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MEASUREMENT SYSTEM EVALUATION FOR AIRCRAFT SEAT TRACK HOLE DIAMETER: A GAGE R&R STUDY

This study set out to evaluate the hole diameter measuring method used in aircraft seat tracks. The Gage R&R study's conclusions point to the measuring system's accuracy and dependability, with the measuring tool serving as the main source of variance. The measurement method works well for production and quality control applications, but regular calibration and maintenance are needed to ensure accurate and consistent results. To reduce any potential operator-introduced variation, regular operator training and assessment are also required. To guarantee the security and effectiveness of the seat track assembly, it is essential to measure the hole diameter of the airplane seat track properly. The study's findings show that the measuring system can generate precise measurements that are helpful for production and quality management. To establish the precision of the measurement technique, however, more investigation with a greater variety of components is required. To improve the repeatability and reproducibility of the measurement system, the sources of variance should be investigated, and remedial actions should be taken. To make sure the system stays within the permissible range of fluctuation, it is also advised to monitor it throughout time. In conclusion, it is critical to select the proper materials, put them through rigorous testing and certification processes, and constantly inventing and upgrading them to assure the safety and effectiveness of aircraft seat tracks. The seat track hole diameter measurement system is dependable and precise, but to keep it that way, ongoing testing, and evaluation are required.

Keywords: Seat track; Gage study; aerospace industry; measurement system evaluation; hole diameter

1. Introduction

The aviation industry relies heavily on the precision of its components, particularly in security systems like aircraft seat tracks. A fundamental aspect demanding precision is the measurement of hole diameters. In this paper, we delve into the specifics of the Gage R&R (Repeatability and Reproducibility) study, focusing on measurement methods critical to ensuring aircraft safety [1-5].

The safety criteria for airplane seat safety belts are outlined in the ASTM F2425-17 standard [6]. For aircraft in the transport category, the Federal Aviation Administration's 14 CFR part 25 establishes airworthiness regulations, which include the seating arrangement [7]. To ensure the security and functioning of aircraft seat tracks, aircraft materials and analyses, as well as aircraft systems design and integration, play a critical role [8-15].

Our research seeks to accomplish several key objectives. Firstly, we aim to evaluate the reliability and consistency of measurement methods for aircraft seat track hole diameters, particularly emphasizing the Gage R&R approach. Secondly, we intend to identify factors contributing to measurement variance and their potential implications for safety. Lastly, we aim to provide practical recommendations for enhancing measurement accuracy and, subsequently, aviation security.

The central message of this study revolves around the critical role of precise hole diameter measurements in maintaining aircraft seat track safety. By employing the Gage R&R analysis, we illuminate the factors impacting measurement accuracy and, in doing so, contribute to the broader field of aviation safety.

To achieve our objectives, we employ the Gage R&R methodology, a systematic approach to assess the consistency and dependability of measurement systems. By conducting a comprehensive analysis, we evaluate the contributions of variables such as the measuring device and operator to measurement variations.

The study's findings will shed light on the reliability of the measurement system, offering insights into its suitability

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for manufacturing and quality control processes. Moreover, this research addresses a critical gap in the aviation industry's understanding of measurement accuracy concerning aircraft seat tracks, making a significant contribution to safety and quality assurance.

2. Research methodology

A Gage R&R study was conducted to evaluate the measurement system for the hole diameter of the Aircraft Seat Track. The measurements were made using the RS PRO Internal Micrometer, spanning 5 mm to 30 mm, which is a precision tool for measuring internal diameters. Its key features contributing to measurement variance are its wide range, high precision, anvil and spindle quality, construction materials, calibration, operator skill, environmental factors, and readout system. These factors collectively influence measurement accuracy and must be carefully controlled for reliable results. 24 pieces were to be measured by three operators, each with a different degree of competence. Setting the height gauge on top of the seat track hole and measuring the diameter were the steps in the measurement process. Each operator ran five trials to make sure their measurements were repeatable [16,17]. The proportion of variance in the measurements attributable to the measuring device, the operator, and their interactions was calculated using the Analysis of Variance (ANOVA) method. The measurements' repeatability and reproducibility were also supplied by the Gage R&R study, which was used to assess the measuring system's capacity. In TABLE 1 the measurements used to make the analysis are presented.

