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Static Stress Analysis and Fatigue Life Prediction of Rocket Motor Test Stand Using Numerical Simulation

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Abstract. *The rocket motor test stand is the equipment used to test the rocket motor's performance under controlled conditions. This equipment is used to measure the thrust of the Dextrose rocket motor and test the ability of components such as the tube, fuel, nozzle and cap of the rocket itself. Before the Dextrose rocket flight test is carried out, it must go through this test. In this study, the variations in the thrust are 2000, 2250, 2500, 2750, and 3000 N. The rocket motor test stands used Aluminum 6063-T6 which has light density and medium strength. Numerical simulations were carried out with Ansys Workbench software using the finite element method. The results of the static stress analysis show that the greater the thrust, the greater the maximum von Mises stress and deformation. It is inversely related to the safety factor. The greater the thrust, the lower the safety factor of the rocket motor test stand. The results of the fatigue simulation show that the greater the thrust, the lower the prediction of fatigue life and the safety factor. Rocket motor test stand fails to reach a 1 million cycle life at 3000 N thrust.*

Keywords - *Ansys workbench; fatigue life prediction; rocket motor test stand; static stress analysis; thrust*

INTRODUCTION

The Dextrose rocket is an amateur rocket that uses Potassium Nitrate (KNO3)/Dextrose fuel to generate thrust. Potassium nitrate is the basic component of fertilizers. It is soluble in water and acts as an oxidant. Dextrose, which is a combination of simple sugar and water is used as a fuel binder. In general, the ratio between Potassium Nitrate and Dextrose is 65 percent to 35 percent (13: 7). Rocket fuel from Potassium Nitrate/Dextrose (KNDX) is widely used for student amateur rocket research in various parts of the world, in addition to Potassium Nitrate/Sucrose (KNSU) and Potassium Nitrate/Sorbitol (KNSB) [1]–[6].

Glucose rocket, which is another name for the Dextrose rocket, can be used as a learning medium for relatively inexpensive rocket technology in addition to water rockets. Some of the Dextrose rocket advantages compared to water rockets are its more stable flying capability and longer range. In addition, potassium nitrate (KNO3)/dextrose fuel has a lower explosion risk than propellants using hydroxyl-terminated polybutadiene (HTPB).

The rocket motor test stand is the equipment used to test the rocket motor's performance under controlled conditions. This equipment is used to measure the thrust of the Dextrose rocket motor and test the ability of components such as the tube, fuel, nozzle and cap of the rocket itself. The equipment is used by space agencies, aviation agencies and some universities for educational purposes [7]–[15]. Before the Dextrose rocket flight test is carried out, it must go through this test. The testing is an important part of ensuring that the rocket propulsion system meets the required requirements to operate safely and successfully.

The test stands for the rocket motor has dimensions of length 1000 mm, a width of 200 mm, and the testbed internal diameter is 78 mm. It means that the maximum diameter of the Dextrose rocket tube that can be tested is 3 inches or 76.2 mm. The rocket motor test stands used Aluminum 6063-T6. Al 6063-T6 has light density and moderate strength.

In this study, the variations in the thrust are 2000, 2250, 2500, 2750, and 3000 N. Numerical simulations were carried out with Ansys Workbench software using the finite element method. Ansys Workbench is software that is widely used for simulating rocket and aeroplane components [16]–[22]. Ansys has several advantages, including that it can be integrated with almost any type of Computer-Aided Design (CAD) software such as SolidWorks, Catia, Autodesk Inventor, and Creo.

METODS

Figure 1 shows the dimensions of the Dextrose rocket motor test stand in detail. Figure 2 shows the boundary conditions of the finite element method, namely the fixed constraint on the 6 bolt holes (left) and the direction of loading on the load cell (right). The FEM assumptions using Ansys Workbench software are shown in Table 1.

The criteria for the material the test stand for the rocket motor is light and medium strength. Al 6063-T6 was chosen for this material. The mechanical properties of Al 6063-T6 are shown in Table 2.

Analysis of the static stress and fatigue life of the rocket motor test stand was performed using Ansys Workbench software. Static stress analysis is performed to determine the effect of thrust on von mises stress, deformation, and safety factors.

