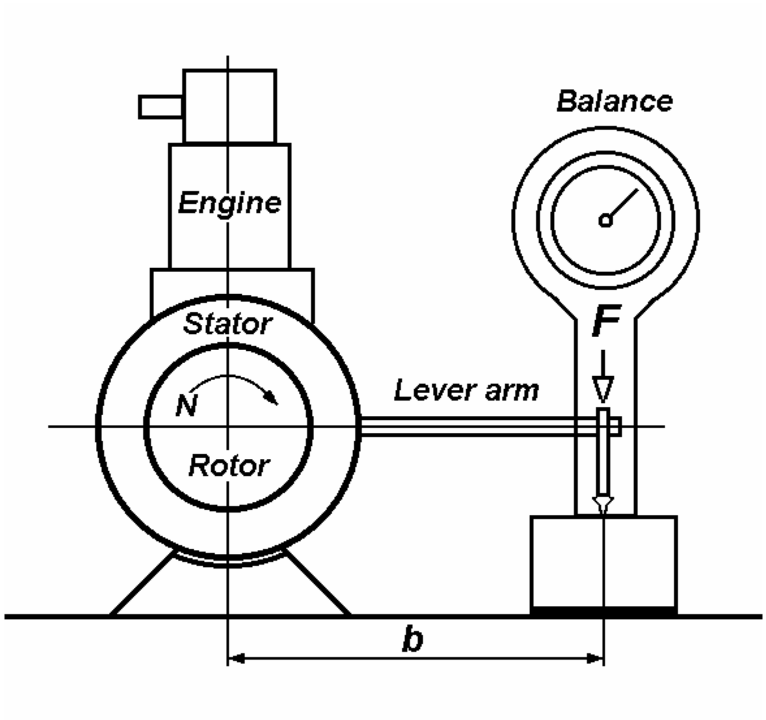



**Figure 2. Operation principle of a dynamometer.**

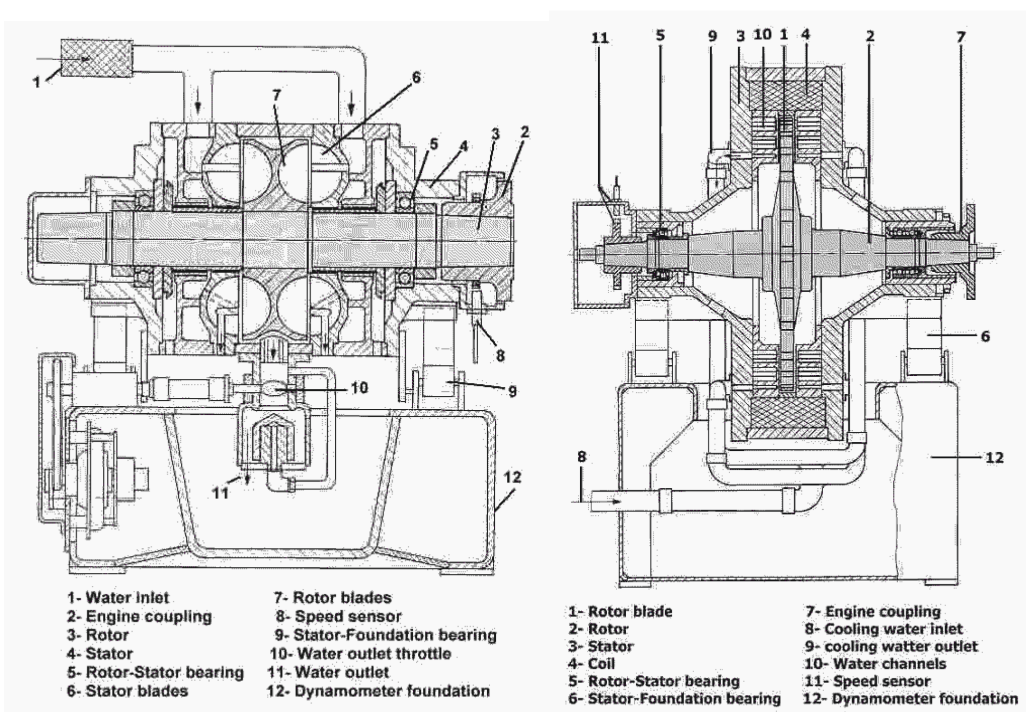



**Figure 3. Hydraulic and Eddy current dynamometers.**

**The objectives of the experiment:**

1. Determinations of the engine's effective torque (Te), break mean effective pressure *(BMEP)*, power (*Pe*) and break specific fuel consumption (*bsfc*) characteristics at full and partial load conditions.

