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Engineering Report: AVS4CYL001-1

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Subject: Finite Element Analysis Cylinder Head Cracks

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2 Introduction

An issue was raised by the RAA regarding the cylinder heads of Jabiru Engines (RAA airworthiness letter 10102014). It was perceived that small cracks which sometimes develop in the junction between three of the Cap Screw landings and the adjacent fin could be a potential safety risk. Analysis was conducted to justify why these cracks do not pose a serious threat to the integrity of the cylinder and the engine as a whole.

3 Cylinder Head Cracks

As mentioned the cracks in the Cylinder head occur between the junction between the Cap Screw landing and the adjacent fin. These cracks have been seen to occur on the front three Cap Screw landings and most commonly on the middle one. Figure 1 below shows a cylinder head which had developed one if these cracks

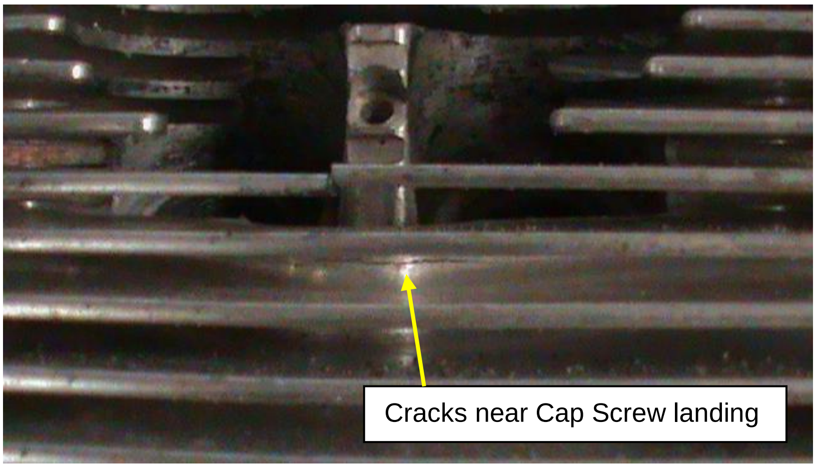

Figure 1 - Cracks in Cylinder Head near Cap Screw landing

It is suspected that these cracks develop simply because the amount of material at these points is very thin. It is therefore likely that the crack develops because of thermal creep, where the cylinder head temperature increases and decreases cyclically causing the thinner material to expand at a different rate to the surrounding thicker material and therefore it ‘gets left behind’ creating a crack.