3. Gage R&R study - average and range method - measurements [mm]

Based on a study involving 3 operators, each measuring 24 parts 5 times, the estimated standard deviation of the measurement process equals 0.00294718. Including parts, the total variation (TV) equals 0.00299911. The percentage total variation due to R&R is relatively small. In this case, the value equals 98.2685%. The number of distinct categories (ndc) that can reliably be distinguished by the measurement system analyzed in this study equals 0. Of the total variance, 38.6389% is due to differences between operators (Reproducibility) while 61.3611% is due to the instrument (Repeatability). These aspects are presented in TABLE 2. In TABLE 3 it is presented the Tolerance Analysis.

TABLE 1

The hole diameter measurements

Parts	**Trials**	**Measurements [mm] / Operators**			**Parts**	**Trials**	**Measurements [mm] / Operators**		
		1	**2**	**3**			**1**	**2**	**3**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	19.762	19.765	19.768	13	3	19.767	19.765	19.773
2	1	19.757	19.763	19.771	14	3	19.766	19.762	19.773
3	1	19.767	19.763	19.77	15	3	19.766	19.765	19.773
4	1	19.765	19.764	19.772	16	3	19.765	19.764	19.77
5	1	19.765	19.764	19.77	17	3	19.765	19.766	19.769
6	1	19.763	19.765	19.769	18	3	19.764	19.765	19.768
7	1	19.765	19.765	19.77	19	3	19.763	19.753	19.769
8	1	19.765	19.764	19.77	20	3	19.761	19.767	19.768
9	1	19.766	19.766	19.77	21	3	19.762	19.767	19.768
10	1	19.767	19.765	19.769	22	3	19.76	19.769	19.766
11	1	19.765	19.767	19.768	23	3	19.763	19.769	19.764
12	1	19.766	19.766	19.767	24	3	19.762	19.768	19.764
13	1	19.763	19.766	19.766	1	4	19.764	19.769	19.765
14	1	19.764	19.756	19.766	2	4	19.765	19.769	19.767
15	1	19.764	19.766	19.765	3	4	19.765	19.77	19.767
16	1	19.763	19.766	19.765	4	4	19.766	19.768	19.767
17	1	19.763	19.768	19.763	5	4	19.764	19.767	19.768
18	1	19.761	19.765	19.764	6	4	19.766	19.755	19.766
19	1	19.76	19.769	19.764	7	4	19.765	19.765	19.766
20	1	19.762	19.767	19.765	8	4	19.766	19.765	19.769
21	1	19.763	19.768	19.764	9	4	19.764	19.763	19.766
22	1	19.763	19.766	19.761	10	4	19.762	19.763	19.769
23	1	19.764	19.765	19.764	11	4	19.764	19.765	19.768
24	1	19.763	19.763	19.763	12	4	19.763	19.765	19.77
1	2	19.763	19.765	19.763	13	4	19.764	19.766	19.77
2	2	19.761	19.764	19.765	14	4	19.763	19.765	19.768
3	2	19.765	19.765	19.766	15	4	19.763	19.765	19.77
4	2	19.767	19.765	19.767	16	4	19.764	19.766	19.767

TABLE 1. Continued

1	2	3	4	5	6	7	8	9	10
5	2	19.768	19.765	19.769	17	4	19.762	19.766	19.769
6	2	19.766	19.765	19.77	18	4	19.762	19.765	19.769
7	2	19.766	19.766	19.77	19	4	19.761	19.764	19.769
8	2	19.766	19.765	19.77	20	4	19.761	19.764	19.768
9	2	19.767	19.765	19.771	21	4	19.761	19.766	19.769
10	2	19.766	19.765	19.772	22	4	19.759	19.766	19.766
11	2	19.766	19.765	19.771	23	4	19.759	19.768	19.766
12	2	19.765	19.762	19.771	24	4	19.759	19.767	19.764
13	2	19.765	19.766	19.768	1	5	19.761	19.769	19.764
14	2	19.765	19.768	19.769	2	5	19.761	19.768	19.767
15	2	19.764	19.768	19.768	3	5	19.762	19.768	19.766
16	2	19.763	19.768	19.766	4	5	19.76	19.769	19.763
17	2	19.764	19.766	19.766	5	5	19.763	19.768	19.764
18	2	19.762	19.766	19.766	6	5	19.764	19.769	19.765
19	2	19.763	19.766	19.764	7	5	19.762	19.767	19.765
20	2	19.763	19.768	19.764	8	5	19.761	19.766	19.766
21	2	19.765	19.763	19.765	9	5	19.762	19.765	19.764
22	2	19.763	19.76	19.766	10	5	19.763	19.764	19.765
23	2	19.766	19.76	19.763	11	5	19.763	19.762	19.764
24	2	19.765	19.765	19.767	12	5	19.765	19.763	19.765
1	3	19.763	19.765	19.768	13	5	19.765	19.762	19.766
2	3	19.765	19.766	19.767	14	5	19.764	19.764	19.767
3	3	19.764	19.766	19.768	15	5	19.764	19.766	19.767
4	3	19.763	19.766	19.766	16	5	19.763	19.765	19.77
5	3	19.764	19.762	19.768	17	5	19.764	19.764	19.768
6	3	19.765	19.766	19.766	18	5	19.764	19.764	19.768
7	3	19.765	19.767	19.768	19	5	19.763	19.765	19.768
8	3	19.764	19.768	19.765	20	5	19.767	19.765	19.768
9	3	19.767	19.767	19.766	21	5	19.765	19.764	19.767
10	3	19.765	19.766	19.768	22	5	19.765	19.765	19.767
11	3	19.764	19.766	19.77	23	5	19.764	19.763	19.767
12	3	19.765	19.765	19.771	24	5	19.762	19.767	19.769