Fatigue analysis was conducted to determine the effect of thrust on the prediction of fatigue life and safety factors. The analysis is expected to provide conclusions about the maximum thrust so that the rocket motor test stand can last up to 1 million cycles. This fatigue life prediction uses the Gerber mean stress theory.

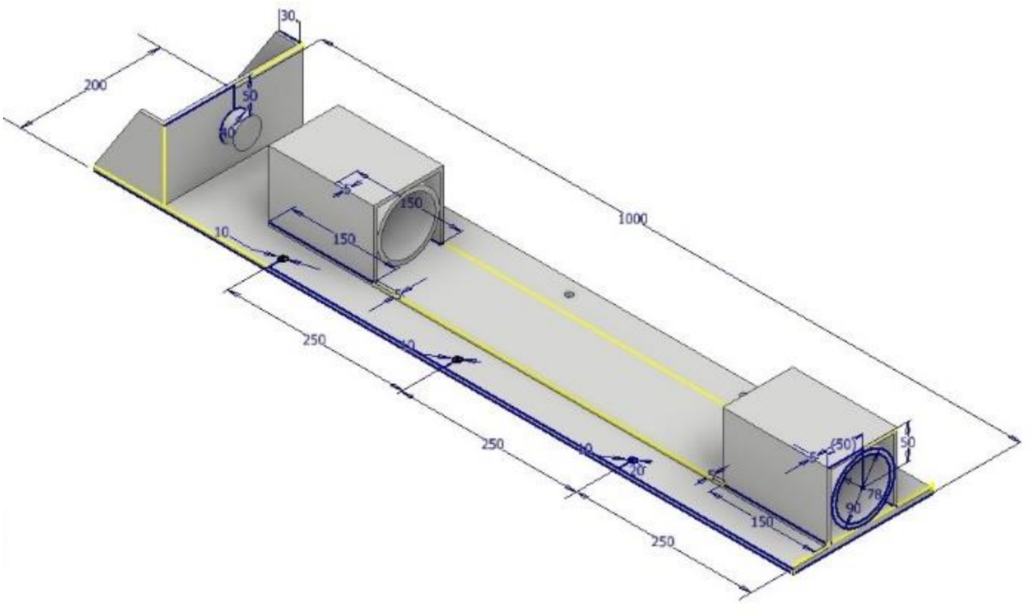

Figure 1. Dextrose rocket motor test stand design.

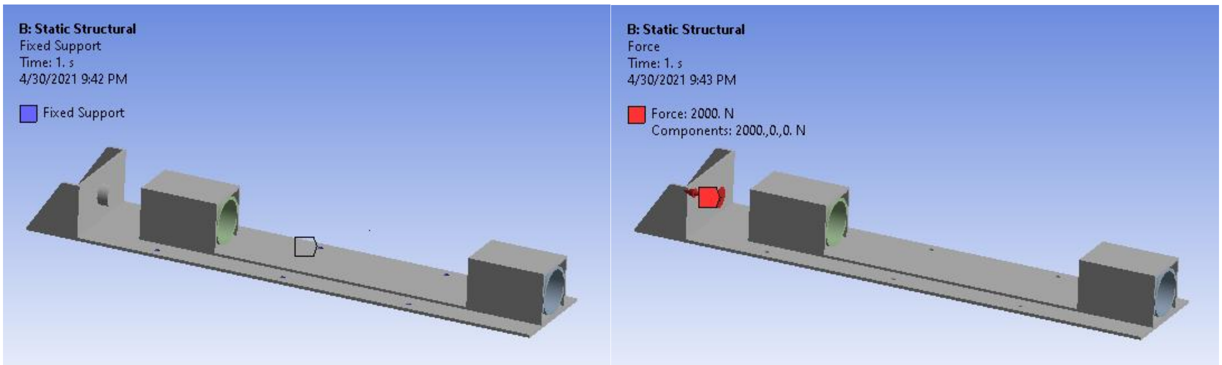

Figure 2. Boundary conditions Dextrose rocket motor test stand: the fixed constraint on the 6 bolt holes (left) and the direction of loading on the load cell (right).

Table 1. The FEM assumptions using Ansys Workbench software.