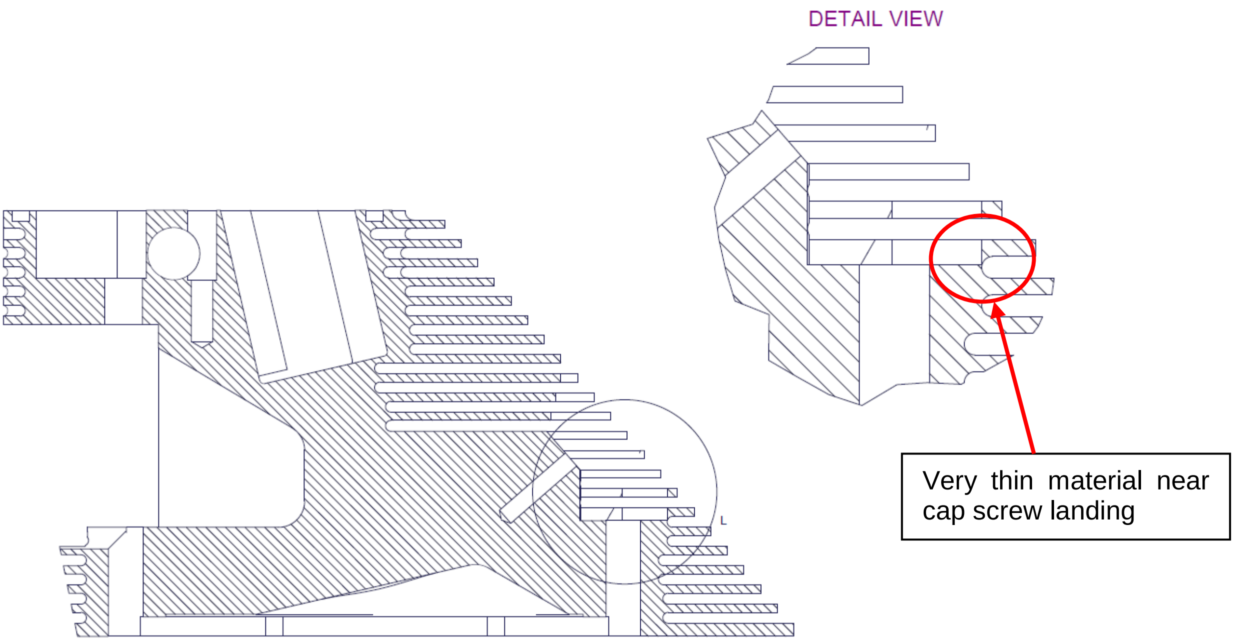

Figure 2 - Details of the Cap screw landing of the Cylinder heads

4 Finite Element Analysis

Finite Element Analysis (FEA) was conducted to determine the level of stress at these points on the cylinder where cracks have been observed. The CAD package ‘Inventor’ was used to construct the model while the FEA package ‘Strand7’ was used to mesh, apply loads and boundary conditions and solve it.

4.1 FEA Model

The accuracy and speed of FEA is very much dependant on reducing the number of elements in the model by removing un-necessary details and other simplification techniques. Beginning with the CAD model for the 2200 cylinder head (P/No 4A499B0D-4) the following simplifications were made

- The model was cut in half – This obviously reduces the number of elements which must be solved to half. On the cut face a symmetrical boundary condition can be applied, therefore the solution given for the half model will be equivalent to that of the full model.
- Unnecessary cooling fins were removed – The fins themselves are thin plates with an edge being free and unsupported, they do not influence the stiffness of the cylinder head. Of course the fin which has the cap screw landings machined into it was kept in full, since this is the area of interest.
- Several holes were removed – This included the spark plug and exhaust port screw holes. Compared to the total size of the cylinder head these holes are all small and will not affect the stiffness of the cylinder head very much. The cylinder ports however were kept in the model since they are large and will influence the stiffness substantially. The cap screw holes were kept since they are the points of interest.
- Other details such a O-ring grooves and shaft slots were all removed since they are dissociated from the area of interest and again do not affect the stiffness of the cylinder head very much.

