# DESIGN OF FORCE MEASURING SYSTEM ON MAIN LANDING GEAR WEIGHT DROP TESTING MACHINE FOR THE APPLICATION OF LSU SERIES

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**ABSTRACT**

In this research, the design of the force measuring system on the main landing gear weight drop test for the LSU series developed by LAPAN was carried out. The principle of this machine is to apply the load according to the weight of the aircraft on the main landing gear and drop it at a certain height assisted by the guiding rail. At the bottom of this machine, there is an impact platform where each angle is mounted with a load cell that functions to measure the reaction force due to the impact of the main landing gear. Besides, there is a data acquisition system whose function is to process the output signal from the load cell and display measurement data. The data acquisition system used consists of DAQ measurement hardware made by national instruments and LabVIEW software installed on a PC. The design of this testing tool aims to carry out a dynamic impact test on the main landing gear structure of the UAV. The results of the test and calibration show that the force measurement system has an average relative error value is 0.49% and linearity ($R^2$) is 0.99.

***Keywords:*** *Drop test, Impact platform, Load cell, Landing gear, UAV*

## 1 Introduction

The development of UAV (Unmanned Aerial Vehicle) is growing rapidly both in Indonesia and all around the world. The demands of research activities related to UAV is not only created high performances products but also must be able to enter the downstream phase.

The most important thing in downstream aerospace technology products is the requirement to have the capabilities required by regulation. In the world of aviation, the safety aspect is mandatory. To ensure the safety aspect, the certification process is carried out by the applicable regulations.

One of the main components in the UAV with a fixed-wing configuration is the landing gear. The landing gear has the function to assist the aircraft in the process of take-off and landing. In several regulations governing aircraft design, both manned and unmanned explained how the minimum specifications of the landing gear structure must be met.

In this research, a device was designed to test the strength of unmanned aircraft landing gear, especially for dynamic loads. The design of this tool is dedicated to LSU (LAPAN Surveillance UAV) Series aircraft. As it is known that LAPAN, especially the Aeronautics Technology center has succeeded in developing UAV variants of LSU starting from LSU 01, LSU 02, LSU 03, LSU 04, LSU 05, LSU 02 NGLD, and LSU 05 NG. This tool is expected to become the standard testing tool for the landing gear UAV that was developed in

Indonesia to meet the safety aircraft regulation certification.

Previously at the LAPAN Aeronautics Technology Center (Wijaya, *et al.*, 2019), LSU landing gear testing was carried out using a static method where the landing gear was given a static load up to its strength limit. The dynamic testing is carried out following the representation of the landing gear load in the flying environment by free fall of the landing gear frame complete with the wheels and the MLW (maximum landing weight) load according to the design of the aircraft's landing gear.

Drop weight testing is one of the destructive testings to investigate the behavior and material characteristics (Mahesh, *et al.*, 2017). One of the functions of drop weight testing is to know the energy absorption of some specimens or part of the structure component. From this testing, the force versus displacement graph can be obtained to analyze the energy absorption characteristics (Taheri-Behrooz, *et al.*, 2013). A similar design is also provided by Galdino et.al (Galdino, *et al.*, 2013). Not only have the function to know the energy absorption but drop weight testing is also can be used to test the performance of the helmet. Shell helmet is impacted using a strike impactor (Yaakob, *et al.*, 2015). Amin et.al use the weight drop test to investigate the characteristics and the behavior of 3D printed bi-material structure, especially on its dynamics characteristics (Amin, *et al,*, 2017).

