

Prediction Snow Ingress into Air Intake System

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ABSTRACT

The following two objectives were set for the development of predictions for snow ingress into the air intake system.

- To enable snow ingress predictions in the design stage so that vehicles can be developed in a short period of time.
- To guarantee performance in very cold regions such as Canada.

To achieve these objectives, it was decided to develop snow ingress prediction tools that use computational fluid dynamics (CFD). First, research was conducted in Canada to collect the snow information that was required for the simulation. In this research, snow particle measurement equipment was used to measure in detail the number of snow particles and their diameters. The research results that were obtained were reflected in the simulation, and a correlation was found between the calculations and test results obtained in Canada. Finally, tools were developed to facilitate results analysis from the snow ingress simulation. These analysis tools will be useful when formulating countermeasures against snow ingress or for deepening designer understanding of the phenomenon.

INTRODUCTION

New vehicles are constantly being launched to meet the changing needs of consumers, new laws or regulations, or an increasing number of markets. As such, it is desirable to cut vehicle development periods to help ensure the timely launch of new vehicles into a market. Being able to evaluate performance during the design stage means that specifications can be determined without constructing a prototype vehicle or prototype parts, and leads to much quicker vehicle development. Then, performance prediction technology to be used in the design stage is developing. In this case sturdy, the prediction technology of snow ingress into the air intake system was developed.

There are cold regions in overseas markets such as Canada, Northern Europe, China and Russia, and snow should be considered carefully when designing vehicles for these areas. If snow enters the air intake system and obstructs the air cleaner, the engine power will drop, and in the worst case it may cause an engine stop. The air intake system needs to be designed so that large amounts of snow do not enter. Figure 1 shows regions where the average temperature in January is -20°C or less [1]. Canada has one of the most severe climates in the world, making it likely that a large amount of snow ingress into the air intake system occurs there. The objective was to develop prediction tools that could be applied to Canada.

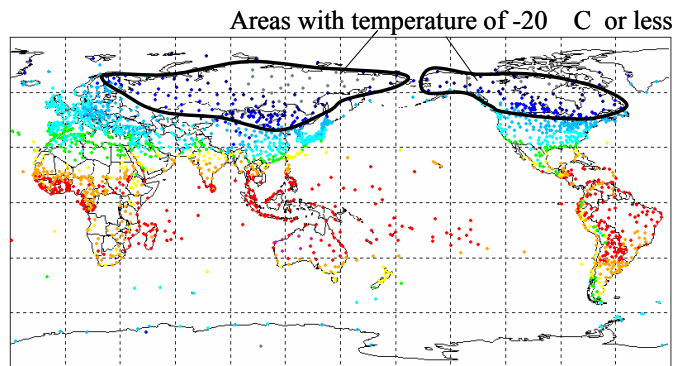


Figure 1: Areas where the average temperature in January is -20°C or less

SNOW PROPERTY RESEARCH

Research was conducted to obtain the physical parameters of snow that were required in the snow particle calculations. The following physical parameters were researched:

Particle shape, particle diameter, particle mass, restitution coefficient, drag of snow particles

Figure 2 shows the relationship between the shape of snow crystals and temperature and the ice supersaturation vapor density [2]. In the sky, the crystals are actually generated there are layers with

different temperature distributions and vapor distributions. Different types of snow crystals are generated in these different layers.

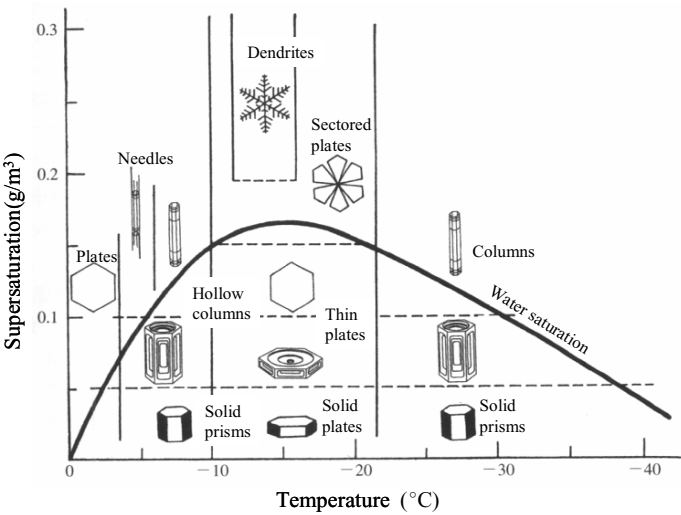


Figure 2: Relationship between the shape and temperature of snow crystals and the ice supersaturation vapor density

Table 1 shows the particle diameters and masses of single crystals [3].

