High Speed Gears Overheating due to Lubrication

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Abstract

Rotorcraft gearboxes are quite unique in the industry as they generally deal with high power, high overall gear ratio, low available space and a strong push towards weight reduction. The main functional components (gears and bearings) typically require pressurized lubrication; when for any reason oil is not effectively drained away it can lead to overheating, especially on high-speed gears. Two cases are shown here to exemplify the issue and its solution; the first example represents an MGB where one of the Input Modules got entirely filled with oil until the issue was understood and then easily solved; the second example shows a Nose Gearbox where an unexpected windage phenomenon prevented oil drainage to the scavenge pump, thus leading to extreme and almost instantaneous overheating of the module.

1. INTRODUCTION

Rotorcraft gearbox structural function is mainly provided by housings, whereas the functional role (i.e. transferring torque from engine(s) to rotor(s)) is provided by gears and bearings. These parts need lubrication, which causes fair amounts of oil being sprayed and splashed around the gearbox. Sprayed oil is supposed to drain back to lubrication or scavenge pumps after it lubricates the relevant components. When this does not occur effectively, a significant increase in power losses can be seen, and things can get dramatic when this happens on high-speed stages, where the power dissipation can lead to unacceptable overheating. This paper deals with two cases where oil churning created major issues at gearbox level, showing how understanding the phenomena often allows to solve the situation with minor design changes. Both the cases hereby presented represent a gearbox 1st stage module, i.e. the section that carries out the first speed reduction from the engine speed. Peripheral speed higher than 100m/s for the gears make it a situation where having too much oil may cause significant power losses. The subject was discussed by many authors, such as in references [1], [2] and [3], but review paper [4] reports that "making a general conclusion regarding the best methodology is very difficult".

2. CASE 1 – MGB INPUT MODULE

2.1. System Description

This case refers to the first stage of a conventional twin-engine helicopter main gearbox (MGB), where both the first stage input shaft (pinion) and output shaft (gear) are located with a horizontal axis. This module is generally referred to as the "input module", and it represents the section of the gearbox where peripheral speeds reach the highest values. A simple gearbox schematic, as shown in figure 1, is ideal to explain the phenomena that caused the issue.

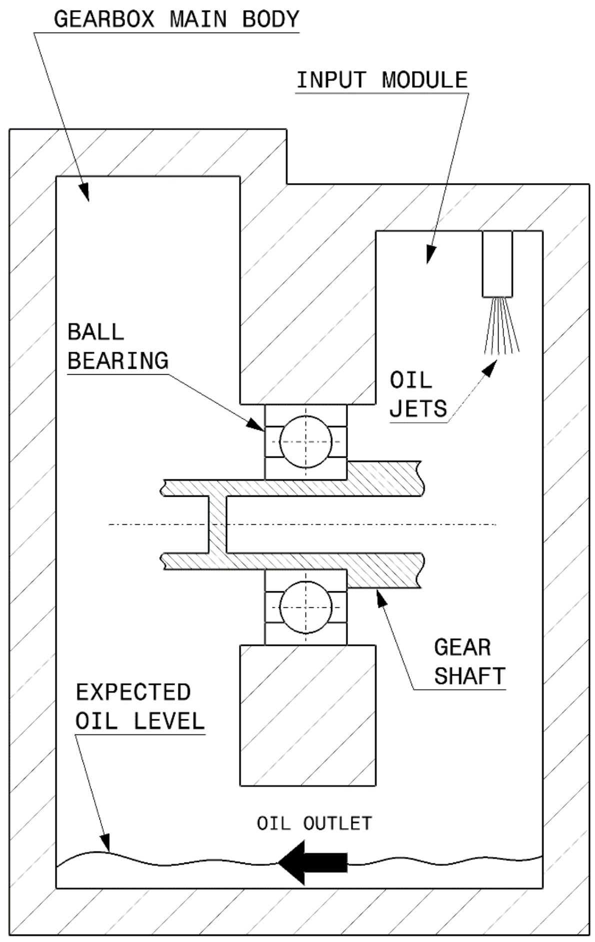

Figure 1: Case 1, a schematic of the system

2.2. Malfunctioning Symptoms

The issue initially manifested as general gearbox overheating, approximately 20 °C above nominal levels, occurring only under specific operating conditions. Under these conditions, the oil cooler exhibited a temperature differential indicative of a 50% increase in heat dissipation relative to expectations. Consequently, aircraft operation was inhibited due to first-stage bearing overheat warnings, even at relatively low ambient temperatures. Investigation revealed that the conditions leading to the anomaly were atypical and not representative of standard operational scenarios:

1) temperatures increased abruptly when the aircraft performed some specific high torque maneuvers, and then never reverted to the initial values.
2) the same behavior was seen on the test rig, where high torque tests triggered a sudden and irreversible increase in gearbox temperatures.
3) reducing the lubrication oil flow delivered to the gearbox only delayed the insurgence of the issue, without solving it.

