Study on Mutual Work of a Diesel Engine with a Hydro-Mechanical Transmission

Constantin-Iulian PÂNTECE, Marin NICOLAU, Gabriel-Ionuţ DOROBANȚU, Leonard-Iulian CUCU, and Ion COPAE

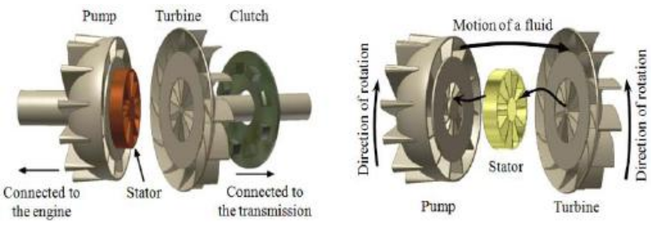
***Abstract*—The purpose of this paper is to present some aspects of hydro-mechanical transmissions and their link with combustion engine. In order to establish the static characteristics of torque converter, there are used graphical representations of turbine torque, impeller torque, efficiency and transfer ratio. Static characteristics of hydro-mechanical transmissions are presented using torque and power charts measured at secondary gear axle and also using energy efficiency and rate of power turned into-heat charts. Using external characteristic values of engine torque and engine power charts, there are presented static characteristics resulted from the correlation of combustion engine and hydro-mechanical transmission. Static characteristics obtained by mathematical expressions are used to study vehicle dynamics within this paper. Therefore, using Matlab and Simulink, general dynamics performances of a system are established. Other purpose of this paper is to establish specific performances of the diesel combustion engine functioning along with a hydro-mechanical transmission, such as maximum speed and maximum slope on different types of frequently used roads.**

***Index Terms*—diesel, engine, hydro-mechanical transmission, torque converter, vehicle dynamics.**

I. Introduction

At the moment, hydro-mechanical transmissions are one of current solutions in automotive construction industry, being represented by hydraulic component (torque converter) and its link with mechanical planetary gear-box.

The complex torque converter of modern car's hydro-mechanical transmissions has two main purposes: to increase engine torque and to increase efficiency when is engaged in hydro-clutch status functioning (with no influence of engine torque) **Error! Reference source not found.-Error! Reference source not found.**.



a) b)

Figure 1. Torque converter: a) main components: pump, turbine and stator; b) motion of torque converter fluid and direction of rotation for both pump and turbine

The main components of torque converter are described in Fig. 1: pump, turbine and stator. It can be seen that the pump is linked to the engine crankshaft and the turbine to the transmission shaft (Fig. 1a). In Fig. 1b there are represented motion of torque converter fluid and the direction of rotational movement for both pump and turbine.

II. Characteristics of Torque Converter

Because stator's location, between the turbine and the pump, the torque converter transforms pump torque as a hydro-decelerator.

The transformation ratio (k_h) is:

$$k_h = \frac{M_t}{M_p} \tag{1}$$

where M_t is turbine shaft torque and M_p is pump shaft torque.

Using pump shaft speed n_p (or angular velocity ω_p) and turbine shaft speed n_t (or angular velocity ω_t) we define kinematic gear ratio (i_h):

$$i_h = \frac{n_p}{n_t} = \frac{\omega_p}{\omega_t} \tag{2}$$

Torque converter efficiency η_h is defined by ratio between turbine shaft power P_t and pump shaft power P_p:

$$\eta_h = \frac{P_t}{P_p} = \frac{M_t \omega_t}{M_p \omega_p} \tag{3}$$

Using (1) and (2):

$$\eta_h = k_h \frac{1}{i_h} = k_h i_h' \tag{4}$$

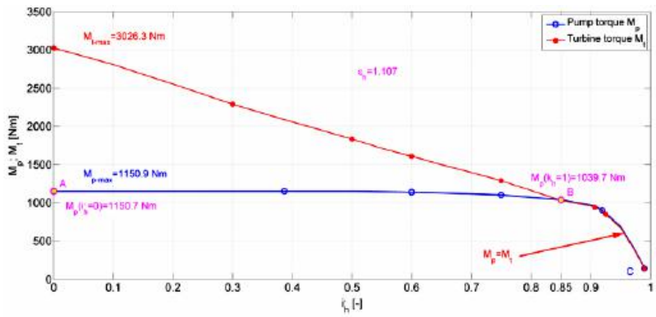


Figure 2. Static characteristics of torque converter: turbine and pump torques

The static characteristics of torque converter are presented in Fig. 2 and Fig. 3 **Error! Reference source not found.**.