Parameter	Value
Variation of thrust	2000, 2250, 2500, 2750, and 3000 N
Element size	10 mm
Number of nodes	26020
Number of element	10204

Table 2. Mechanical properties of Al 6063-T6.

Material	*Density* (g/cm³)	*Yield Strength* (MPa)	*Tensile Strength* (MPa)	*Young Modulus* (GPa)
Al 6063-T6	2.70	214	241	68.9

RESULT AND DISCUSSION

Figure 3 (top left) shows the simulation results of von Mises stress. Rocket motor test stand for thrust 900 N.The maximum von Mises stress is 94.38 MPa and below the yield strength Aluminum 6063-T6, which is 214 MPa. This means that in the initial cycle, the rocket motor test stands the component will not fail.

Deformation is the process of changing the shape or distortion of a component that occurs because of its existing load. The maximum deformation value in this study is relatively small, namely, 6.97 mm shown in Figure 3 (top right).

The safety factor is used to evaluate the safety of a component or structure through minimally used dimensions. Using Ansys Workbench, the minimum safety factor is calculated as the yield strength of the material divided by the maximum von Mises stress. A safety factor less than 1 indicates a permanent failure of a design [23]. The rocket motor test stands with a thrust of 2000 N is relatively safe. That's because the minimum safety factor value is 2.27 (Figure 3 bottom). These values exceed the standards required for components capable of withstanding static loads. The safety factor required for a structure that can withstand static load is 1.25-2 [24].

The effect of the variation of the thrust on the maximum von Mises stress is shown in Table 3. The results of the static stress analysis show that the greater the thrust, the greater the maximum von Mises stress and maximum deformation. This is inversely related to the safety factor. The greater the thrust, the lower the safety factor of the rocket motor test stand.

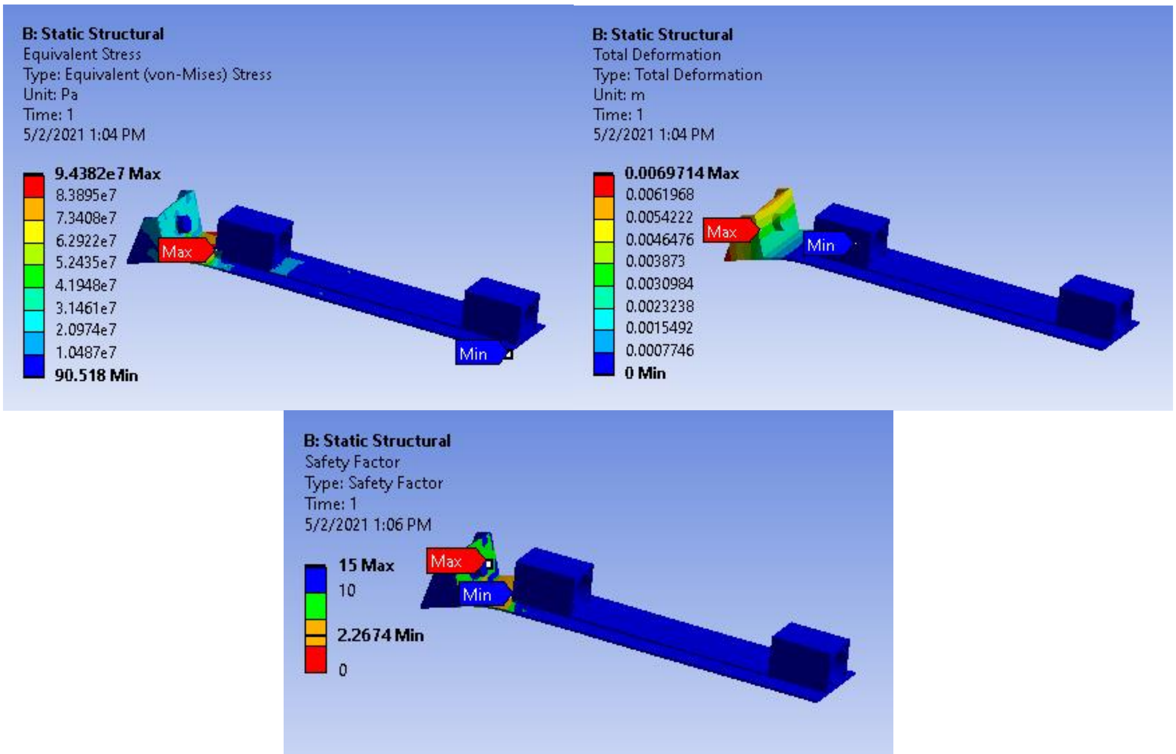

Figure 3. Static stress analysis with 2000 N thrust variation: Von mises stress (top left), deformation (top right), and safety factor (bottom).