2.3. Fault Identification

Based on this first evidence, a more thorough testing activity was carried out; since the bearing temperature appeared very high only in one of the two input stages the attention was focused on that specific area. The stage was provided with dedicated means to evaluate oil level inside its case; a normal operating stage would show low oil level inside, whereas the presence of a significant oil level would highlight some oil outflow issue. Running the test with such equipment revealed an even more puzzling behavior: the oil level trapped within the input stage was initially higher than expected, but still quite low; however, it suddenly raised when torque was increased, up to filling the whole housing, as shown in figure 2:

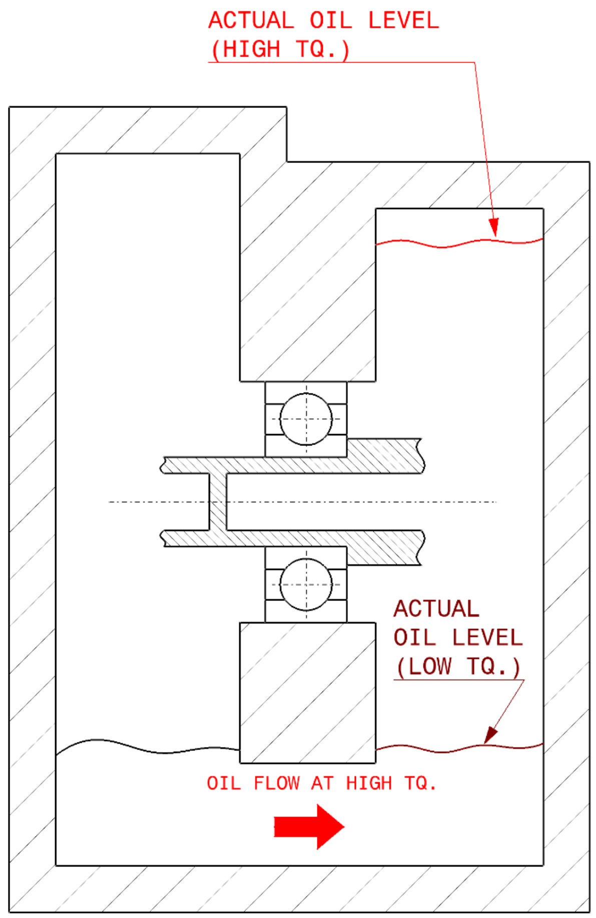

Figure 2: Case 1, measured oil levels

This observation readily accounts for both general and localized bearing overheating; however, its underlying cause is not immediately evident. The gearbox does not incorporate any torque-dependent lubrication mechanisms or features, making a torque-related variation in oil level difficult to justify. A focused examination of the gearbox design allows to take some steps forward in understanding the causes of the issue. The first critical observation is that the entire input module oil outlet flow must pass through a relatively wide opening located at the bottom, as shown in figure 1. According to the original design intent, air pressure equalization between the input stage compartment and the rest of the main gearbox should have been ensured by airflow through the bearings and/or the upper portion of the oil outlet, which is expected to be only partially occupied by the oil stream. Unexpectedly, tests results indicate that the oil level fully occupies the outlet duct cross-section, thereby obstructing air passage through this route. Based on these findings, it can be inferred that air pressure balance is also not ensured by flow through the bearings. As a consequence, the following phenomena are believed to be occurring within the gearbox:

1) when the oil level reaches the oil outlet opening upper wall air pressure balance is lost;
2) in this condition, air pressure in the first stage case and in the rest of the MGB are no longer balanced.
3) an MGB temperature increase (such as that generated by torque increase) causes an air expansion within the MGB main body.
4) due to the limited flow capacity of the gearbox breathers, thermal expansion of the air results in a pressure increase within the input module.
5) this translates into a backpressure effect which forces oil back through the input module oil outlet opening and into the module, rather than allowing it to exit as intended.
6) oil accumulates within the input module, significantly increasing power losses and operating temperatures

Although not all aspects of this sequence of events could be conclusively verified, this was selected as the only plausible explanation for a torque-transient-dependent oil level within the input module.