It can be seen that in Fig. 2, the turbine and pump torques have the same values in B-C area and this means that the torque converter has the hydro-clutch status (for $i_h' \geq 0.85$); in that situation, using expression (1), it results that $k_h = 1$

C. I. Pântece, Military Technical Academy, 39-49 George Coșbuc Ave., Sector 5, 050141, Bucharest, Romania (e-mail: pantece.iulian@gmail.com).

M. Nicolau, Military Technical Academy, 39-49 George Coșbuc Ave., Sector 5, 050141, Bucharest, Romania.

G. I. Dorobanțu, Debt Management Expert, 18 E Cluceru Udricani street, sector 3, Bucharest, Romania.

L. I. Cucu, Asirom Insurance, 10 Teiul Doamnei Street, Sector 2, 23582 Bucharest, Romania.

I. Copae, Military Technical Academy, 39-49 George Coșbuc Ave., Sector 5, 050141, Bucharest, Romania.

Digital Object Identifier 10.32754/JMT.2018.2.10

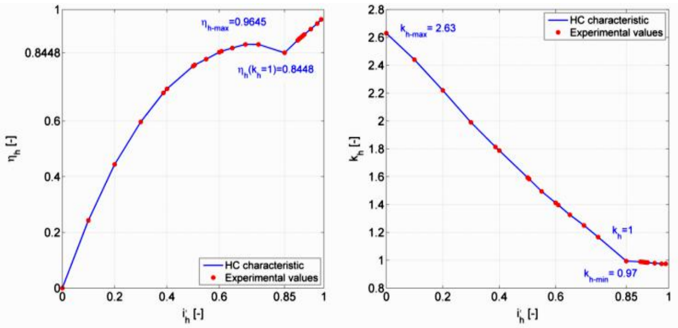
and using (4) it is obtained $\eta_h = i'_h = 0.85$ (Fig. 3a).

Fig. 2 shows maximum values for turbine and pump torque and also pump torque values for $i'_h = 0$ (point A) and $k_h = 1$ (point B), resulting non-adaptive coefficient value, ε_h :

$$\varepsilon_h = \frac{M_p\left(i'_h = 0\right)}{M_p\left(k_h = 1\right)} = \frac{1150.7}{1039.7} = 1.107 \qquad (5)$$

The static characteristic from Fig. 3a confirms the complex torque convertor existence because of the increasing values of efficiency after B inflexion point (where $k_h = 1$ and the torque converter has the hydro-clutch status). It can be noticed the maximum efficiency value of 0.9898.

In Fig. 3b the maximum value of the transformation ratio is 2.63 for vehicle starting.

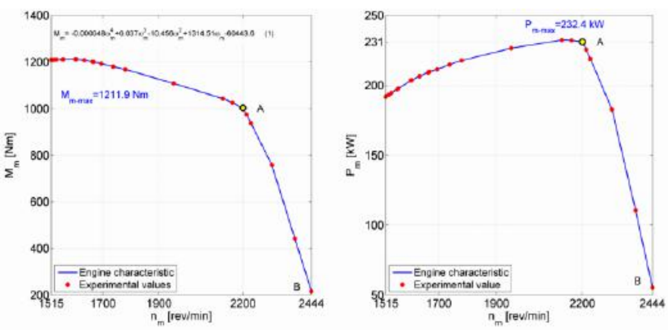


a) b)

Figure 3. Static characteristics of torque converter: efficiency (a) and transformation ratio (b)

III. COMBUSTION ENGINE STATIC CHARACTERISTIC

In Fig. 4 it is represented the characteristic of the combustion engine (whom the hydro-mechanical transmissions it is linked) meaning maximum load speed characteristic (engine torque M_m and power P_m variation with engine speed). In the charts there are mentioned the maximum values of the engine torque and power and also the regulator curve starting point (A). The analytical expression for engine torque used for dynamic study is also mentioned in Fig. 4a.



a) b)

Figure 4. Combustion engine static characteristic: a) engine torque; b) engine power

IV. TRANSMISSION STATIC CHARACTERISTICS

Transmission static characteristics are represented by torque, power and efficiency variation in different speed gears measured on final shaft. Therefore, the transmission torque and power values variation function of final shaft speed $\left(n_{tr}\right)$ and as well as the inverse gear ratio $\left(i'_h\right)$, with free torque converter ($i'_h \neq 1$), are shown in Fig. 5 and Fig. 6.

