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Ground Vibration Testing of a Rocket Model

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ABSTRACT: The paper investigates the characteristic movement of a PVC-made rocket with a glass fiber nosecone. For this exploration ground vibration experiment is carried out through impact hammer testing. The configuration includes 22 vibration detectors positioned on the main body and side boosters and a rocket structure mounted on a horizontal beam. The impact hammer was used to initiate vibrations, and a vibration analyzer equipped with a built-in piezoelectric accelerometer recorded the reactions. To exactly become aware of the rocket's natural frequencies, form and damping ratio, inertial forces (MIF), frequency response capabilities (FRF), levels, and coherences are tested. The experimental findings offer essential knowledge of the rocket's structural movement, stability, and strength at some point of flight. The test highlights the significance of floor vibration in evaluating the dynamic characteristics of aerospace components and ensuring protection in the field of aerospace engineering.

I. INTRODUCTION

Ground vibration assessments play a pivotal function in assessing the dynamic traits of rocket systems [1] [2] [3]. These tests involve experimental techniques geared toward figuring out natural frequencies, vibration modes, and dynamic responses, essential for validating numerical fashions and ensuring structural integrity against release-added approximately masses. For example, studies have targeted on characterizing large structures like solid rocket vehicles and release cars to estimate thrust oscillations and dynamic hundreds [4]. Additionally, the research emphasizes the importance of song tests for ballistic planes, simulating actual operational situations and evaluating structural responses below intense vibration and shock loading situations [5]. The machine for natural frequency and mode shape defined in reference [6] guides those investigations, shaping the methodologies hired in unraveling the complex dynamics of rocket structures.

Impact hammer attempts emerge as a cornerstone in detecting potential balance problems in rockets, as highlighted in diverse improvements and studies [7] [8] [9] [10]. These impactful improvements introduce attempting out gadgets utilizing drop hammers to evaluate the structural integrity and impact resistance of various additives [11][12][13]. By deploying an effect hammer to excite the specimen and accumulating dynamic reaction facts via accelerometers, this take a look at approach turns into instrumental in identifying natural frequencies, mode shapes, and damping ratios. Thus, this check now not best delves into the essential expertise of these essential parameters however additionally lays the muse for enhancing the resilience and performance of rocket systems in the stressful realm of aerospace exploration.

II. METHODOLOGY

The methodology of ground vibration testing (GVT) that we have utilized for our composite rocket structure involves the methodical placement of accelerometers at strategic locations throughout the structure. These accelerometers function as precise data collecting instruments, capturing critical information such as natural frequency, mode shape, and damping ratio. Such characteristics play critical roles in determining the structure's dynamic reaction under simulated launch conditions. This examination's comprehensiveness extends beyond the fundamental construction made of PVC, which is known for its combination of lightweight and durable features. It includes a thorough examination of the glass fibre composite material used in the manufacture of the nose cone, as well as the delicate structural components that comprise the side boosters. Valuable insights into the intrinsic resonant frequencies and structural dynamics of the entire system are obtained by means of direct observation and analysis of the vibration frequencies emanating from each constituent member. This empirical approach, supported by rigorous experimental

examination, not only elucidates the intricate interaction of material properties, but also serves as the foundation for informed design revisions targeted at optimizing aerodynamic efficiency and assuring mission success.

Material Properties:

Material	Young's Modulus (GPa)	Poisson's Ratio	Density (kg/m ⁻³)
PVC(PolyvinylChloride)	2.5-4	0.35 - 0.4	1350
Glass Fiber Composite	40 - 70	0.25 - 0.3	1500-2000