Table 1: Crystal particle diameters and masses

Crystal Type	Diameter (mm)	Mass (mg)
Needle	1.53	0.004
Flat Dendrite	3.26	0.043
Solid Dendrite	4.15	0.146
Powder Snow	2.15	0.064

When snow falls, crystals bind together or intertwine to form snowflakes. Figure 3 shows the relationship between the air temperature and the snowflake size. The figure shows that large snowflakes were measured at around 0° C. This is because crystals attach to each other when the temperature reaches about 0° C. Snowflakes become smaller when the air temperature drops below 0° C, but become larger again when the temperature is about -15° C. This is because dendrite crystals are generated at -15° C. It is easier for these crystal types to intertwine together [2]. If the air temperature in Canada is assumed to be -20° C, then from Figure 3 it can be seen that the snowflake diameter there should be approximately 1 mm. Figure 4 shows the relationship between the restitution coefficient and the temperature of ice particles. As the temperature drops, the restitution coefficient becomes larger [2]. If the air temperature in Canada is assumed to be -20° C, then the restitution coefficient there should be approximately 0.9.

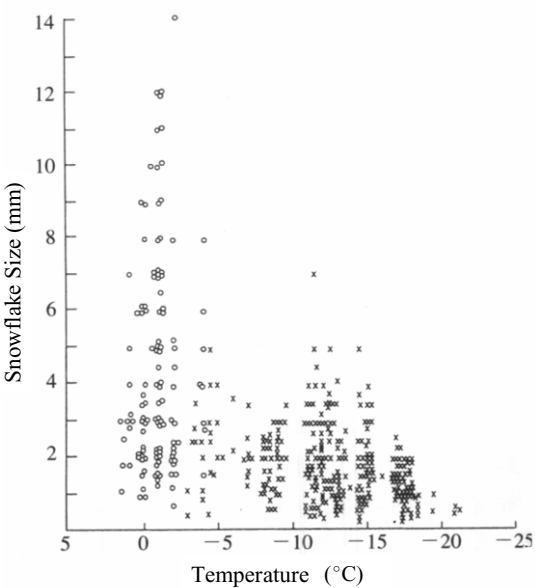


Figure 3: Relationship between the air temperature and snowflakes size

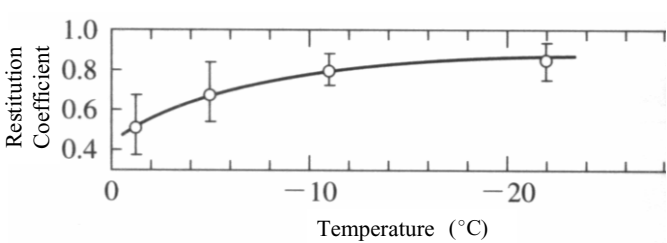


Figure 4: Relationship between the restitution coefficient and temperature

If the snow particle is spherical, then the drag (F) of the snow particle is expressed by either equation (1) or equation (2) below. If the snow particle diameter is 1 mm as derived from the previously described relationship between the air temperature and snowflakes, then equation (2) is applied [2].

Small particles (less than about 0.05 mm)

$$F = 6\pi\mu v \tag{1}$$

Large particles (more than about 0.05 mm)

$$F = \frac{1}{2} C_D S \rho v^2 \tag{2}$$

Where μ is air viscosity coefficient, v is particle speed, C_D is drag coefficient, S is frontal area, ρ is air density.

The snow particles investigated in the reference materials came from snow that fell from the sky. However, snow that enters the vehicle while driving is mainly snow that has been rolled up by vehicles in front. Since this snow is likely to be different from the snow that was researched in the reference materials, it was decided to conduct actual snow property research in a cold region. A snow particle counter (SPC) like the one shown in Figure 5 was used to measure the snow

particles by installing it onto a vehicle. The SPC works by shining a light from one side. The shadows of the snow particles that pass through this light are detected by a light diode positioned on one side, from which the particle diameters and number of particles are measured [4].



Figure 5: Snow Particle Counter

The vehicles used in the snow property research were driven as follows. Two vehicles were used in the test, with one driving after the other. Snow that was rolled up by the vehicle in front blanketed the second vehicle that was moving a certain distance behind. The snow particle measurements were then made by the SPC that was installed on the second vehicle. Figure 6 shows the distribution of particle diameters that were measured in Canada. Although in the reference materials the snowflake size at -20°C was approximately 1 mm (see Figure 3), it was understood from the test that the airborne snow was composed of small particles, about 0.1 to 0.4 mm.