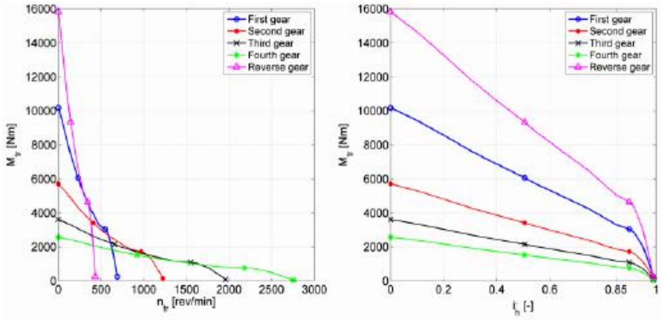


Figure 5. Engine torque variation, with free torque converter, in different speed gears, measured on final shaft

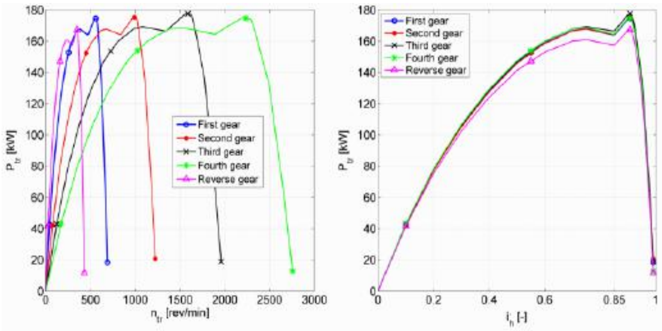
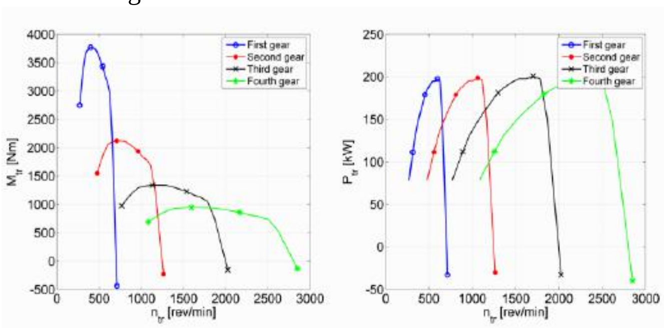


Figure 6. Engine power variation, with free torque converter, in different speed gears, measured on final shaft

Similarly, the variation of transmission torque and power values, in case of locked torque converter ($i'_h = 1$), are shown in Fig. 7.



a) b)

Figure 7. Engine torque (a) and power (b) variation, with locked torque converter, in different speed gears, measured on final shaft

Analyzing the charts from Fig. 5 to Fig. 7 there can be noticed the bigger values of the vehicle starting torque with free torque convertor.

In Fig. 8 and Fig. 9 there are represented the transmission efficiency values in different speed gears with free torque converter and power to heat transformation ratio for this case.

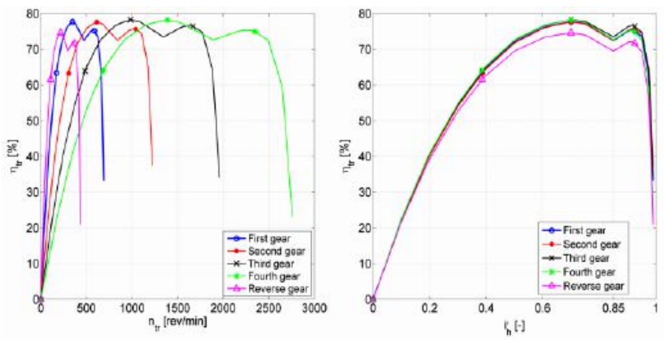


Figure 8. Transmission efficiency values in different speed gears with free torque converter

In the charts from Fig. 10, there can be seen transmission efficiency values in different speed gears (Fig. 10a) with blocked torque converter and transformation ratio of power to heat for this case (Fig. 10b).