Table 1: Materials And Physical Properties

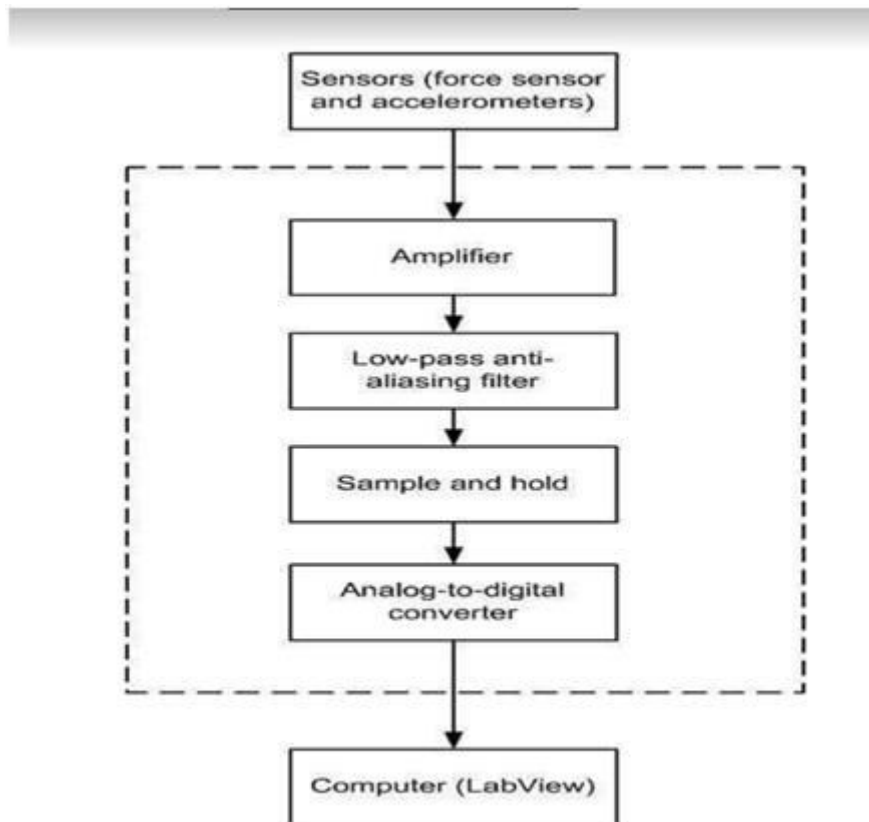


Figure 1: Flow Chart

1. Preparation and calibration.

The sensors are pre-installed on the rocket framework at specific points. The complete measurement system, including sensors and data gathering hardware, is calibrated for accuracy.

2. Data Collection

Excitation forces are delivered to the rocket construction, and the vibrations produced are monitored by the sensors. The amplified and filtered signals are digitized by the ADC and stored in LabVIEW.

3. Data Processing and Analysis

The captured data is processed in LabVIEW to eliminate noise and retrieve useful information. The inherent frequencies of the rocket structure are determined via frequency domain analysis, such as the Fast Fourier Transform (FFT). Mode shapes and damping ratios are calculated to better understand the structure's dynamic behavior.

4. Validation

The results are validated by comparing them to theoretical predictions or previously collected experimental data. Any differences are investigated, and the system is recalibrated as needed.

Model Measurement and Fabrication:

The main structure of the rocket features a cylindrical body with a diameter of 1000 mm and serves as the central framework for the entire assembly. It is constructed from PVC (Polyvinyl Chloride), selected for its lightweight properties and structural durability. The side boosters, standing at a height of 650 mm, are characterized by a diameter of 75 mm, optimizing aerodynamic efficiency during flight. These components are also crafted from Glass Fiber composite material, renowned for its high strength-to-weight ratio and thermal stability.

The nose cones, crucial for minimizing aerodynamic drag and ensuring optimal flight

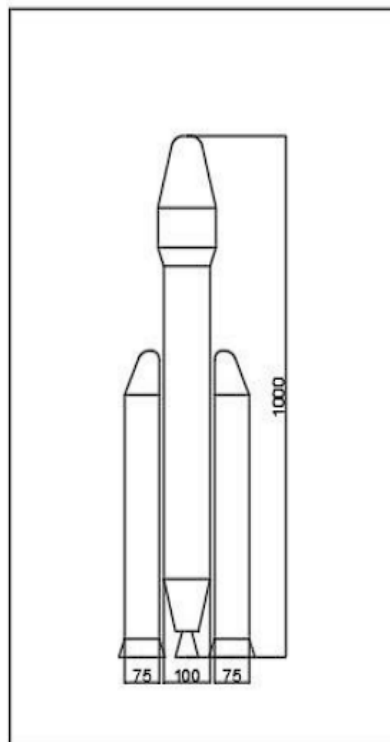


Fig. 2: Rocket Model Configuration

performance, vary in size across the main structure and side boosters. The main structure's nose cone begins with a diameter of 100 mm at its base, extends to 125 mm in the middle, and tapers to 30 mm at the top. Similarly, the side boosters' nose cones have diameters ranging from 75 mm at the base, 90 mm in the middle, and taper to 30 mm at the top. Each nose cone is precision-cut using CNC machining to ensure exact dimensions and achieve optimal aerodynamic profiles.

