

## MODELING THE THERMAL LOADS IN THE SUBARU EJ25 ENGINE

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### Abstract

The research focuses on the solutions to avoid overheating the intake and exhaust valves due to engine overload. Subaru EJ25 engines are currently mounted in passenger cars such as Subaru Impreza but the author's innovative idea is to use them in small passenger airplanes. The paper describes the coupled thermo - mechanical load model of a supercharged Subaru EJ25 engine. The engine piston was tested thermally and mechanically, and the intake and exhaust valves only thermally. The calculations were done using the finite element method (FEM) in ABAQUS 6.10. Parts were divided into Hex and Tet mesh elements, depending of their geometry. The models used in the simulation were previously created using CATIA v5. Because there were only separate parts, the authors used only Part Module. The process of 3D scanning based on the method of reverse engineering was for fine mapping the surface of the examined parts, e.g. a piston. The boundary conditions and material properties are based on the literature and the information provided by the companies that sell spare parts for this engine. The simulations were done for varied heating times and mechanical load (25, 50, 100, 250, 400 seconds).

**Keywords:** modelling, thermal model, ABAQUS, piston engine

### 1. Introduction

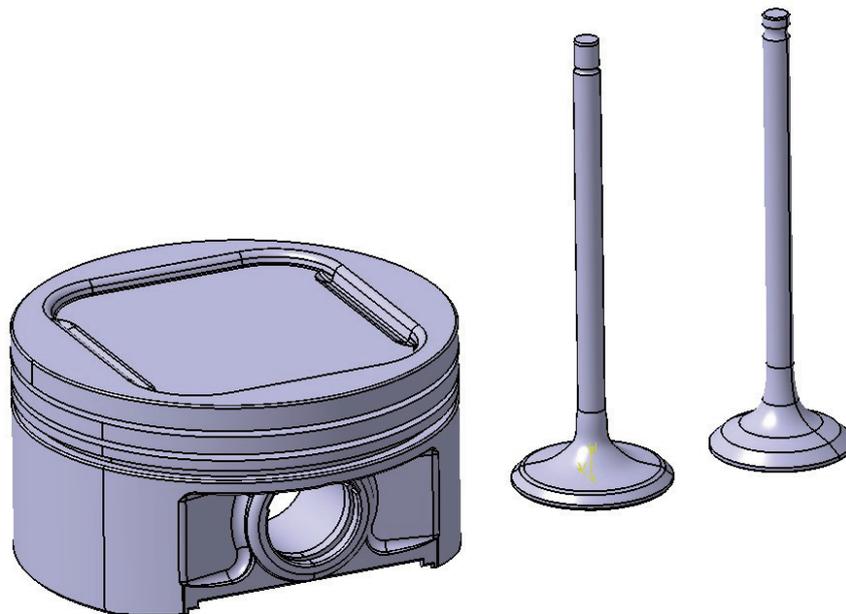
The authors' main challenge is to update the EJ25 Subaru engine currently used as a power unit for passenger cars so that it could be used in small passenger airplanes. With the analysis described in the paper, the current level of stress and maximum temperatures occurring in the present Subaru EJ25 engine can be assessed. Thus, possible changes in the engine design to adapt it to a small aircraft can be identified. Nowadays, the finite element method to simulate thermal loads and conjugated mechanical loads for the parts of internal combustion engines is widely used. Such techniques allow for determining the maximum values of stresses and temperatures in the tested parts, which is useful for updating or changing their size and shape.

### 2. Geometric model of the Subaru EJ25 engine

The modelling of selected parts of the Subaru EJ25 engine, i.e. its piston, intake valves and exhaust valves is described in the paper. The geometric models of these parts were developed in Catia v5 using the Part Design module. The geometry of the valves was mapped by measuring the real valves removed from the engine. Three-dimensional scanning with a stationary scanner Picza model LPX-600 was used for piston modelling. The real part was used to map the piston side surfaces, whereas scanning created the complex piston head surface. The scanning processed the so-called three-dimensional point cloud which using Catia v5 helped generate definition curves to model the piston head surface (Fig. 1). Then such a developed surface was joined with the side surfaces created by measuring the real element. As a result, a complete model of the Subaru EJ25 engine piston was developed. The ready geometry of the selected engine components was recorded as \*.stp file and loaded into Abaqus 6.10. (Fig. 2).