The charts from Fig. 9 and Fig. 10 are showing a higher value for transmission efficiency with locked torque convertor but a higher power to heat transformation ratio for free torque convertor.

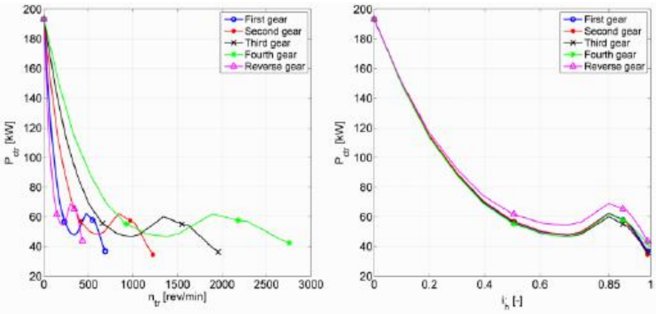
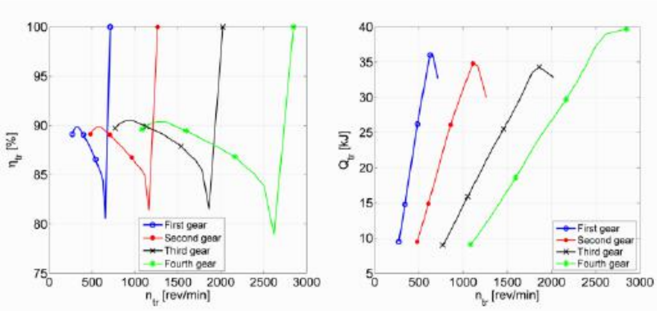


Figure 9. Transmission power to heat transformation ratio for different speed gears with free torque converter



a) b)

Figure 10. Transmission efficiency (a) values in different speed gears with locked torque converter and power to heat transformation ratio (b) for this case

V. Vehicle Dynamics

First grade differential equations are used in literature for vehicle dynamic study **Error! Reference source not found.Error! Reference source not found.**. For that purpose, there are used combustion engine and transmission static characteristic values and also some different vehicle parameters

$$\begin{cases} J_{mp}\omega'_m = M_m - M_p \\ J_v\omega'_r = i_{tf}\left(M_{tr} - M_r\right) \end{cases} \quad (6)$$

where J_{mp} – engine and pump inertia torque, J_v – vehicle inertia torque, i_{tf} – final transmission gear ratio and M_r – driving resistance torque.

For solving equations system (6) it will be used Matlab-Simulink diagram (Fig. 11) **Error! Reference source not found.**, where it can be noticed the possibility to study the dynamics of a vehicle considering the driver's influence on acceleration and braking.

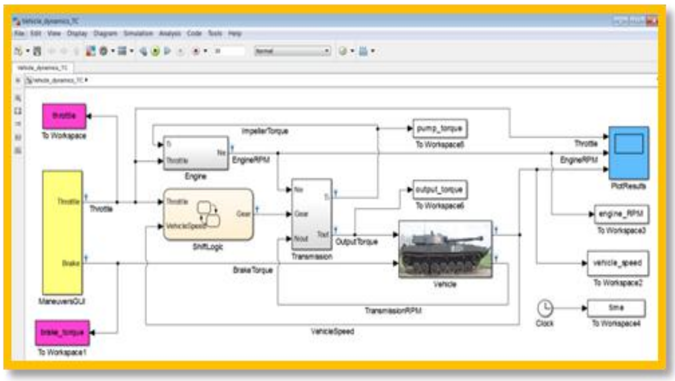
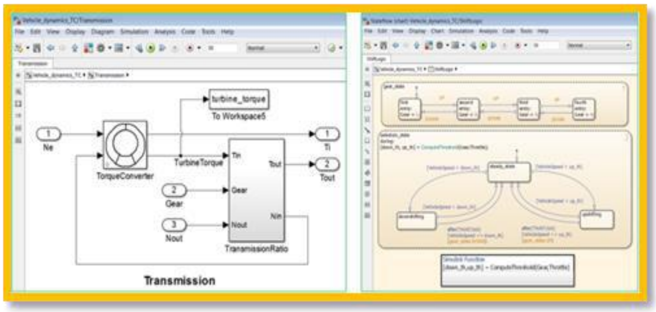


Figure 11. Matlab-Simulink diagram for vehicle dynamics

In Fig. 11, there can be seen the existence of hydro-mechanical transmission with torque convertor (Fig. 12a). Automatic control of transmission is assured by Matlab-Stateflow diagram presented in Fig. 12b.