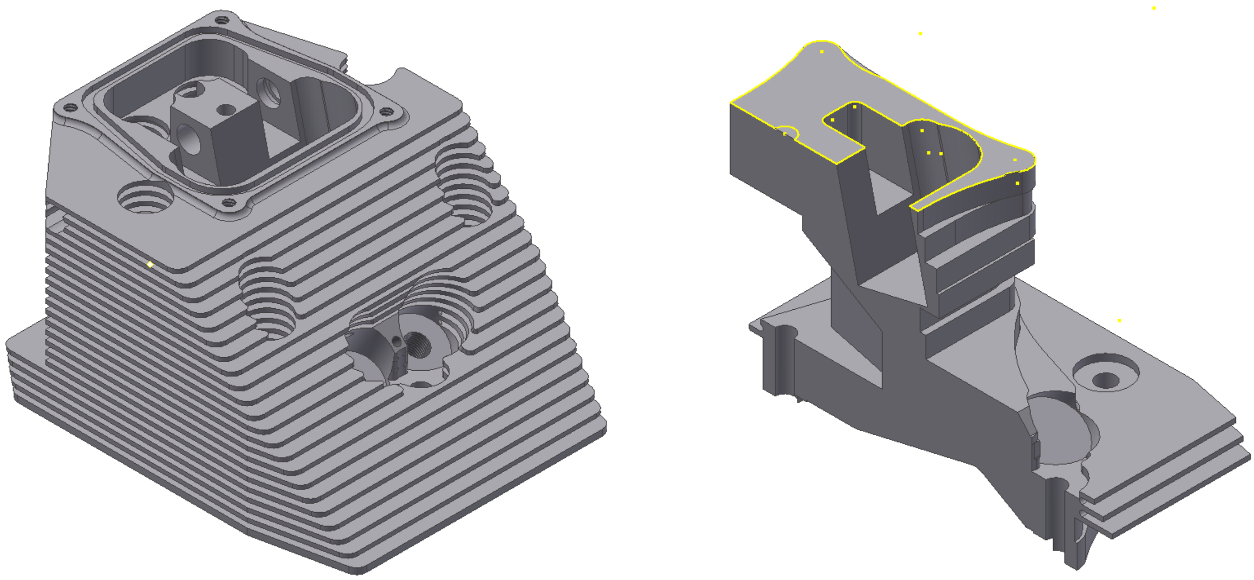

Figure 3 - Cylinder Head model (left) was simplified (right) for FEA

4.1.1 Meshing

After defining the model, the model was meshed as an array of Constant Strain Triangle plate elements. These were in tern used to mesh the model as tetrahedral brick elements. The mesh generated was composed of 27728 nodes with 124881 brick elements. All the brick elements were attributed the material properties of 5083-H112 grade aluminium alloy which is the material used to make the cylinder heads.

4.1.2 Loads and Boundary Conditions

On the cut face, symmetrical boundary conditions were used. On the bottom of the cylinder head model, restraints on the barrel butting face and the barrel concentric face were placed to represent the support from the barrel.

Cap Screw preloads were applied to the Cap screw landing faces in the form of a surface pressure distributed over the entire circular landing. The pressure used was 76.3 MPa which is equivalent to a 20.1 kN cap screw preload. This preload tension is achieved for a torque setting of 24 ft.lb when the 5/16" cap screw is installed.

On the bottom surface of the cylinder model a pressure load of 7 MPa was applied. This is equal to 1000 psi, which is the highest combustion chamber pressure that Jabiru Engines operate at for the given compression ratio.