TABLE 2

Gage Repeatability and Reproducibility Report

Measurement Unit	Estimated Sigma	Percent Total Variation	Estimated Variance	Percent Contribution	Percent of R&R
Repeatability	0.00230862	76.977	0.00000532974	59.2546	61.36
Reproducibility	0.00183197	61.0839	0.00000335612	37.3124	38.64
R & R	0.00294718	98.2685	0.00000868586	96.5669	100.00
Parts	0.00055569	18.5285	3.08791E-7	3.43306	
Total Variation	0.00299911	100.0	0.00000899465		

TABLE 3

Tolerance Analysis

Measurement Unit	6.0 Std. Dev.	Percent of Tolerance
Repeatability	0.0138517	4.61725
Reproducibility	0.0109918	3.66394
R&R	0.0176831	5.89436
parts	0.00333414	1.11138

TABLE 4

Confidence Intervals

	Lower Limit	6.0 Std. dev.	Upper Limit
Repeatability	0.0127587	0.0138517	0.0151513
Reproducibility	0.00572299	0.0109918	0.0690807
R&R	0.0162926	0.0176831	0.0193351
Parts	0.00246722	0.00333414	0.00514171

Given a tolerance or specification 0.3 units wide (+/–0.15), the variability from the measurement process can be expected to cover 5.89436% of that range. General rules of thumb classify a measurement system as acceptable if this percentage is less than 10%, although up to 30% may be acceptable for some situations.

This table shows intervals equal to 6.0 times the standard deviations due to Repeatability, Reproducibility, combined R&R, and variability between parts. These intervals can be expected to contain 99.73% percent of the errors attributed to each source. We would expect the measurements to deviate from the true values by +/–0.00884154 due to combined R&R, an interval 0.0176831 units wide. Since the estimates of variability are subject to sampling error, the confidence intervals show how precise these estimates are.

4. Results and discussions

Next, based on the Gage R&R study, the results obtained can be interpreted using the following graphs presented in the figures below.

In Fig. 1 the run chart displays the data in sequential order, grouped by operators and parts. Any consistent pattern indicates a change in the gage over the duration of the study.

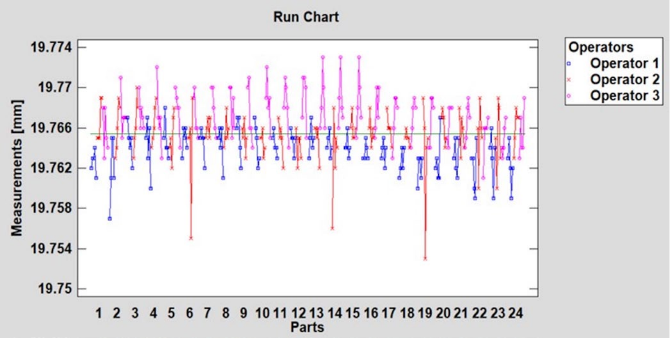

Fig. 1. Run chart

In Fig. 2 it is presented the Operator and Part Plot. This graph shows the average measurement recorded by each of the operators on each of the parts. We can see the differences between operators.