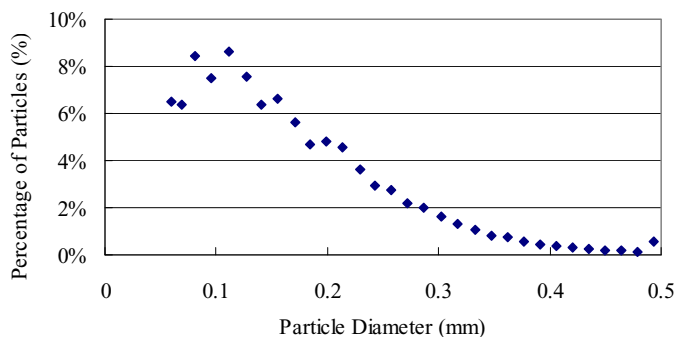


Figure 6: Distribution of snow particle diameters in Canada

Figure 7 is a photograph taken with a microscope of snow particles that were attached to the air cleaner element. In the photograph, many spherical particles of approximately 0.1 mm can be seen, which matches the results of the SPC. There are no dendrite crystals. Figure 8 shows the distribution of the number of particles at different heights from the ground. It can be seen that at a height of 300 mm there were about double the number of airborne snow particles than at a height of 900 mm, and that most of the particles were near the ground.

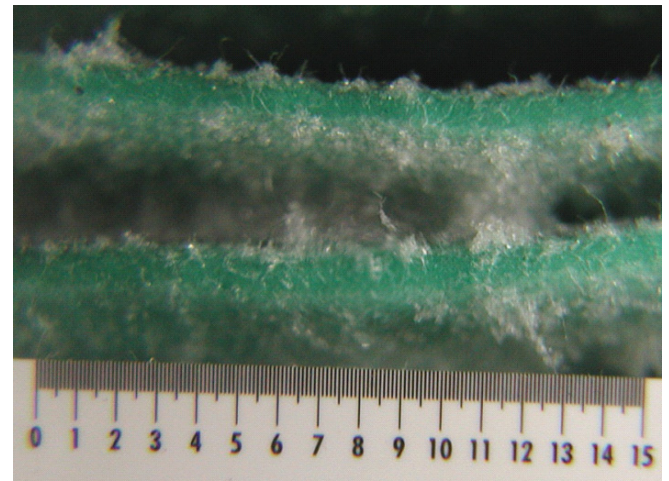


Figure 7: Snow particles that were attached to the element (one scale graduation is 0.1 mm)

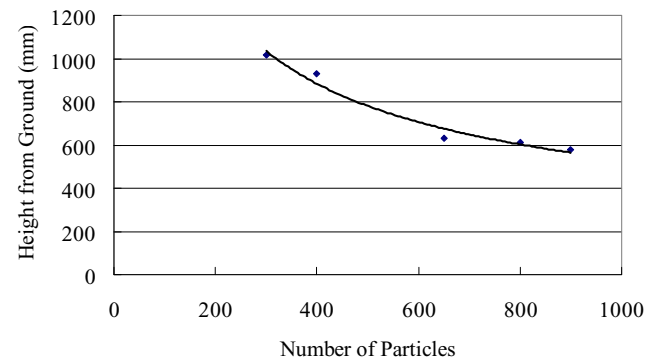


Figure 8: Relationship between height and the number of particles

Figure 9 shows the distribution of particle diameters at different heights from the ground. There was no difference in the particle diameter distribution according to height.

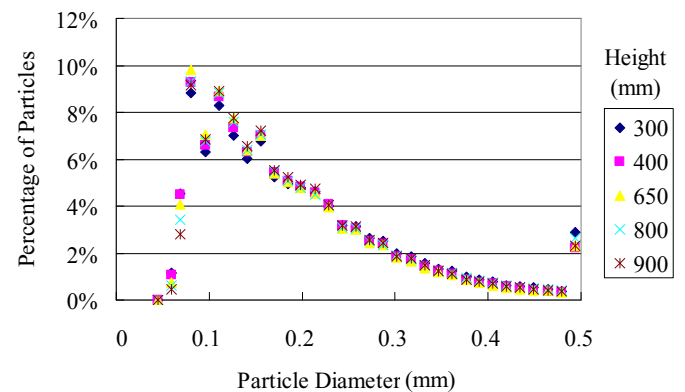


Figure 9: Distribution of particle diameters by height

Figure 10 compares the number of airborne snow particles in areas where the temperature was -16°C and -9°C . On average, there were about twice as many airborne particles at -16°C as at -9°C .