The model mesh, Boundary Conditions and loads are shown below in Figure 4

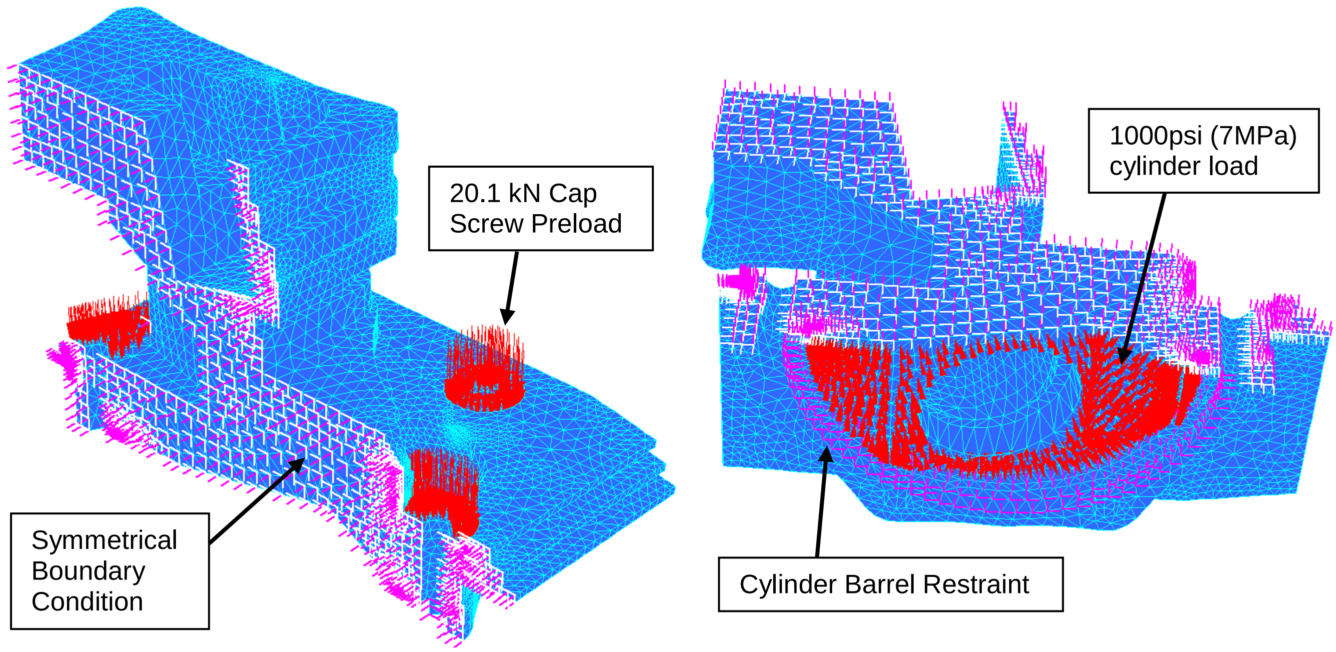

Figure 4 - Cylinder Head FEA mesh, Loads and Boundary Conditions

4.2 FEA solution and results

Results were obtained for a linear static solution using the loads and Boundary conditions as previously described. The results come in the form of a colour contour plot visually showing the nature of the stress level on the cylinder head. Figure 5 below provides an overview. Note that for this and all following results figures show Von Mises combined stress. As is expected the most highly stressed regions of the cylinder head are where the cap screw preload pressures are applied. Which develops at most about 70-80 MPa combined stress.

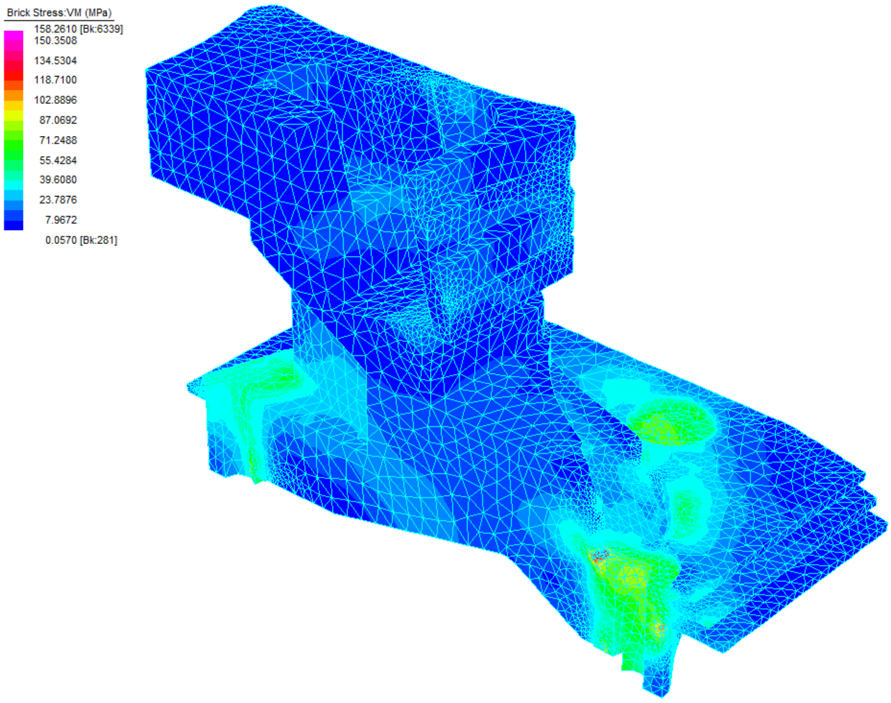

Figure 5 - FEA results - overview of the stress level in the cylinder head

Of primary interest is the stress level at the fin grooves adjacent to the front and side cap screw landings. Looking at the cylinder head front on the stress level of the front cap screw landing can be seen. Figure 6 shows this general area (top image) with a close up and the stress determined for the point at which the cracks initiate on the front cap screw landing.