2. Determination of the engine's volumetric efficiency ($\eta_v$) and relative air/fuel ratio ($\lambda$) at full and partial load conditions.

3. Determination of the engine's heat balance i.e. heat for power ($\dot{Q}_e$), heat rejected to cooling ($\dot{Q}_{water}$), heat rejected to exhaust ($\dot{Q}_{exh}$) and heat rejected to overall friction ($\dot{Q}_{friction}$).

**Experimental setup:**

**Engine specifications:**

Model: TZDK-Basak diesel engine
Type: Direct injection diesel engine, four stroke
Cylinder: 4
Bore diameter: 100 mm
Stroke: 100 mm
Displacement: 3.14 liter
Compression ratio ($\varepsilon$): 16.8

**Dynamometer:**

The engine that will be used for this experiment is coupled with an Eddy-current dynamometer. The load and speed of the engine is controlled by a fuel pump injection rate and dynamometer resistance. Fuel injection rate is controlled by the adjustment of the fuel pump. Dynamometer resistance is controlled by the adjustment of electromagnetic field density. The power of the engine will be converted to heat in the dynamometer and rejected from the dynamometer with the help of cooling water.

The torque on the engine crankshaft is transmitted to the dynamometer by a coupling and acts on the dynamometer lever arm as a force. This force that is proportional to the engine torque will be measured with a balance.

Engine speed will be measured through the tacho-generator that is coupled to the engine dynamometer.

**Fuel consumption measurement:**

Volumetric fuel consumption will be measured through time period measurement with a chronometer for a given volume of fuel in a glass tube (Figure 4).

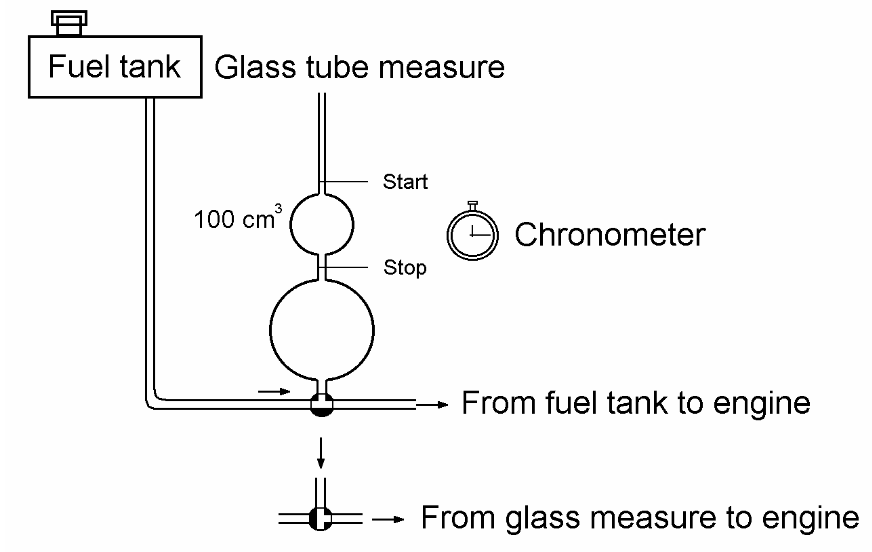



**Figure 4. Volumetric fuel consumption measurement.**

**Air consumption measurement:**

Volumetric air consumption will be measured with a rotary type flow-meter. Between the flow-meter and intake manifold of the engine a surge tank is connected to obtain a steady flow in the flow-meter. This is necessary in order to eliminate the pulsation of air flow caused by the variation of intake valve motion. Time period measurement with a chronometer for a given volume of air will give the air consumption.

**Intake air temperature measurement (ambient air):**

A simple ordinary thermometer is used to measure the ambient air temperature.