Table 3. Effect of variations in thrust on static stress of rocket motor test stand.

Thrust (N)	Maximum von Mises stress (MPa)	Deformation (mm)	Safety factor
2000	94.38	6.97	2.27
2250	106.18	7.84	2.02
2500	117.98	8.71	1.81
2750	129.78	9.59	1.65
3000	141.57	10.46	1.51

In static stress analysis, the material will not fail as long as the maximum von Mises stress does not exceed the yield strength of the material. However, this does not apply to the fatigue life analysis. In fatigue analysis, the material can fail even though the maximum von Mises stress is less than the yield strength of the material. The failure occurs because the material has been fatigues due to repeated loads for a long time. That the majority of these failures occur due to fluctuations due to the compressive stress in the material. The sequence of fatigue processes is an initial crack, crack propagation, and final failure.

Figure 4 shows that the main landing gear frame has a minimum fatigue life of up to 32.06 million cycles. It means that the rocket motor test stand can withstand loads up to a minimum of 32.06 million cycles with a minimum safety factor of 1.42.

Table 4 shows the effect of thrust on the prediction of fatigue life rocket motor test stand. The results of the fatigue life prediction show that the greater the thrust, the lower the prediction of fatigue life and the safety factor. At 3000 N thrust, the rocket motor test stands failed to reach a life of 1 million cycles.

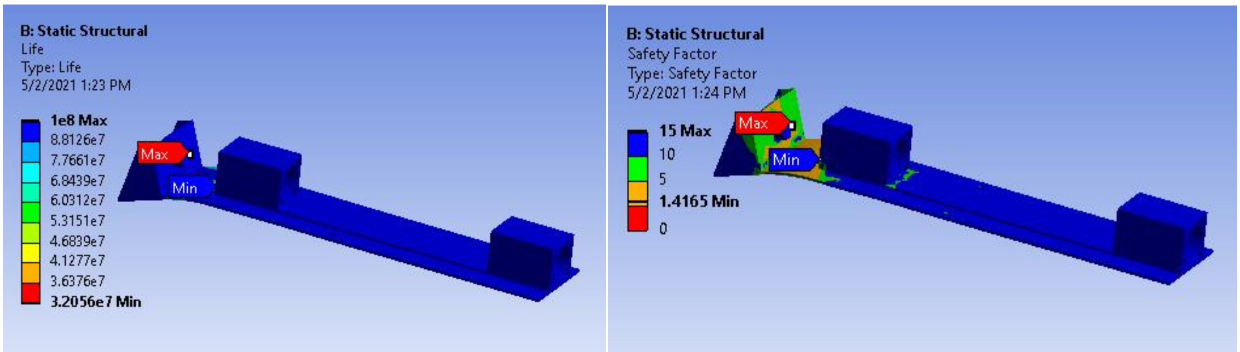

Figure 4. Fatigue life prediction (left) and safety factor (right) of rocket motor test stand with 2000 N thrust variation.

Table 4. Effect of variations in thrust on the prediction of fatigue life of rocket motor test stand.

Thrust (N)	Fatigue life prediction (million cycles)	Safety factor
2000	32,06	1,42
2250	8,39	1,26
2500	2,30	1,13
2750	1,23	1,03
3000	0,66	0,94

Conclusion

The results of the static stress analysis show that the greater the thrust, the greater the maximum von Mises stress and deformation. It is inversely related to the safety factor. The greater the thrust, the lower the safety factor of the rocket motor test stand. The results of the fatigue simulation show that the greater the thrust, the lower the prediction of fatigue life and the safety factor. Rocket motor test stand fails to reach a 1 million cycle life at 3000 N thrust.

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