2.4. Solution

Once the underlying phenomenon is understood, its solution appears quite straightforward and easy: by creating an air passage between the input module and the main body, pressure can be balanced, thereby ensuring proper oil outflow. Specifically, this can be implemented by introducing a hole on the plug that closes the inner diameter of the gear shaft (as shown in figure 3).

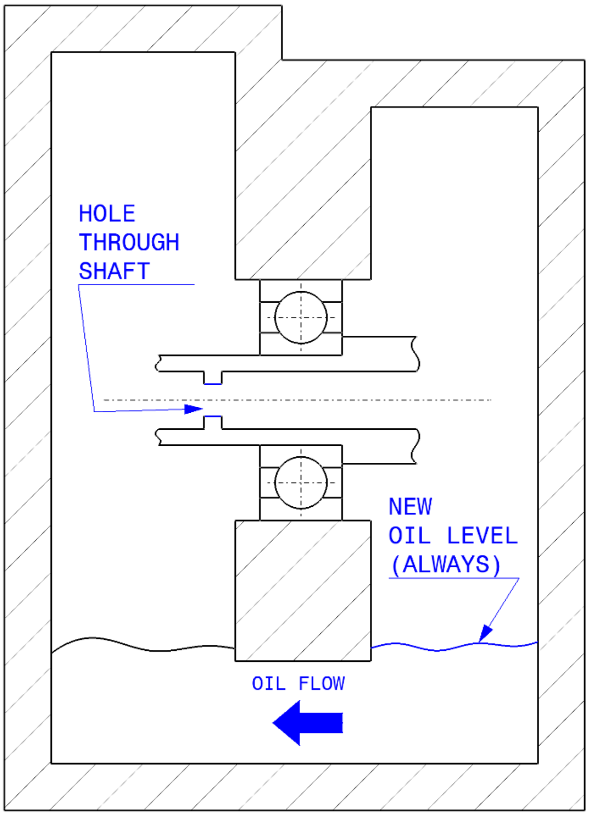

Figure 3: Case 1, the easy solution

When this change was implemented, the overheating issue completely disappeared. The change had virtually no impact on cost, weight or performance, but it was only identified through a detailed understanding of the underlying facts.

For the sake of clarity, figure 4 provides a detailed view of the area so far described highlighting the plugs that had to be drilled and the outlet area.

3. CASE 2 – Nose Gearbox

3.1. System Description

This case refers to a first stage gearbox module for another rotorcraft where the first stage input shaft (pinion) axis is roughly horizontal, and the output shaft (gear) axis is roughly vertical. This module, briefly referred to as “nose gearbox”, is provided with lubrication spray nozzles aimed at gears and bearings, and an oil sump on the lowest part, where oil is collected through a duct leading to a scavenge pump.