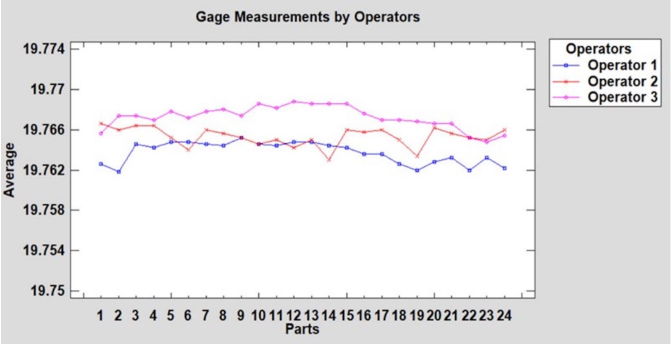

Fig. 2. Operator and Part Plot

The R&R plot is presented in Fig. 3. The data used in the analysis are shown in this graphic. Each operator is represented by a box, and each portion is represented by a vertical line inside the box. Each point shows the variation between a particular measurement and the sum of all measurements. The distance between the operators' average measurements and the overall average is shown by the horizontal lines inside the boxes. We may examine the three operators' variability by comparing the heights of the boxes. We can identify some operators prefer to measure higher or lower than others by comparing the positions of the boxes. The vertical line heights demonstrate the measuring procedure's repeatability. Comparing boxes to boxes demonstrates reproducibility. Next in Fig. 4, it is presented the Box-and-Whisker Plot.

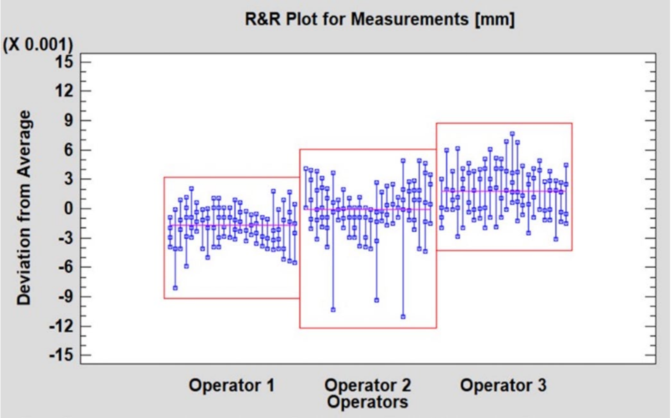

Fig. 3. R&R plot

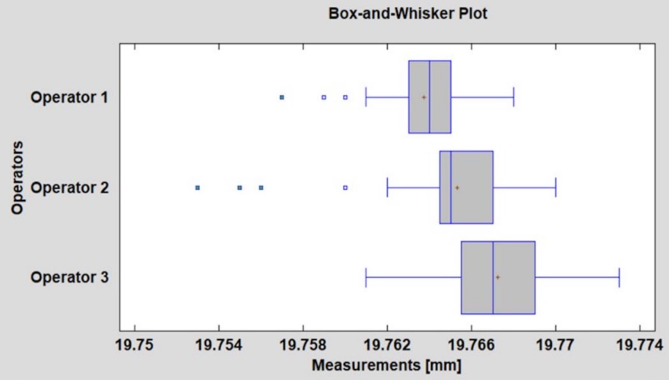

Fig. 4. The Box-and-Whisker Plot

Three box-and-whisker plots are displayed in this graph, one for each operator. From the lower to the upper quartiles, the rectangular portion of the plot encompasses the middle half of the sample. Each box's center lines indicate where the sample medians are located. The position of the sample means is shown by plus signs. Except for any outside or extremely outside points, which will be shown individually, the whiskers extend from the box to both the minimum and maximum values in the sample. Outside points are points that are shown as tiny squares and are located above or below the box by a distance more than 1.5 times the interquartile range. Points that are beyond the norm are those that are 3.0 times the interquartile range or above. Far outside points are indicated as little squares with plus signs through them and are defined as points that are more than 3.0 times the interquartile range above or below the box. There are 4 far outside points and 8 outside points in this situation.

The Range Chart by Operator is presented in Fig. 5.