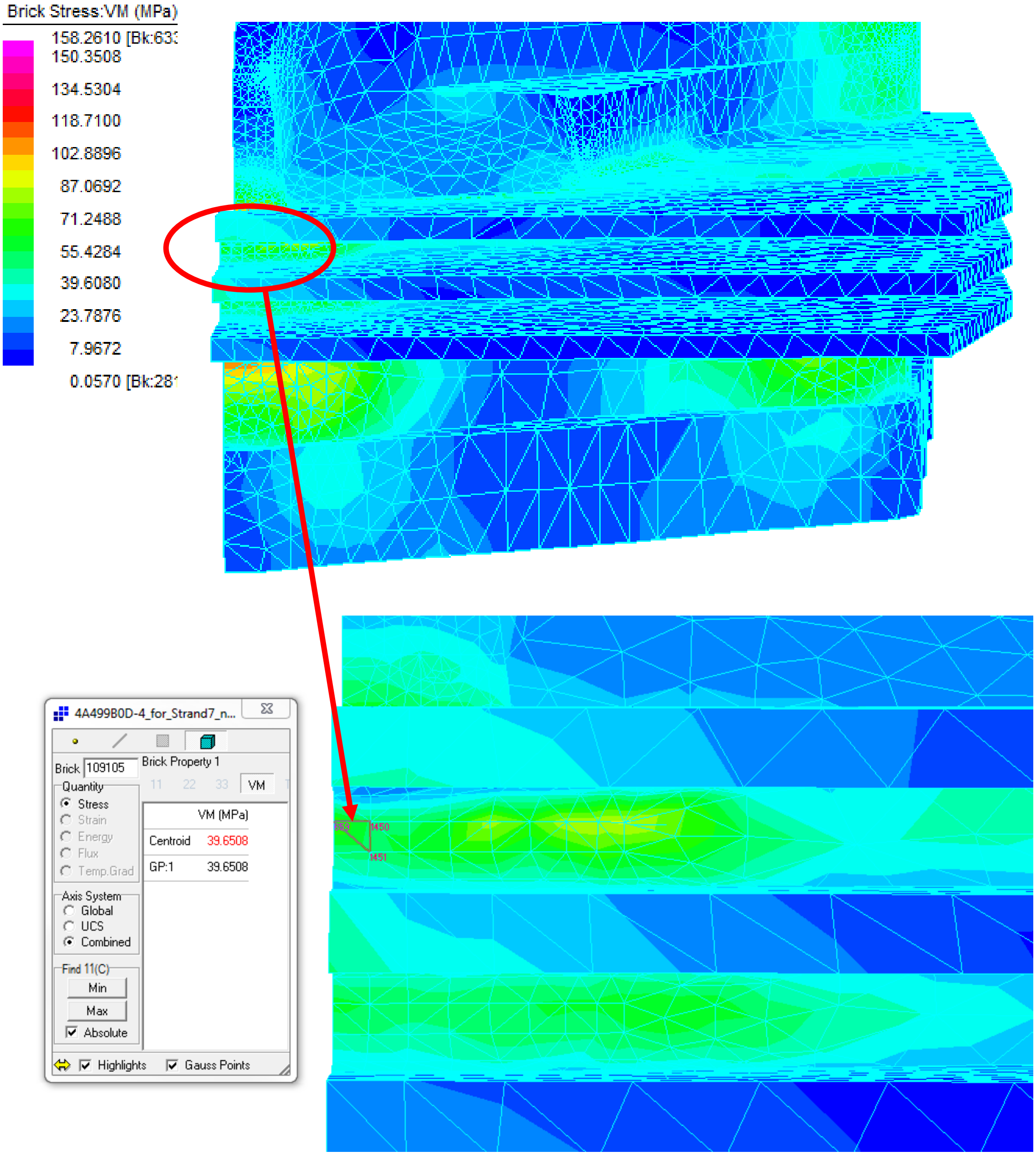

Figure 6 - Stress levels on the front cap screw landing (a place where cracks have been detected)

It can be seen that the stress levels around this area of the cylinder are relatively low as indicated by the light blue colouration. More specifically the magnitude of Von Mises combined stress is only 39.6 MPa.

5083-H112 aluminium alloy has an ultimate tensile strength of 269 MPa (as taken from the MIL5HBK5J). The stress level in the area where these cracks have been observed is only 15% of the Ultimate tensile stress. This is too low to be the reason for the crack initiating in the first place and also too low to cause the crack to propagate.

5 Conclusion

From FEA analysis it was found that the stress level where these cracks had been found is too low for pure overstress to be responsible. Therefore the crack had developed due to thermal creep. The level of stress is also too low for the cracks to propagate. From analysis conducted these crack do not present a threat to the cylinder head structural integrity or the integrity of the engine as a whole.