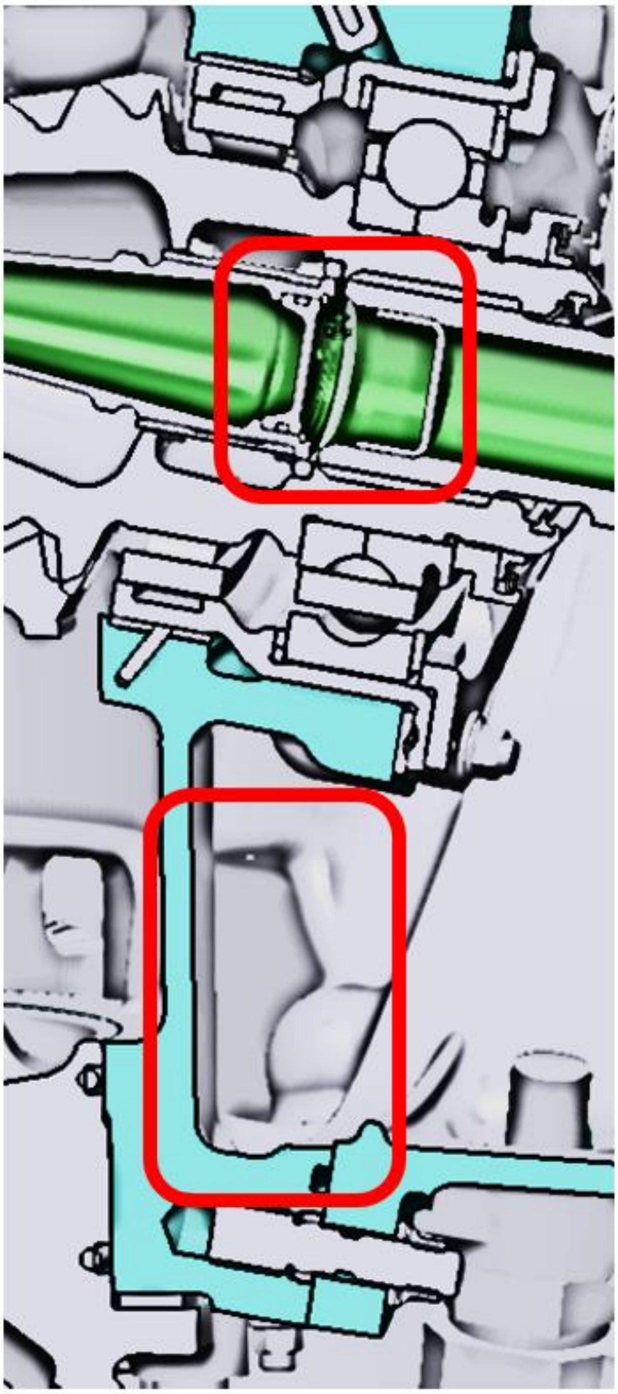

Figure 4: Case 1, the real components

3.2. Malfunctioning Symptoms

The issue appeared in terms of pinion bearings overheating. More specifically, temperature on bearings increased very steeply, exceeding 170°C in less than two minutes with no signs of stabilization. This is shown in figure 5, which reports the thermal behavior during a test run at idle speed (≈80% of nominal rpm) with no power flow through the gearbox. Operating at full speed and full power would have resulted in significantly higher temperatures. Under such conditions, use of the input stage must be avoided to prevent component damage. Consequently, dedicated investigations and testing across multiple configurations are required.

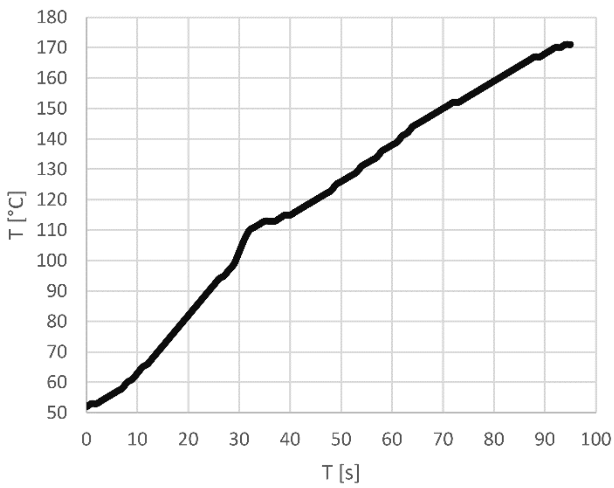

Figure 5: sharp increase in bearing temperature

3.3. Fault Identification

The initial dedicated tests were conducted on the first stage in isolation by disconnecting the shaft linking the first and second stages. This configuration ensured that any observed power losses could be attributed solely to the first stage, with no power transmission occurring through it. Testing in these conditions highlighted that the whole input stage and its outer surface would rise to 200°C (still with a steep increase trend) in just 2-3 minutes, without even reaching nominal speed. Power losses through the stage while running at 60% of nominal speed were found to exceed three times the expected values for operating at nominal speed.

A first part of the investigation dealt with the amount of pressurized oil flow delivered to the input stage. It was shown that more oil flow slightly reduced temperatures, while it increased power losses, while a reduction in oil flow increased local temperatures. This strategy provided no relief to the issue.

In a second phase of the investigation, temperature distribution maps provided by thermo-imaging were also employed, as shown in figure 6. Based on these and other data, it was generally concluded that the issue was associated with the restricted clearance between the gear baffle and the upper section of the input stage housing, as shown in figure 7. According to this initial hypothesis, oil would find obstructions in going past the gear baffle during its path towards the sump. This led to the proposal of increasing the gap between the baffle and the housing, introducing holes in the gear web and even considering the addition of external oil drainage ducts. A revised baffle design (shown in figure 8), providing an improved shielding of the whole gear, was 3D printed and (unsuccessfully) tested.