There is so many research before that developed the weight drop test system for so many applications. One of the weight drop test development has been done by Sharma et.al in 2017. This system is dedicated to investigating the impact force on a carbon composite. This tool also has some function to determine the material toughness of composite material (Sharma, *et.al.*, 2017). The design and manufacture of low-speed impact tester have been done by Navarrete et.al. This machine is used to investigate the impact response of composite sandwich panel structure. This weight drop testing machine can drop the impactor toward the testing specimen from the maximum height of 2 m. The mass of the impactor is varied from 5 to 25 kg so can provide the maximum kinetic energy to the testing specimen up to 500 Joule (Navarrete, Godinez, & Serrania, 2004). Kurşun et.al investigate the different shapes of the impactor of the weight drop testing machine. This test is done on a sandwich structure to investigate its rigidity (Kurşun, *et al.*, 2016)

Miguel and Alves have done their design of high energy drop weight rig to perform a drop weight tearing test (DWTT). This drop weight rig has a maximum capacity of 42 kJ. To hold the high impact load, some 4.6 tons of steel anvil is used to be the impact platform. At the bottom of this impact platform, 31.8 ton reinforced concrete is used to be its foundation (Miguel & Alves, 2014).

Tanadrob and Suvanjumrat compare the experimental testing and numerical analysis of drop weight testing. The numerical analysis is done using the finite element method. This research is done to benchmarking the material that is used in a speed boat to support the collision accident (Tanadrob & Suvanjumrat, 2017). Kara et.al use image processing to investigate the damage of composite structure when this specimen is tested using drop weight impact machine (Kara, *et al.*, 2017).

From all of this research so it is important to develop the weight drop test machine to investigate the dynamics characteristics of the landing gear of UAV. The landing gear structure must not fail during its take-off and landing operation. To evaluate this aspect, it is necessary to do the drop impact test on the landing gear structure. The most important thing about this machine is to obtained the force impact data to analyze the absorption energy and the strength of the material.

## 2 Methodology

### 2.1. Location and time

Research activities in the form of designing and testing were done in the aerostructure laboratory located in the aeronautics technology center – LAPAN. This research was conducted from October 2019 to February 2020.

### 2.2. Research Methodology

Figure 2-1 is the flow of this research activity. This research is consists of several steps. The first thing to do is to design the test rig of the weight drop test machine. This tool is operated by drop the mass using a guiding rail by gravity. In the impact area, the force platform is designed to obtain the force data. This design then manufactures in the aerostructure laboratory of the Aeronautics technology center.

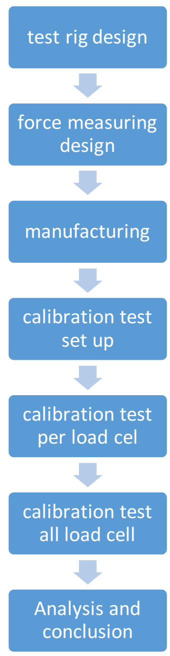


Figure 2-1: Research workflow

After the manufacturing process is done the next step is to do the calibration testing to make sure this machine is can work well. This machine is good to do a test on low strength to weight ratio materials (El-Ariss, 2011).

According to Gunawan, et.al, if there is no friction on the guide rail with the fixture, then to calculate the speed at which the fixture falls, the free fall object equation can be used (Gunawan, *et.al.*, 2011).

The theoretical approach to calculate the speed of the free fall object shown in the equations below:

$$Ep + Ek = constant \quad (2\text{-}1)$$

$$Ep + Ek = constant \quad (2\text{-}2)$$

$$mgh_1 + \frac{1}{2}mv_1{}^2 = mgh_2 + \frac{1}{2}mv_2{}^2 \quad (2\text{-}3)$$

The first state is the condition of the object that has an altitude and has no speed, so the object just has the potential energy due to its height. The second state is the condition of the object that impacts the ground, so the object has no altitude.

$$mgh_1 + 0 = 0 + \frac{1}{2}mv_2{}^2 \quad (2\text{-}4)$$

So, the speed of the object that impacts the force plate can be expressed on the equation below:

$$v = \sqrt{2gH} \quad (2\text{-}5)$$

Where g is the value of earth's gravity, which is 9.8 m / s² and H is the height of the test object to be dropped.