The above static characteristics will be used in differential equations system (6) for establishing the analytical expression (1) from Fig. 4a and Fig. 13, such as $M_m = f\left(\omega_m\right)$ and $M_p = f\left(\omega_m\right)$.



a) b)

Figure 12. a) Matlab-Simulink diagram for vehicle transmission dynamics; b) Matlab-Stateflow diagram for automatic control of transmission

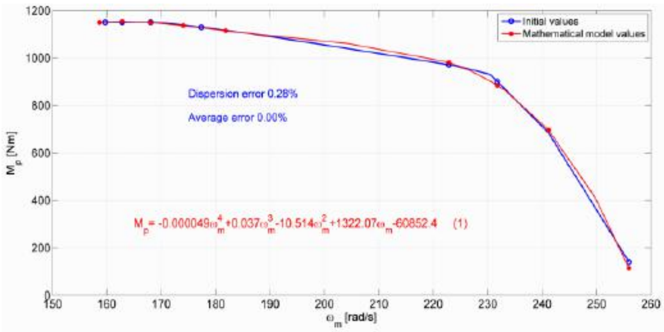


Figure 13. Establishing mode for analytical expression (1) of plan static characteristic: $M_p = f\left(\omega_m\right)$

Consequently, there are obtained the charts from Fig. 14 and Fig. 15 with mentioned functional values. Analyzing chart 14, it can be seen that the maximum vehicle speed value is 58.9 km/h and it is obtained after 100 s.

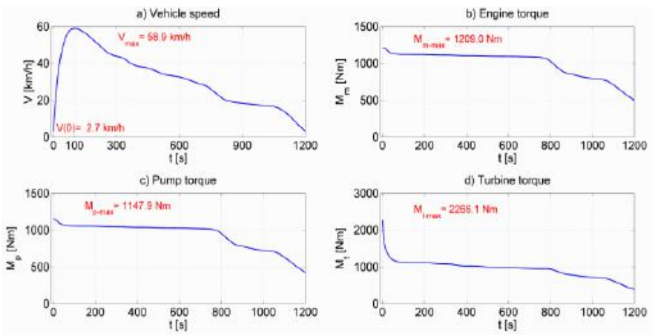


Figure 14. Vehicle dynamics (equipped with hydro-mechanical transmission)

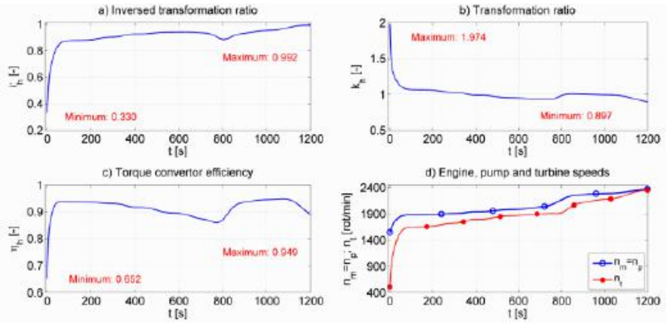


Figure 15. Vehicle dynamics (equipped with hydro-mechanical transmission)

VI. Establishing Maximum Performances

In order to obtain vehicle's maximum speed, vehicle starting and slope resistance will be null, therefore the only driving resistances taking into consideration will be the air and road resistance:

$$R = f\,G_a + k\,S\,v^2, \tag{7}$$

where f represents road resistance coefficient, k is aero-dynamic coefficient, S is vehicle transverse area and v is vehicle speed.

The theoretical maximum vehicle speed determination will be determined in last gear (fourth) with locked torque convertor ($i_h' = 1$). It is represented by the junction point for traction characteristic in last gear and the driving resistance curve.

To determine the traction characteristic, the following equation will be used:

$$F_t = \frac{P_R}{v} = \frac{P_m \eta_t}{v}, \tag{8}$$

where P_R is wheel power, P_m – engine power and η_t is transmission efficiency.