**Exhaust temperature measurement:**

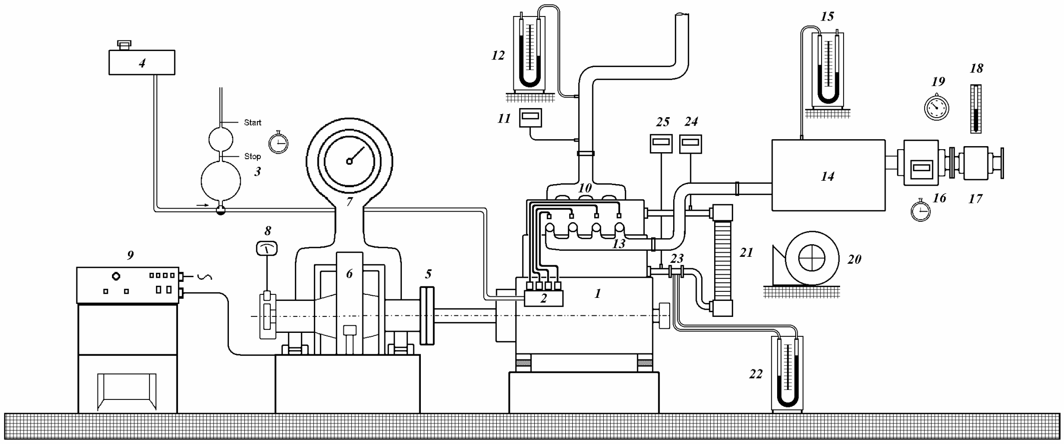
Exhaust temperature will be measured with a thermocouple that is connected to exhaust pipe close to the exhaust manifold.

**Cooling water flow rate measurement:**

Volumetric flow rate of cooling water will be measured through an orifice on the pipe that causes a pressure drop. This pressure difference will be measured by a U manometer. Flow rate is proportional to the square root of the pressure drop across the orifice. Hence, the flow rate can be calculated using the Bernoulli equation.

**Cooling water in and out flow temperature measurement:**

Cooling water in and outflow temperatures will be measured with Platinum resistance Pt 100 thermometers, which are connected to the engine water out (radiator in) and engine water in (radiator out) pipes.




***ENGINE TEST SYSTEM FOR DETERMINATION***
***OF THE PERFORMANCE AND HEAT BALANCE CHARACTERISTICS OF A DIESEL ENGINE***

*1- Test engine*
*2- Fuel pump*
*3- Fuel consumption measurement*
*4- Fuel tank*
*5- Coupling*
*6- Dynamometer*
*7- Dynamometer balance*
*8- Tachogenerator*
*9- Dynamometer control unit*
*10- Exhaust manifold*
*11- Exhaust temperature measurement*
*12- U manometer (exhaust back pressure)*
*13- Intake manifold*
*14- Surge tank*
*15- U manometer (intake manifold pressure)*
*16- Rotary flowmeter*
*17- Air filter*
*18- Ambient air temperature measurement*
*19- Ambient air pressure*
*20- Blower*
*21- Radiator*
*22- U manometer*
*23- Orifice*
*24- Cooling water inlet temperature*
*25- Cooling water outlet temperature*

**Figure 5. Experimental setup.**

**Experimental procedure:**

**Warnings:**

*Note: Students must adhere to written and verbal safety instructions to prevent any accident. Engine laboratories have fire hazards. Smoking or carrying lighted material is strictly prohibited within the automotive laboratory. Rotating parts may cause serious injuries. Never stand by the both sides of the test engine or the dynamometer during the experiment. If you have long hair or loose clothes, make sure they are tied back or confined. If you see any unusual condition, report to your instructor immediately.*

**Preparation:**

At first some preparation steps must be done.

1. Check the mechanical, electrical, fuel, oil, water and air couplings and leakages.
2. Check the oil level of the test engine.
3. Switch on the dynamometer control panel.
4. Connect the battery to the engine starter.
5. Open the fuel circuit of the engine and water circuit of the dynamometer.
6. Start the engine and run it at light load to warm up.
7. After these steps the main part of the experiment begins with the adjustment of the measuring points (load and speed) respectively.