To perform the energy absorption analysis some data is required such as the force, acceleration, distance, velocity, and time unit. The energy absorption is present in the Joule unit (Metz, 2007). The calibration process is done in each load cell and then all of the force sensors, in total are four load cells. The final step is to analyze the data obtained from this calibration process.

## 3 Hardware And Software Design

### 3.1 Design and principle of Weight drop testing machine

This weight drop testing machine is designed to simulate the conditions under which the UAV is makes a landing. Therefore the method used is to imitate the principle of free fall objects, as has been done by Sharma et.al in 2017 which is used for composite testing (Sharma, *et.al.*, 2017).

The mechanical system in this weight drop testing machine consists of several constituent components, namely: mainframe, guide rail, fixture release mechanism, fixture, and impact platform. The mainframe of this machine is made of H beam iron which functions as a platform to place the guide rail. The guide rail is used as a place for the fixture to slide attached to the landing gear. The fixture attached to the landing gear can be lifted and removed using the fixture release mechanism system. Between the guide rail and the fixture is made as smooth as possible to eliminate the friction. The design of the landing gear drop test machine can be seen in Fig. 3-1.

The way this machine works is by attaching the landing gear to the fixture. The fixture is positioned at its altitude using a control panel that is adjusted to the desired test specifications. At a suitable height, the fixture is released by means of a release mechanism system so that it will fall in the direction of the guide rail and will hit the impact platform.

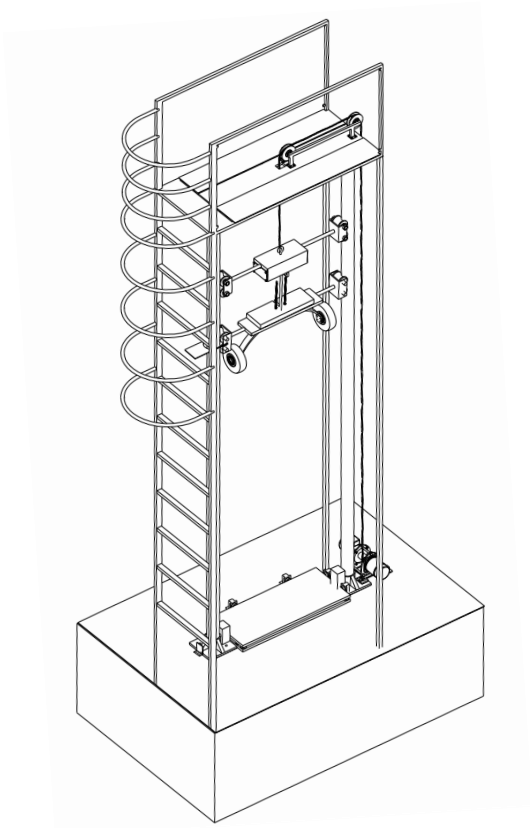

Figure 3-1: The design of landing gear drop test machine

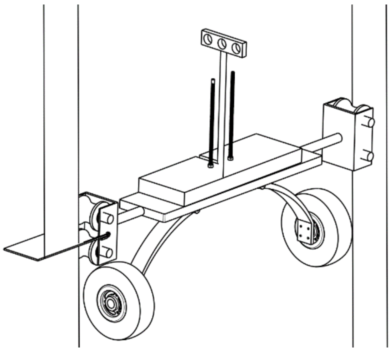

Figure 3-2: The release mechanism of free-fall landing gear

The release mechanism of the machine showed in Fig. 3-2. The test article is locked on the plate with three holes at the top of the machine. When the fixture locking is released, the test article will drop freely due to its weight. The impact force that occurs on the impact platform will be measured using a load cell. The final build of the machine can be seen in Fig. 3-3.

Figure 3-3 : Landing gear drop test Machine

**3.2 Impact platform**

The impact platform is a part of the landing gear drop test machine whose function is to receive the impact load from the fall of the landing gear when tested. Impact platforms must be designed strong, rigid, and not curved when receiving impact loads. Impact platforms must have a flat surface. The design of the impact platform can be seen in Fig. 3-4.