*Fig. 1. Surface of the piston crown created by 3D scanning*



*Fig. 2. 3D models of the piston, intake valve and exhaust valve*

### **3. Preparing thermo-mechanical loads simulation**

The thermo-mechanical load (piston) and thermal (valves) simulation was performed by means of Abaqus 6.10 and Finite Element Method (FEM). The initial discretization of the models revealed that small changes in developing a mesh for valves can help to develop a Hex-dominated mesh. This model discretization is similar to a full Hex mesh and allows for much more accurate simulation results. With dividing the geometry of the intake and exhaust valve into several separate features, a more precise mesh can be developed. The Bottom up method was used here. As a geometric structure of the piston was very complicated, a less precise Tet mesh was adopted to develop its model.

The mesh of the piston, inlet valve and outlet valve comprise 249063, 17316 and 14688 elements, respectively. All of the tested engine parts and their mesh are given in Fig. 3.

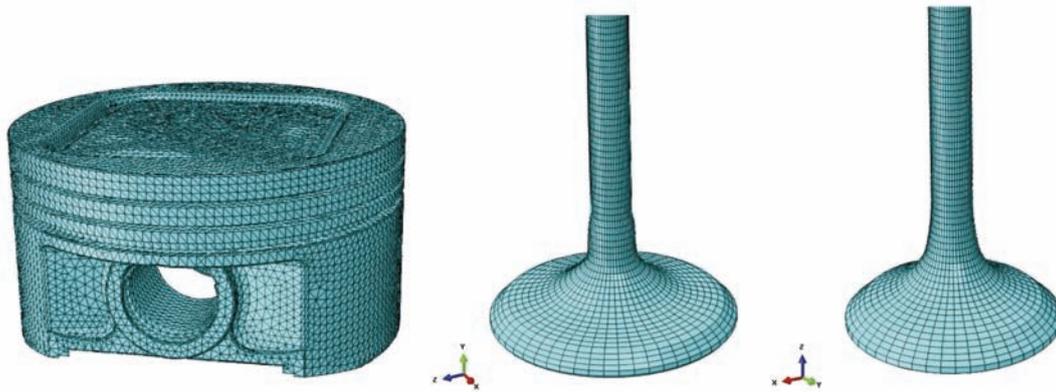


Fig. 3. Mesh of the piston, intake and exhaust valve

Boundary conditions were selected on the basis of the literature data that describe the thermal loads of the engines of a similar design and capacity to the tested Subaru EJ25 engine. The geometry of the valves was divided into appropriate areas, having different boundary conditions:

- the lower surface of the valve and the side surface up to a contact point with the valve seat,
- a contact area between the valve and its seat,
- a side valve surface up to a contact point with the valve guide,
- a contact area between the valve and its guide,
- a side surface of the part above the valve guide.

The piston is divided into the areas defined by a series of grooves for sealing rings. Each of the above mentioned surfaces has been specified by two parameters that define thermal loads:

- film coefficient –  $\alpha$ : coefficient of convection (heat transfer) [ $\text{W}/\text{m}^2\cdot\text{K}$ ]
- sink temperature: heating agent temperature [ $^{\circ}\text{C}$ ].

All of the surfaces were warmed up to the initial temperature of  $20^{\circ}\text{C}$ . The boundary conditions for mechanical simulation were defined as the pressure acting on the entire piston head surface (maximum pressure in the engine cylinder).

It is necessary to load certain data on material that refer to both its mechanical and thermal properties to do the coupled thermo-mechanical calculations in Abaqus. The data provided by the manufacturers of the Subaru EJ25 spare parts related to the materials for the pistons and valves was used to introduce material properties as given in Tab. 1 and Tab. 2. The values of the all parameters for two materials [2618T-61 Aluminum Alloy and 21-4n (Ev8)] given in the two tables come from the literature.