Table 2: Structure Dimensions:

Component	Diameter (mm)	Height (mm)		Material
Main Structure	100	1000	100 (main), 125 (mid), 30 (top)	PVC
Side Booster	75	650	75 (side booster), 90 (mid booster), 30 (top booster)	PVC
Nose Cone	-	-	-	Glass Fiber Composite (Cut Using CNC for Precision)



Figure 3: Structure, Nose Cone and Material

III. EXPERIMENTAL SETUP

The setup involves using advanced vibration measurement tools to ensure accurate data collection and analysis across 22 points on the rocket structure.

Equipment Used

1. **Fluke 805 FC Vibration Meter**
2. Used for initial vibration screening and overall health monitoring.
 - a. Provides a severity assessment by measuring overall vibration levels and identifying trends.
3. **Fluke 810 Vibration Tester**
 - a. Employed for diagnosing complex vibration issues and providing actionable recommendations.
 - b. Offers advanced diagnosis capabilities and on-site problem-solving.
4. **Viper II by PRUFTECHNIK**
 - a. Used for precision balancing and alignment tasks to ensure the accuracy of vibration measurements.
 - b. High-precision sensors and alignment tools optimize the test structure setup.
5. **Fluke 3563 Analysis Vibration Sensor**
 - a. Collects detailed vibration data for thorough analysis.
 - b. Continuous monitoring capabilities with real-time data transmission and high-resolution measurements.
6. **VIBGUARD IIoT by PRUFTECHNIK**
 - a. Provides comprehensive condition monitoring and data acquisition for the rocket structure.
 - b. Advanced Industrial Internet of Things (IIoT) capabilities for remote monitoring and data analysis.

Setup Procedure

1. **Preparation of the Rocket Structure**
 - a. The model rocket is horizontally fitted with a structural beam to minimize external influences and ensure stable measurements.
 - b. Critical points on the rocket are identified for sensor placement: 10 points on the main body and 6 points on each of the two side boosters.
2. **Sensor Placement**
 - a. **Main Body (Points 1-10):** Sensors are placed with a gap of 12.83 cm between each point.
 - b. **1st Side Booster (Points 11-16):** Sensors are placed with a gap of 11.4 cm between each point.
 - c. **2nd Side Booster (Points 17-22):** Sensors are placed similarly with 11.4 cm gaps.
 - d. A vibration sensor is connected at the bottom of the rocket, and a hitting meter is set up to create exposure and initiate vibrations at each point.
3. **Calibration and Alignment**
 - a. **Viper II by PRUFTECHNIK:** Utilized to ensure precise alignment and balance of the rocket structure and sensors. This step is crucial for obtaining accurate and reliable vibration data.
 - b. All sensors and measurement devices are calibrated according to the manufacturer's specifications to ensure the accuracy of the data collected.
4. **Data Collection**
 - a. The vibration sensors, including the Fluke 805 FC, Fluke 810, Fluke 3563, and VIBGUARD IIoT, continuously monitor and record the vibration data as forces are applied to the rocket structure.
 - b. The accelerometers capture vibration data, convert it into electrical signals, and transmit real-time data to a laptop for analysis.
5. **Data Analysis**
 - a. A laptop is connected to the vibration meters and hitting sensors for real-time data acquisition and analysis.
 - b. The recorded data is processed to identify natural frequencies, mode shapes, and damping ratios using specialized software tools, including LabVIEW.
6. **Validation and Verification**
 - a. The results obtained from the vibration measurements are validated against theoretical models and previous experimental data to ensure their accuracy.

- b. Any discrepancies are investigated, and the setup is adjusted accordingly to improve measurement accuracy.