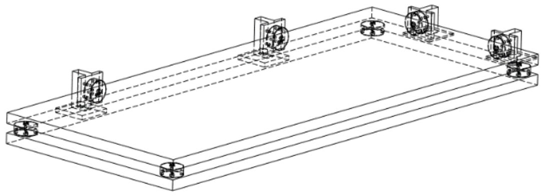

Figure 3-4: The design of impact Platform

Impact platforms are made of iron plates with dimensions of length times width of 0.5m x 1m and with a thickness of 10cm. The weight of the impact platform is 100 kg. With this size, it is expected to be used for various sizes of landing gear or various types of UAV sizes. The design of the impact platform can be seen in Fig. 3-5.

Figure 3-5: Impact platform

A load cell is installed to support the impact platform. The impact force received by the impact platform will be forwarded to the load cell, so we can find out the value of the impact load. Four load cells are installed at each edge of the impact platform. The load cell is bolted firmly on a base plate with iron material and is embedded in a cast cement so that it is strong, rigid, and not easily swayed. To isolate the effect of vibrations on the surface of the ground that can affect the results of the test, then around the base plate is made a ditch filled with sand.

### 3.3 Instrumentation

A load cell is a sensor or device used to measure force or weight. The selected load cell is the Strain gauge load cell type. It converts the forces on its surface into changes in electrical resistance. To acquire these sensors, a Wheatstone bridge is used to convert the change in resistance to a change in voltage.

The selected load cell is type H8C manufactured by Zemic. The maximum capacity of the load cell is 500 Kg. Based on information from the datasheet, this sensor has a good level of accuracy and reliability. This load cell sensor material is made from nickel plated alloy steel. The recommendation for the excitation voltage in this load cell is 5 to 12V DC. This load cell has an output rate is 3mV/V. 3mV/V means that the load cell will provide a 30 millivolt signal at full load when excited with 10V DC. Figure 3-6 is the load cell used in this research.

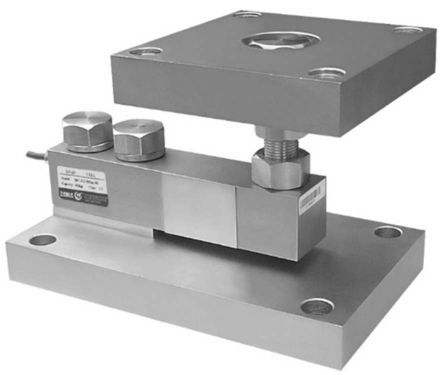

Figure 3-6: Load cell instrument

The output signal from the load cell is processed with a signal processing module made by a national instrument with type NI 9237. This module has 4 analog input channels with half / full Wheatstone bridge configuration and 24-bit ADC circuit resolution. The NI 9237 module is installed in the cDAQ-9184 module, which is a data acquisition system made by NI and is connected to a PC using a LAN cable (Ethernet). The configuration of the force measurement system can be seen in Fig. 3-7.

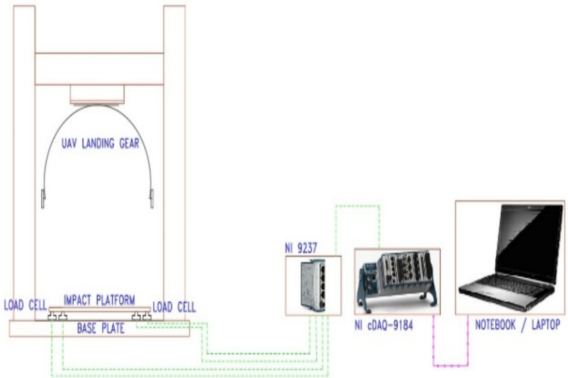


Figure 3-7: Block diagram of the force measuring system

Using Labview to create a user interface software to display the results of force measurements. Labview can be used to create user interface software because of its easy, stable, and powerful programming. With LabVIEW, we can create systems for measuring, controlling, monitoring, and storing data in one application. Data from the test results are stored in Excel form which will simplify the processing and analysis of data. The design of the user interface software made using the LabVIEW program can be seen in Fig. 3-8.