Tab. 1. Piston made of 2618T-61 Aluminum Alloy

Material properties	Value
Young's modulus. E [GPa]	73 GPa
Poisson's ratio	0.33
Density $\rho$ [ $\text{kg}/\text{m}^3$ ]	$2760 \text{ kg}/\text{m}^3$
Thermal expansion coefficient $\alpha$ [ $1/^{\circ}\text{C}$ ]	$2.29 \cdot 10^{-5}$
Thermal conductivity $\lambda$ [ $\text{W}/\text{m}^{\circ}\text{C}$ ]	$146 \text{ W}/\text{m}^{\circ}\text{C}$
Specific heat	$875 \text{ J}/\text{kg}^{\circ}\text{C}$

Tab. 2. Intake and exhaust valves made of 21-4n (Ev8)

Material properties	Value
Young's modulus. E [GPa]	211 GPa
Poisson's ratio	0.29
Density $\rho$ [kg/m <sup>3</sup> ]	7740 kg/m <sup>3</sup>
Thermal expansion coefficient $\alpha$ [1/°C]	10·10 <sup>-6</sup>
Thermal conductivity $\lambda$ [W/m°C]	18 W/m°C
Specific heat	500 J/kg°C

#### 4. Thermal and mechanical loads simulation results

There were done two kinds of simulation, i.e. thermo-mechanical simulation for the piston and thermal simulation for the valves. Numerous simulation tests were carried out for varied heating times for these two cases. Figures 4, 5, 6, 7 show some selected distribution maps of the stresses and temperatures for the sample heating time.