**Speed characteristic at full load:**

Adjust the fuel pump for maximum fuel injection rate after warm up of the engine. This means the engine runs at full load.
Regulate the speed of the engine by the dynamometer.
Experimental points are 1200, 1600, 2000 and 2400 rpm at full load.
After reaching stationary conditions (speed, torque, water and exhaust temperatures), begin to measurement starting with 1200 rpm.

**Parameters to be measured:**

| **Explanation** | **Symbol** | **Unit** |
|---|---|---|
| Read the ambient air temperature. | $T_{air}$ | ( $^0$C ) |
| Read the ambient air pressure | $P_{atm}$ | (mbar) |
| Read dynamometer balance. | $F$ | ( N ) |
| Read tacho-generator. | $n$ | (rpm) |
| Switch off the valve to fuel tank and switch on the measurement glass tube. Measure the time period of fuel consumption for the given fuel volume (100 cm$^3$). | $\Delta t_{fuel}$ | ( s ) |
| Measure the time period for a definite air volume passed trough the rotary flowmeter (2 m$^3$). | $\Delta t_{air}$ | ( s ) |
| Read the intake pressure difference | $\Delta H_{intake}$ | (mm Water) |
| Read the manometer difference on the orifice of engine cooling water flow. | $\Delta H_{Hg}$ | (mm Hg) |
| Read the in flow temperature of engine cooling water. | $T_{w-in}$ | ( $^0$C ) |
| Read the out flow temperature of engine cooling water. | $T_{w-out}$ | ( $^0$C ) |
| Read the exhaust gas temperature. | $T_{exh}$ | ( $^0$C ) |
| Read the exhaust back pressure | $\Delta H_{exh}$ | (mm Water) |

**Load characteristic at constant speed:**

After making the measurement of four points of speed characteristic at full load set the engine speed at 1600 rpm.
Set the load of the engine with respect to full load at 60% and 30% through adjusting the injected fuel rate from fuel pump.
Measure and read the same variables of preceding experiment.

**Assumptions:**

Use the given density and specific heat values as constant for all experimental points for calculations.
Due to the marginal effect, the air humidity is taken as zero (dry air).
Fuel temperature is equal to ambient air temperature.

**Given values for calculations:**

| Definition | Symbol | Value-Unit |
|---|---|---|
| Length of lever arm of dynamometer | $b$ | 0.955 m |
| Engine displacement | $V_h$ | 3.14 liter |
| Measured fuel volume | $V_{fuel}$ | 100 $cm^3$ |
| Measured air volume | $V_{air}$ | 2 $m^3$ |
| Density of water | $\rho_{water}$ | 1000 $kg/m^3$ |
| Density of fuel | $\rho_{fuel}$ | 840 $kg/m^3$ |
| Density of mercury | $\rho_{Hg}$ | 13600 $kg/m^3$ |
| Gas constant of air | $R_{air}$ | 0.287 kJ/kg K |
| Specific heat of water | $c_{water}$ | 4.20 kJ/kg K |
| Specific heat of exhaust gases | $c_{exh}$ | 1.09 kJ/kg K |
| Orifice diameter | $D_{orifice}$ | 11.7 mm |
| Orifice discharge coefficient | $\alpha_{orifice}$ | 0.63 |
| Heating value of fuel | $H_u$ | 41800 kJ/kg |
| Ratio of stoichiometric mass of air to mass of fuel | $(m_{air}/m_{fuel})_{stoichiometric}$ | 14.05 kg air/kg fuel |

**Parameters to be calculated :**

| Definition | Symbol | Unit |
|---|---|---|
| Break (effective) torque | $T_e$ | (Nm) |
| Break (effective) power | $P_e$ | (kW) |
| Break mean effective pressure | $BMEP$ | (MPa) |
| Mass flow rate of fuel | $\dot{m}_{fuel}$ | (kg/s) |
| Break specific fuel consumption (effective) | $bsfc$ | (g/kWh) |
| Mass flow rate of intake air | $\dot{m}_{air}$ | (kg/s) |