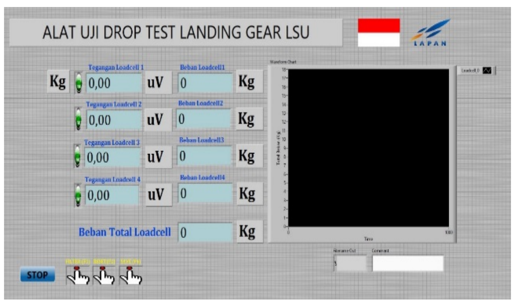


Figure 3-8: Experimental software

## 4. Results and Analysis

### 4.1 Calibration test

The system must be validated first using calibration Calibration is performed to ensure that the measurement data is accurate. Calibration is performed on a data acquisition system for measuring force and load cells. Calibration in the data acquisition system is done by measuring the force input which seems to be an output signal from the load cell. The signal can be simulated using a device called the weight system calibrator manufacture by Vishay with a type 325 model. Figure 4-1 is a tool used to perform system calibration.


Figure 4-1 : Weight system calibrator manufacture by Vishay with type 325 model

The calibration process in the system is done by comparing the values listed in the calibrator, starting from 0 mV/V, 0.5 mV/V, 1 mV/V, 1.5 mV/V, 2 mV/V, 2.5 mV/V, and 3 mV/V with the results of the voltage reading on the LabVIEW. Because what is compared is the voltage value, the values listed on the calibrator need to be multiplied by 10 which is the excitation voltage. From the results of the comparison then the relative error value is calculated. Here is a table of the results of each load cell measurement.

Table 4-1. The result from system Calibration

| **The rated output voltage from weight system calibrator model 325 (mV/V)** | **The output voltage from weight system calibrator model 325 (uV)** | **Voltage reading with a force measuring system based on LabVIEW (uV)** |
|---|---|---|
| 0 | 0 | 0 |
| 0,5 | 5000 | 4968.57 |
| 1 | 10000 | 9948.44 |
| 1,5 | 15000 | 14928.47 |
| 2 | 20000 | 19908.89 |
| 2,5 | 25000 | 24890.99 |
| 3 | 30000 | 29870.91 |

The relative error value from the calibration process is 0.49%. This value is the average of the relative error values in each measurement calculated using the equation:

$$\text{Relative error value} = \frac{[(\text{read value}) - (\text{true value})]}{\text{read value}} \, x \, 100\% \quad (4\text{-}1)$$

The process of calibrating load cells is using a scale made of iron with varying sizes. The size of the scales is 1.1 kg, 5.2 kg, and 10.6 kg. Measurements were started by adding the scales of 1.1 kg 10 times, the scales of 5.2 kg 5 times, and the scales of 10.6 kg 2 times. Then the measurement is continued by reducing the scales in reverse order from the addition of the weight earlier. The values of the scales are compared with the reading voltage values in the Labview GUI, then the data is recorded or stored on a worksheet. The calibration activity is carried out on all four load cell sensors used. The data that has been recorded is then made into a graph. Figure 4-2 to 4-5 show the calibration of the first load cell until the fourth loadcell, namely.