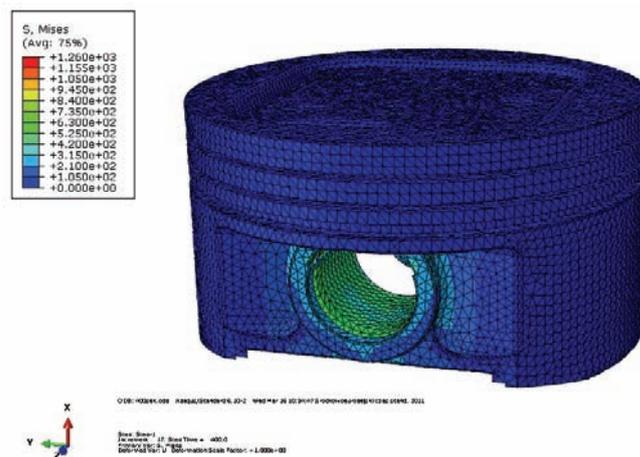


Fig. 4. Stress distribution in the piston

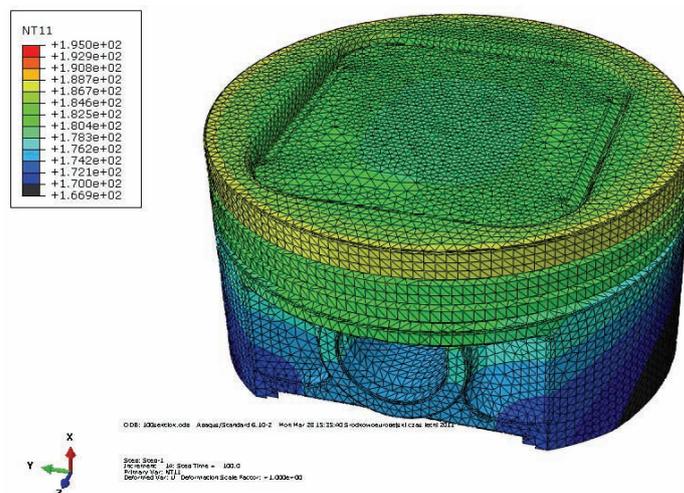


Fig. 5. Temperature distribution on the piston surface for 100 second heating

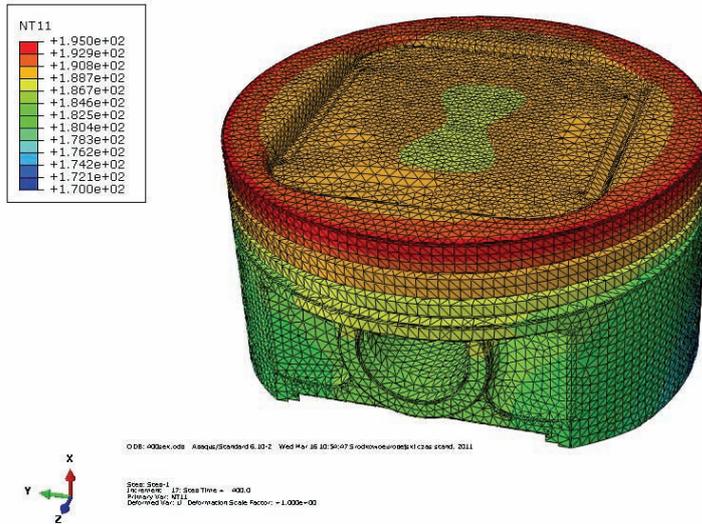


Fig. 6. Temperature distribution on the piston surface for 400 second heating

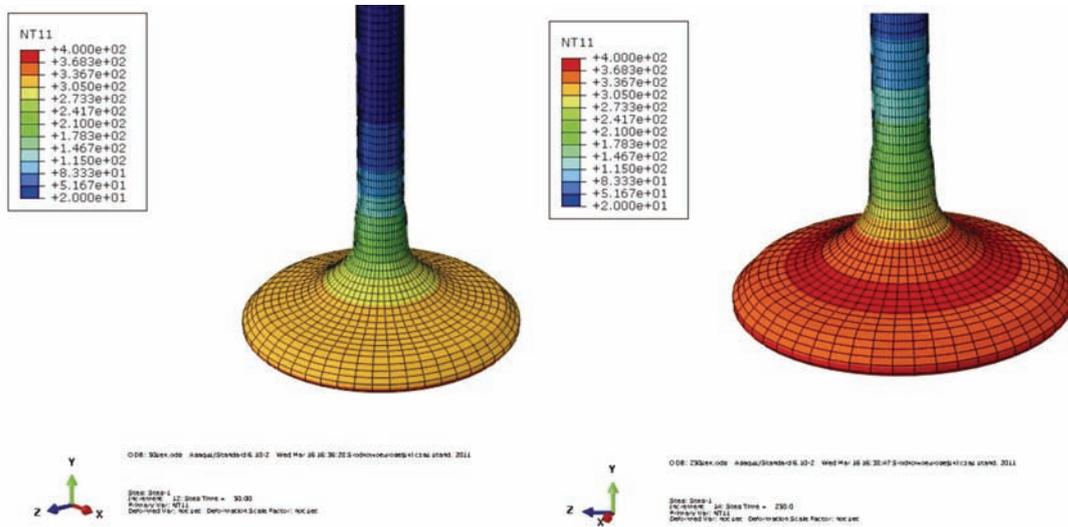


Fig. 7. Temperature distribution at the intake valve for heating for 50 and 250 seconds

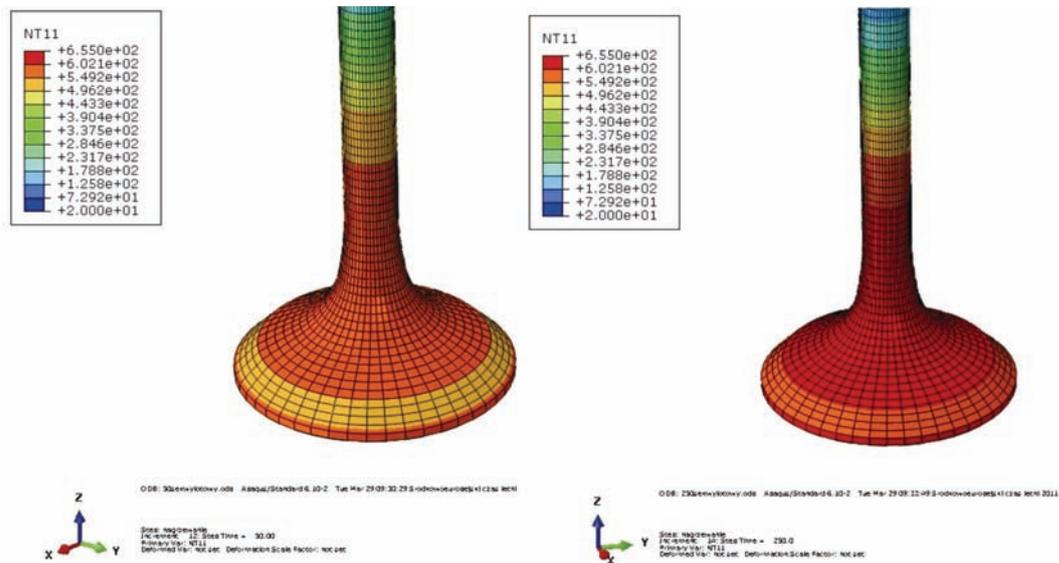


Fig. 8. Temperature distribution on the exhaust valve surface for heating for 50 and 250 seconds

## 5. Conclusion

The temperature and stress maps will be useful for a further analysis to change the Subaru EJ25 engine design. By analyzing the simulation results, the authors are able to evaluate what kind of significant changes in the engine design could be introduced to avoid overheating the intake and exhaust valves.

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