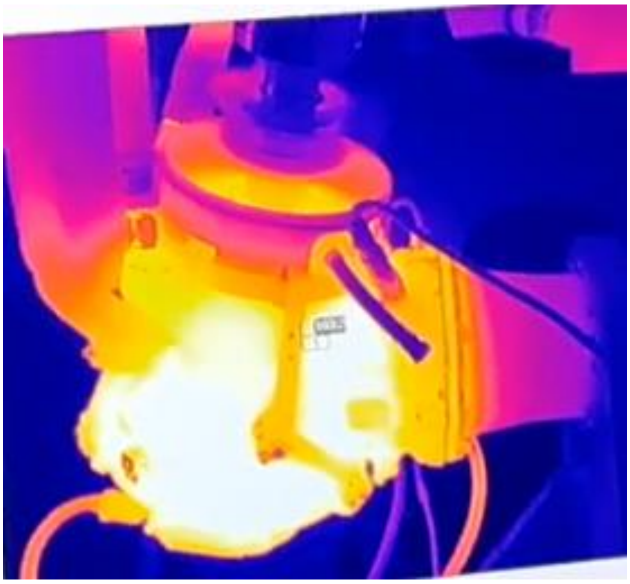

Figure 6: Case 2 thermal imaging showing generalized overheating

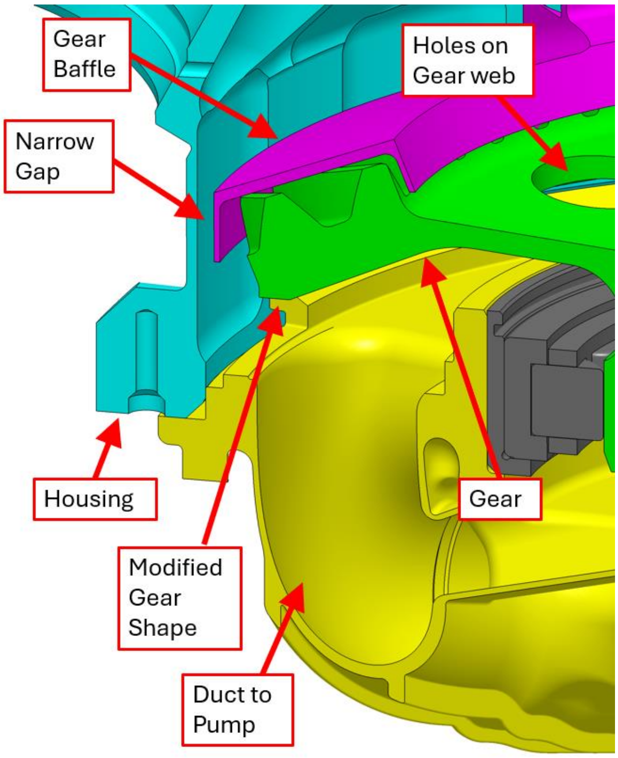

Figure 7: Case 2 initial design around the gear

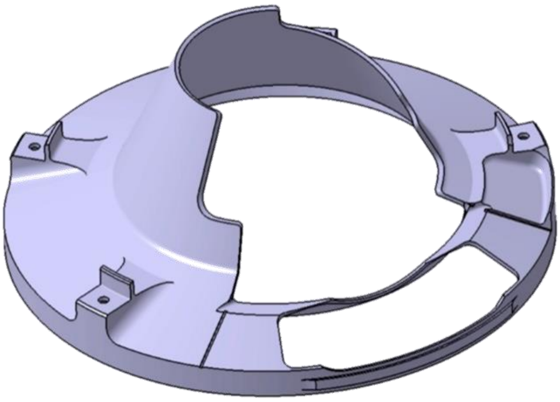

Figure 8: Case 2 improved baffle, full gear protection

Several parts were modified and tested, and none provided a sizable advantage except for a small modification at the bottom of the gear profile shape as shown in figures 9 and 10. Starting from this observation, the idea of an unexpected root cause started to take shape. The issue was likely not attributable to windage generated by the gear teeth or to oil being obstructed from passing beyond the gear, but rather to the fact that the back of the gear (even if axis-symmetric) would induce a windage pattern that ultimately impeded the oil from reaching the duct that leads oil to the scavenge pump.