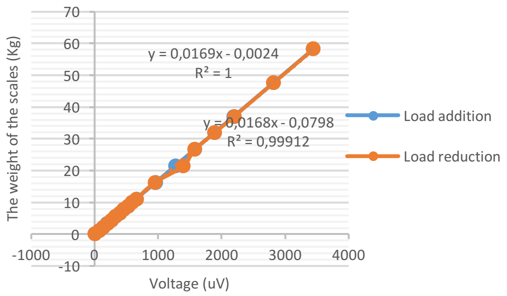


Figure 4-2: First Load cell Calibration

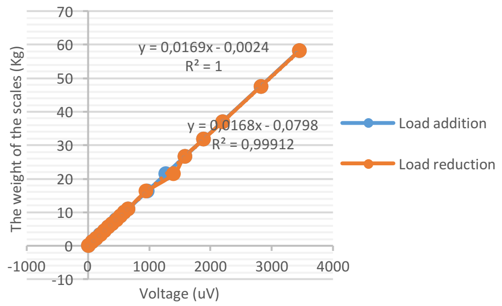


Figure 4-3: Second Load cell Calibration

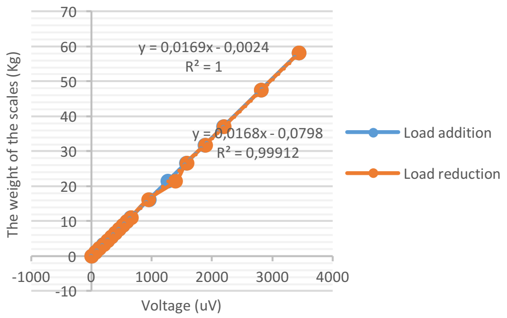


Figure 4-4: Third Load cell Calibration

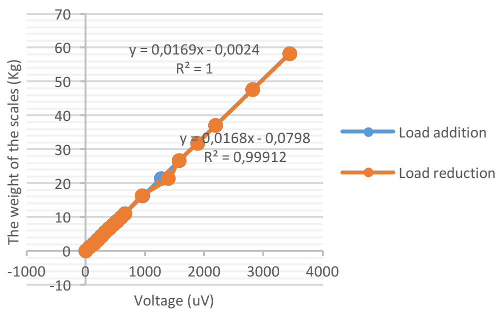


Figure 4-5: Fourth Load cell Calibration

From the results of the calibration for all load cell sensors as seen in Figure 8, 9, 10, and 11, they have almost the same equation that is when adding weight obtained the equation y = 0.0169x - 0.0024, and when reducing weight obtained the equation y = x - 0.0168x - 0.0798. Where y is the weight value of the scale with kg and x is the voltage with a microvolt unit.

The calibration process is continued by measuring the weight of the scales with all four load cells at the same time that have been installed on the impact platform. The calibration method is likened to the time of calibration for one load cell.

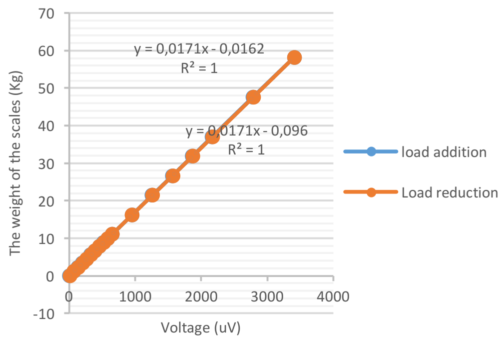


Figure 4-5: Calibration Using Four Load cell

From the calibration as seen in Fig. 4-5, obtained Equation y = 0.0171x - 0.0162 when adding weight and Equation y = x - 0.0171x - 0.096 when reducing weight. Where y is the weight of the scale with kg and x is the voltage value with the microvolt unit. It can be seen from the two activities of adding and reducing weights on calibration we get a similar equation.

## 5 Conclusion

Force measurements on main landing gear weight drop test machines for the LSU series aircraft using 4 load cells mounted on impact platforms that are designed to be strong and rigid produce accurate data. The data is processed using hardware which is a national instrument data acquisition system and displayed on Labview-based software.

This system has been validated by calibration both on the data acquisition system and also on every load cell sensor used. Calibration is also carried out on the force measurement system using 4 load cells at the same time mounted on the foot of the impact platform. The results of the test and calibration show that the force measurement system has an average relative error value is 0.49% and linearity ($R^2$) is 0.99.

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