This graph displays the range for each group of five measurements taken on the 24 components by the three operators. The customary 3-sigma placement for an upper boundary on

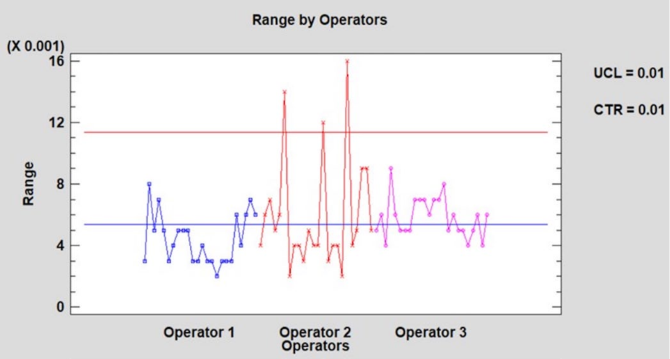

Fig. 5. The Range Chart by Operator

a range chart is used. In this instance, 6 groups exhibit extremely high variability for those operators on those parts and are over the control limit.

Finally, in Fig. 6 it is presented the Range Chart by Part.

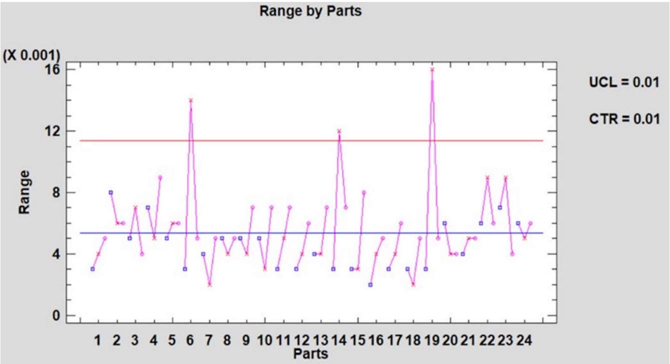

Fig. 6. The Range Chart by Part

This graph displays the range for each group of five measurements taken on the 24 components by the three operators. The customary 3-sigma placement for an upper boundary on a range chart is used. In this instance, 6 groups exhibit extremely high variability for those operators on those parts and are over the control limit.

According to the study, the measuring technique for the Aviation Seat Track's hole diameter was accurate enough to be used for manufacturing and quality control. Just a small portion of the measurement difference could be attributable to the measuring device; the majority was caused by the operator's measurement method. The study's conclusions point to a valid measuring technique for the hole diameter of the aircraft seat track that can be utilized for manufacturing and quality control. The study does, however, also emphasize the significance of operator training and measuring methodology. To make sure that operators are appropriately operating the measurement tool, the research suggests that they undergo frequent training [7].

The paper suggests ongoing monitoring to keep the system within an acceptable range. This involves regular recalibration of the measuring tool and proficiency tests for operators. If fluctuations are detected, quick corrective actions are taken, such as recalibrating the tool or providing additional training to operators, to ensure measurements stay accurate and dependable.

The results presented in this study can be related to other safety-related cases, not only within the aviation industry but also in various fields where precise measurements and the reliability of measurement systems are critical to safety.

In the aviation sector, the findings of this study, particularly those related to the importance of accurate hole diameter measurements and the assessment of measurement system reliability, can be extrapolated to other components and systems beyond aircraft seat tracks. Any safety-critical part that relies on precise measurements, such as fasteners, structural elements, or safety restraints, would benefit from a similar assessment of measurement system reliability using the Gage R&R methodology. The lessons learned from this study can inform best practices in quality control and safety assurance across the aviation industry.

Furthermore, the principles of measurement system analysis, as explored in this research, are applicable in diverse safety-critical domains beyond aviation. Industries such as automotive manufacturing, healthcare (e.g., medical device production), and nuclear energy all necessitate accurate measurements for safety and reliability. Therefore, the insights gained from this study can be translated and adapted to enhance safety protocols and quality control measures in these sectors as well.

In essence, the results of this study have the potential to serve as a valuable reference and guideline for improving safety and reliability not only within aviation but also across a spectrum of safety-sensitive industries where precise measurements are a fundamental component of risk mitigation and quality assurance.

5. Conclusions

The investigation primarily included components related to aircraft seat tracks. These components typically consist of various structural elements used to secure and adjust seats within an aircraft cabin. The components tested were the Seat Track Segments which are the primary structural elements that make up the seat tracks. They are responsible for supporting and securing the seats in place.

The Gage R&R study conducted to evaluate the hole diameter measuring method for aircraft seat tracks identified several factors as sources of variance in the measuring system. The key factors identified as sources of variance in the measuring system were repeatability, reproducibility, and operator differences. These factors were identified through statistical analysis, particularly ANOVA. The potential impact of these factors on measurement accuracy is significant, with the micrometer's precision and operator-related variations being critical contributors to overall variance. Regular calibration, maintenance, operator training, and evaluation are recommended to mitigate these sources of variance and ensure accurate hole diameter measurements for aircraft seat tracks.