| | | |
|---|---|---|
| Volumetric efficiency | $\eta_v$ | - |
| Relative air/fuel ratio | $\lambda$ | - |
| Mass flow rate of exhaust | $\dot{m}_{exh}$ | (kg/s) |
| Mass flow rate of cooling water | $\dot{m}_{water}$ | (kg/s) |
| Total chemical heat of fuel | $\dot{Q}_{total}$ | (kJ/s) |
| Heat for effective power | $\dot{Q}_e$ | (kJ/s) |
| Heat rejected to cooling | $\dot{Q}_{water}$ | (kJ/s) |
| Heat rejected to exhaust | $\dot{Q}_{exh}$ | (kJ/s) |
| Heat rejected to overall friction | $\dot{Q}_{friction}$ | (kJ/s) |
| Proportion of heat for effective power | $q_e$ | (%) |
| Proportion of heat rejected to cooling | $q_{water}$ | (%) |
| Proportion of heat rejected to exhaust | $q_{exh}$ | (%) |
| Proportion of heat rejected to overall friction | $q_{friction}$ | (%) |

**Calculation procedure:**

Break (effective) torque ($T_e$), break power ($P_e$), break mean effective pressure ($BMEP$), mass flow rate of fuel ($\dot{m}_{fuel}$) and break specific fuel consumption (effective) ($bsfc$):

$$T_e = F \cdot b \tag{1}$$

$$P_e = \frac{F \cdot n}{10000} \tag{2}$$

$$BMEP = \frac{120 \cdot P_e}{n \cdot V_h} \tag{3}$$

$$\dot{m}_{fuel} = \frac{\rho_{fuel} \cdot V_{fuel}}{\Delta t_{fuel}} \tag{4}$$

$$bsfc = \frac{\dot{m}_{fuel} \cdot 3600}{P_e} \tag{5}$$

Mass flow rate of intake air ($\dot{m}_{air}$):

$$\rho_{air} = \frac{0.1 \cdot P_{atm}}{R_{air} \cdot (T_{air} + 273)} \tag{6}$$

$$\dot{m}_{air} = \frac{\rho_{air} \cdot V_{air}}{\Delta t_{air}} \tag{7}$$

Volumetric efficiency ($\eta_v$):

$$\eta_v = \frac{V_{air} \cdot 120}{V_h \cdot \Delta t_{air} \cdot n} \tag{8}$$

Relative air ratio ($\lambda$):

$$\lambda = \frac{\dot{m}_{air} / \dot{m}_{fuel}}{(\dot{m}_{air} / \dot{m}_{fuel})_{stoichiometric}} \tag{9}$$

Mass flow rate of exhaust ($\dot{m}_{exh}$):

$$\dot{m}_{exh} = \dot{m}_{air} + \dot{m}_{fuel} \tag{10}$$

Mass flow rate of cooling water ($\dot{m}_{water}$):

$$\dot{m}_{water} = \rho_{water} \frac{\pi (D_{orifice} \cdot 10^{-3})^2}{4} \alpha_{orifice} \sqrt{2g \frac{(\Delta H_{Hg} / 1000)}{\rho_{water}} (\rho_{Hg} - \rho_{water})} \tag{11}$$

Total chemical heat of fuel ($\dot{Q}_{total}$), for effective power ($\dot{Q}_e$), rejected to cooling ($\dot{Q}_{water}$), rejected to exhaust ($\dot{Q}_{exh}$) and rejected to overall friction ($\dot{Q}_{friction}$):

$$\dot{Q}_{total} = \dot{m}_{fuel} \cdot H_u \tag{12}$$

$$\dot{Q}_e = P_e \tag{13}$$

$$\dot{Q}_{water} = m_{water} \cdot c_{water} \cdot (T_{w-out} - T_{w-in}) \tag{14}$$

$$\dot{Q}_{exh} = m_{exh} \cdot c_{exh} \cdot (T_{exh} - T_{air}) \tag{15}$$

$$\dot{Q}_{friction} = \dot{Q}_{total} - (\dot{Q}_e + \dot{Q}_{water} + \dot{Q}_{exh}) \tag{16}$$

