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Team develops computationally quick approach to predict molten droplet solidification on a solid surface

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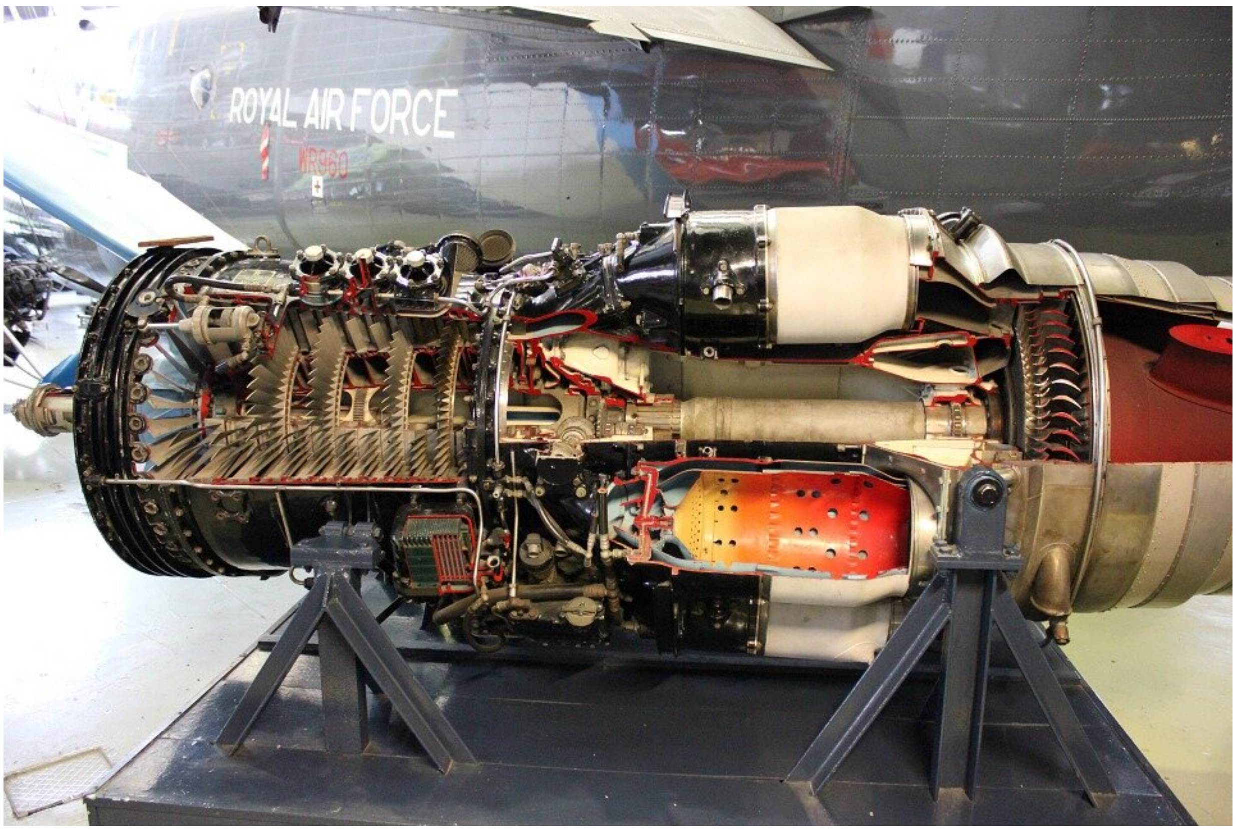

Solid particles sucked in with the air melt in the combustion chamber and solidify on the turbine blades and cooling holes causing deformation and damage to the engine. In a new study, researchers have examined the solidification process of molten droplets with the aim of helping develop a universal model to predict their deposition in jet engines. Credit: PublicDomainPictures from Pixabay

Gas turbine engines in planes provide the required thrust by sucking in air, heating it to very high temperatures in a combustion chamber, and finally exhausting it at high velocities. As they operate, small inorganic particles such as volcanic ash get sucked in along with the air. These particles melt in the high-temperature zones in the combustion chamber and solidify onto the cooler zones in the engine such as the turbine blades. Over time, these droplets solidify and accumulate on the surface of the gas turbine, deforming the blades and blocking cooling holes, which deteriorates the performance and the life of the engine.

While the deposition phenomenon is unavoidable, predicting the process can help engineers develop and modify engine designs. One of the main aspects of the deposition process is determining how molten droplets solidify in contact with a cooler surface, and an accurate simulation of this process is fundamental to understanding the process.

In a study published in the *International Journal of Heat and Mass Transfer*, a group of scientists from Japan developed a model that can quickly and accurately simulate the solidification of a single molten droplet on a flat surface. Their model does not require any prior information to setup and can be used to develop models that can predict the deposition process in jet engines.

The research term consisted of Dr. Koji Fukudome and Prof. Makoto Yamamoto from the Tokyo University of Science, Dr. Ken Yamamoto from Osaka University, and Dr. Hiroya Mamori from The University of Electro-Communications.

Unlike previous models that assumed the surface to be at a constant temperature, the new approach simulates the solidification process by considering the droplet behavior and the heat transfer between the hotter droplet and the cooler surface. "We have been simulating droplet impact, but we could not ignore the difference from the experiment. In this study, we thought that taking into account the temperature change of the colliding wall surface would be consistent with the experiment," explains Dr. Fukudome.

To have a less computationally intensive model, the researchers opted for a meshless moving particle semi-implicit (MPS) method which did not require multiple calculations on each grid. The MPS method is based on fundamental equations of fluid flow (such as the incompressible Navier-Stokes equations and mass balance conservation equations) and has been widely used to simulate complex flows. Meanwhile, the temperature change inside the substrate was computed using the grid-based method, so that we used the coupling method of both particle-based and grid-based methods.

Using this approach, the researchers simulated the solidification of molten tin droplet on a stainless steel substrate. The model performed relatively well and was able to replicate the solidification process observed in experiments. The simulations also provided an in-depth view into the solidification process, highlighting the spreading behavior and the temperature distribution of the droplet as it comes in contact with the solid surface.

Their simulations showed that the solidification is dependent on the thickness of the liquid film that was formed after the molten droplet had come in contact with the surface. Solidification initiates as the liquid film expands on the surface and was first observed at the edge of the liquid film near the surface. As the liquid film continues to spread and become thinner, solidification progresses until the entire film is turned into solid particles.

These findings are an improvement on current solidification models and the team is hopeful that their current approach can be used to build more complex deposition models. "There is no universal model for predicting depositions. Therefore, when considering the deposition of a certain droplet, a model is created by conducting experiments in advance, and numerical predictions are made. This study is expected to be a pioneer in the development of a universal deposition model," Dr. Fukudome remarks.

Thanks to this study, engineers and scientists can get a better understanding of the complex deposition phenomena and jet engine designs can be redesigned to be safer and long-lasting.

More information: Koji Fukudome et al, Numerical simulation of the solidification phenomena of single molten droplets impinging on non-isothermal flat plate using explicit moving particle simulation method, *International Journal of Heat and Mass Transfer* (2021). DOI: 10.1016/j.ijheatmasstransfer.2021.121810

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