The paper underscores the significance of meticulously selecting, testing, and certifying materials for aircraft seat tracks by highlighting their pivotal role in ensuring passenger safety and comfort. It elucidates that the structural integrity of aircraft seat tracks is contingent on the precision of hole diameter measurements. Any inaccuracies or inconsistencies in these measurements could lead to faulty seat track installations, potentially resulting in seats coming loose during flight, thereby posing grave safety concerns for passengers and crew members. The paper emphasizes that adhering to rigorous standards and practices in material selection and hole diameter measurements is imperative to avert such safety risks and ensure the reliability of aircraft seat tracks in the aviation industry.

The presented results have broader implications for safety-related cases. These findings apply not only to aviation but also to various industries requiring precise measurements, like automotive, healthcare, and nuclear energy. The study's insights on measurement system reliability and the use of the Gage R&R methodology can inform safety protocols and quality control in these sectors as well.

The findings and recommendations from this study have practical applications in the aviation industry. They highlight the importance of precise hole diameter measurements for seat track safety and suggest ongoing training and calibration for operators and measuring tools. While the paper doesn't extensively discuss the challenges, it implies that implementing these recommendations may require investment in training programs and regular maintenance of measuring tools. However, the potential benefits, such as enhanced safety and reliability of seat tracks, make these measures worthwhile for the aviation industry, ensuring compliance with safety regulations and providing passengers with a safer and more comfortable flying experience.

The study acknowledges limitations like a small sample size and a focus on specific components but doesn't address them extensively. Future research could expand by using a larger and more diverse sample, investigating the long-term stability of the measuring tool, exploring advanced measurement technologies, and assessing the feasibility of continuous monitoring in aerospace manufacturing.

REFERENCES

[1] N. Zaitseva, T. Pogarskaia, O. Minevich, J. Shinder, E. Bonhomme, No. 2019-01-1887 SAE Technical Paper (2019).

[2] C. David, S. Delbecq, S. Defoort, P. Schmollgruber, E. Benard, Pommier-Budinger, V. **1024**, 1, 012062. IOP Publishing (2021).

[3] B. Safoklov, D. Prokopenko, Y. Deniskin, M. Kostyshak, Transportation Research Procedia **63**, 1534-1543 (2022).

[4] M. Guida, G. Lamanna, F. Marulo, F. Caputo, Progress in Aerospace Sciences **129**, 100785 (2022).

[5] N.C. Trivers, C.A. Carrick, I.Y. Kim, Structural and Multidisciplinary Optimization **62**, 3457-3476 (2020).

[6] American Society for Testing and Materials Standard specification for airplane seat safety belts. ASTM F2425-17 (2017).

[7] Federal Aviation Administration. Airworthiness standards: Transport category airplanes (14 CFR part 25) (2017).

[8] N. Zimmermann, P.H. Wang, Engineering Failure Analysis **115**, 104692 (2020).

[9] T. Li, H. Lockett, C. Lawson, J. of Manuf. Systems **54**, 242-257 (2020).

[10] P.C. Gasson, The Aeronautical J. **123** (1266), 1327-1330 (2019).

[11] S. Lee, M. Park, W. Ji, AIAA SCITECH 2023 Forum (p. 2084) (2023).

[12] S.F. Junjunan, K. Chetehouna, A. Cablé, A. Oger, N. Gascoin, R.O. Bura, Fire technology, 1-40 (2021).

[13] R. Zinno, S.S. Haghshenas, G. Guido, K. Rashvand, A. Vitale, A. Sarhadi, Applied Sciences **13** (1), 97 (2022).

[14] H.A.N. Jiakun, H.U.I. Zhe, T.I.A.N. Fangbao, C.H.E.N. Gang, Chinese J. of Aeronautics **34** (7), 170-186 (2021).

[15] H.J. Aghav, of Engineering Mathematics **137** (1), 4 (2022).

[16] M. Poudel, R.P. Sarode, Y. Watanobe, M. Mozgovoy, S. Bhalla, Applied Sciences **12** (5), 2663 (2022).

[17] A.K. Jeyaraj, Liscouët-Hanke. Aerospace **9** (12), 791 (2022).