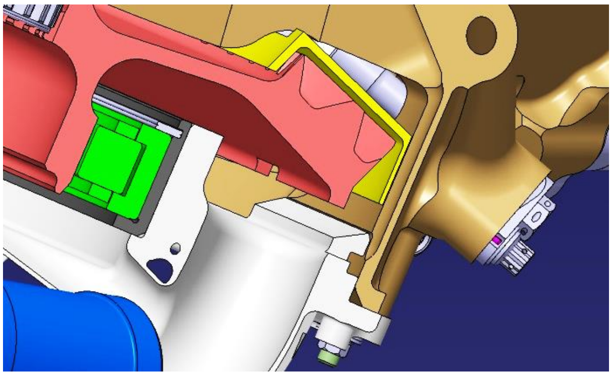

Figure 9: Case 2, the gear prior to modification

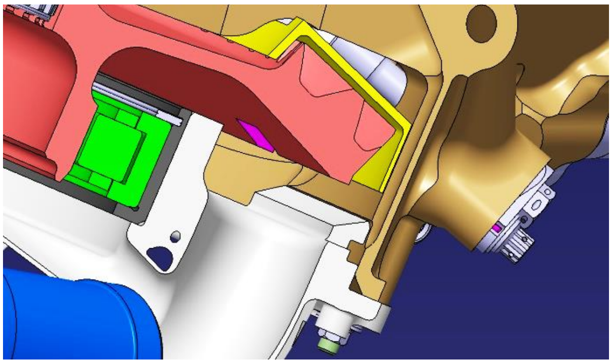

Figure 10: Case 2, the gear after modification

3.4. Solution

Based on this idea, an additional baffle was designed and installed below the gear to minimize any windage effect caused by the gear bottom, as shown in figure 11.

Test outcomes of this solution showed that the overheating issue completely disappeared, with temperatures remaining below 120°C even during long runs at full speed and full power.

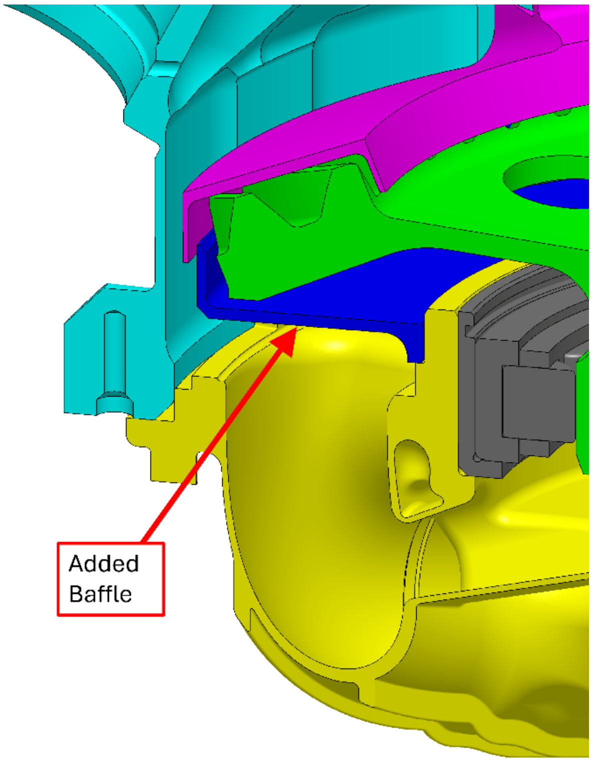

Figure 11: Case 2, added baffle solving the issue

4. CONCLUSIONS

Lubrication system design can significantly affect the behavior of high-speed rotorcraft gearboxes, with undesired effects (high power losses) or even unacceptable situations (overheating). Solving these issues can be as easy as drilling a hole in a component or adding a baffle; implementing the solutions, however, requires a full understanding of the issue which today can only be achieved by full-scale testing, i.e. at a late development stage. Effort shall be spent on identifying analytical models (such as those used in particle simulation software) to enable the identification of issues well before manufacturing the first parts. This allows to solve the issue in better ways, exploiting the wide design freedom of the early design stages as opposed to the almost non-existing freedom of the testing stages.

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5. REFERENCES

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