Proportion of heat for effective power ($q_e$), rejected to cooling ($q_{water}$), rejected to exhaust ($q_{exh}$) and rejected to overall friction ($q_{friction}$):

$$q_e = \frac{\dot{Q}_e}{\dot{Q}_{total}} \cdot 100 \tag{17}$$

$$q_{water} = \frac{Q_{water}}{Q_{total}} \cdot 100 \tag{18}$$

$$q_{exh} = \frac{\dot{Q}_{exh}}{\dot{Q}_{total}} \cdot 100 \tag{19}$$

$$q_{friction} = \frac{\dot{Q}_{friction}}{\dot{Q}_{total}} \cdot 100 \tag{20}$$

**Requirements:**

Write a technical report for the internal combustion engines experiment using the necessary explanations, calculation steps, tables and drawings.

1. Calculate the effective torque *(Te)*, break mean effective pressure *(BMEP)*, power ($P_e$), break specific fuel consumption (*bsfc*), volumetric efficiency ($\eta_v$) and relative air/fuel ratio ($\lambda$) for speed characteristic at full load and load characteristic at constant speed.
2. Derive the *BMEP, bsfc*, $\dot{m}_{air}$, $\eta_v$, and $\dot{m}_{water}$ equations with simple steps.
3. Plot the speed characteristics at full load (x-axis represents the engine speed) and load characteristics at constant speed (x-axis represents the engine load) from the calculated parameters *(Te, BMEP,* $P_e$*, bsfc,* $\eta_v$, $\lambda$). Give a brief explanation about the engine characteristics with the help of the plotted data.
4. Calculate the engine's heat balance i.e. heat for power ($\dot{Q}_e$), heat rejected to cooling ($\dot{Q}_{water}$), heat rejected to exhaust ($\dot{Q}_{exh}$) and heat rejected to overall friction ($\dot{Q}_{friction}$).
5. Plot the heat balance in proportions for speed characteristic at full load and load characteristic at constant speed (x-axis represents the engine speed and the load respectively, y-axis represents the heat balance in proportions in which $q_{\text{total}}$ is equal to 100 %). Give a brief explanation about the engine heat balance characteristic with the help of the plotted data.

**Table 1. Measurements for speed characteristic at full load.**

| Ambient air pressure | $P_{atm}$ (mbar) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Engine speed | Dyn. balance | Time for fuel flow | Time for air flow | Ambient air temperature | Intake manifold pressure | Exhaust gas temp. | Exhaust back pressure | Mano. diff. of cooling water | Inflow water temperature | Outflow water temperature |
| $n$ (rpm) | $F$ ( N ) | $\Delta t_{fuel}$ ( s ) | $\Delta t_{air}$ ( s ) | $T_{air}$ ( $^0$C ) | $\Delta H_{intake}$ (mm Water) | $T_{exh}$ ( $^0$C ) | $\Delta H_{exh}$ (mm Water) | $\Delta H_{Hg}$ (mm Hg) | $T_{w\text{-}in}$ ( $^0$C ) | $T_{w\text{-}out}$ ( $^0$C ) |
| 1200 | | | | | | | | | | |
| 1600 | | | | | | | | | | |
| 2000 | | | | | | | | | | |
| 2400 | | | | | | | | | | |

**Table 2. Measurements for load characteristic at constant speed (n = 1600 rpm)**

| Ambient air pressure | $P_{atm}$ (mbar) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Engine load | Dyn. Balance | Time for fuel flow | Time for air flow | Ambient air temperature | Intake manifold pressure | Exhaust gas temp. | Exhaust back pressure | Mano. diff. of cooling water | Inflow water temperature | Outflow water temperature |
| $F/F_{max}$ (x100) | $F$ ( N ) | $\Delta t_{fuel}$ ( s ) | $\Delta t_{air}$ ( s ) | $T_{air}$ ( $^0$C ) | $\Delta H_{intake}$ (mm Water) | $T_{exh}$ ( $^0$C ) | $\Delta H_{exh}$ (mm Water) | $\Delta H_{Hg}$ (mm Hg) | $T_{w\text{-}in}$ ( $^0$C ) | $T_{w\text{-}out}$ ( $^0$C ) |
| 100 | | | | | | | | | | |
| 60 | | | | | | | | | | |
| 30 | | | | | | | | | | |