In Fig. 16 maximum vehicle speed is determined on two different driving paths. In first case (Fig. 16a) the maximum vehicle speed obtained, with $f = 0.045$, is $V_{\max} = 57.2$ km/h and in second case (Fig. 16b), with $f = 0.06$, maximum vehicle speed obtained is $V_{\max} = 54.8$ km/h.

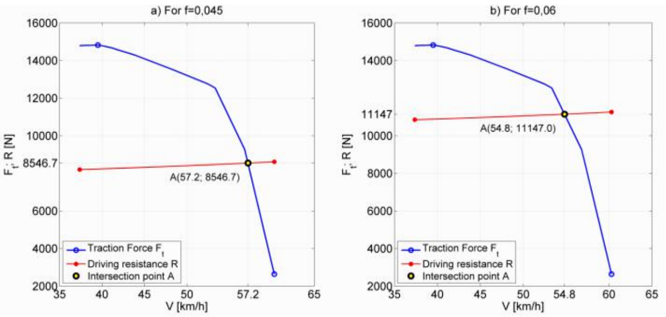


Figure 16. Maximum vehicle speed determination on two different driving paths

To determine the dynamic factor D for maximum slope there will be used low speeds and therefore air resistance will be null.

Maximum slope determination equation is:

$$\alpha = \arcsin \frac{D - f\sqrt{1 + f^2 - D^2}}{1 + f^2}, \tag{9}$$

where

$$D = \frac{F_t}{G_a}. \tag{10}$$

In this case, because of the free torque convertor (the same as maximum speed determination), traction force is obtained with the following equation:

$$F_t = \frac{M_m i_t k_h^2 i_h' \eta_h}{r_r}, \tag{11}$$

where r_r is wheel radius and i_t – gear ratio.

In Fig. 17 maximum driving slope is determined on two roads with different resistance coefficients. In the first case (Fig. 17a) the maximum driving slope with $f = 0.045$ is $\alpha_{\max} = 35.7$ degrees and in the second case (Fig. 17b), with $f = 0.06$, the maximum driving slope obtained is $\alpha_{\max} = 34.8$ degrees.

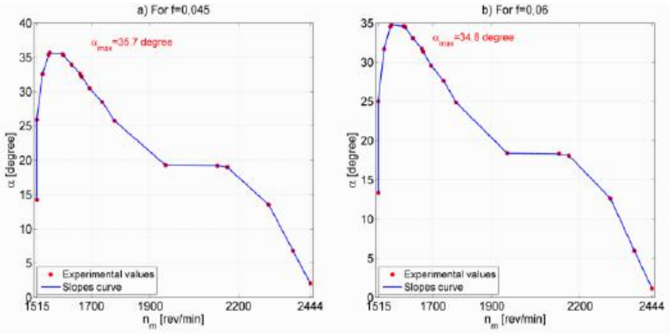


Figure 17. Maximum driving slope determination on two roads with different resistance coefficients

VII. Conclusions

For the dynamic study of vehicles, it is necessary to know both static characteristics of the combustion engine and its linked hydro-mechanical transmission.

In this paper there are highlighted some functional particularities of one specific hydro-mechanical transmission and a study of its functional link with combustion engine.

References

[1] Allison Transmissions, Military Series, http://www.allisontransmission.com/ transmissions/models/military-series

[2] LuK Transmissions, http://www.luk.com/content.luk.de/en/products/ transmission_components/gearing-systems.jsp

[3] J. Banerjee, H. Adibi-Asl, N. L. Azad, J. McPhee, "Parametric Importance Analysis and Design Optimization of Torque Converter Model Using Sensitivity Information," *SAE Int. J. Passeng. Cars - Mech. Syst.*, vol. 5, no. 1, pp. 621-638, 2012. doi.org/10.4271/2012-01-0808

[4] I. Copae, I. Lespezeanu, C. Cazacu, Vehicle Dynamics, ERICOM Editing House, Bucharest, Romania, 2006 (in Romanian).

[5] D. Costache, *Vehicle Hydraulic Transmissions*, Military Technical Academy Editing House, Bucharest, Romania, 2002 (in Romanian).

[6] R. Vilău, "Issues concerning plotting the static characteristics of the servomechanisms of the wheeled military automotive", *MTA Review*, vol. XXV, no. 2, pp. 107-114, Jun 2015.

[7] *Using Simulink and Stateflow in Automotive Applications*, 2017, https://www.mathworks.com/