By following this experimental setup, the ground vibration characteristics of the rocket structure are thoroughly evaluated, providing essential insights for the design and safety assessment of the rocket. The use of advanced vibration measurement tools ensures high precision and reliability in the data collected and analyzed.

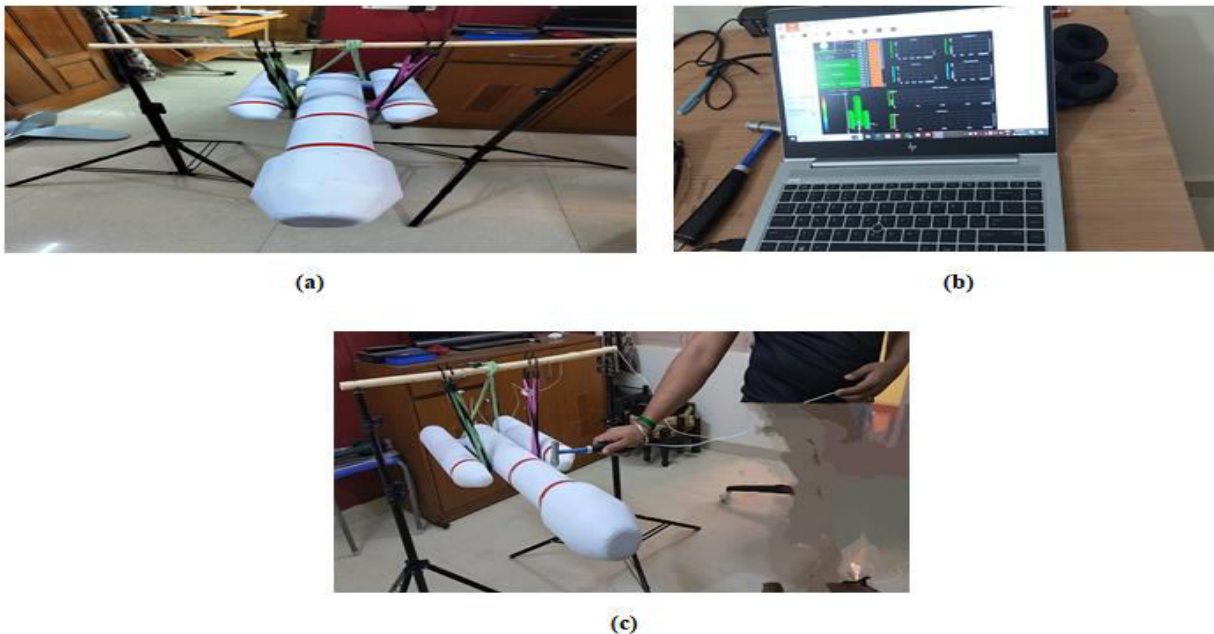


Figure 4

IV.RESULT AND DISCUSSION

The ground vibration test (GVT) for the model rocket was meticulously conducted by considering three key parametric factors. This process involved multiple iterations to ensure data accuracy, with extensive data processing to clean and prepare the collected information for model testing. The primary goal was to identify the natural frequencies, damping ratios, and mode shapes of the rocket structure.

Key Results

1. First Mode Shape

- a. **Natural Frequency:** 38.5 Hz
- b. **Damping Ratio:** 0.019
- c. **Observation:** The first mode shape exhibits a lower frequency, indicating the fundamental natural vibration of the rocket structure. The damping ratio is relatively low, suggesting minimal energy loss per cycle.

2. Second Mode Shape

- a. **Natural Frequency:** 67.9 Hz
- b. **Damping Ratio:** 0.02
- c. **Observation:** The second mode shape shows a higher frequency compared to the first, indicating a more complex vibration pattern. The slight increase in the damping ratio indicates a marginally higher energy dissipation.

3. Third Mode Shape

- a. **Natural Frequency:** 137.5 Hz
- b. **Damping Ratio:** 0.03

- c. **Observation:** The third mode shape presents the highest frequency among the measured modes, representing the most complex vibration pattern. The damping ratio is the highest in this mode, suggesting greater energy dissipation, possibly due to higher structural stiffness and complexity.

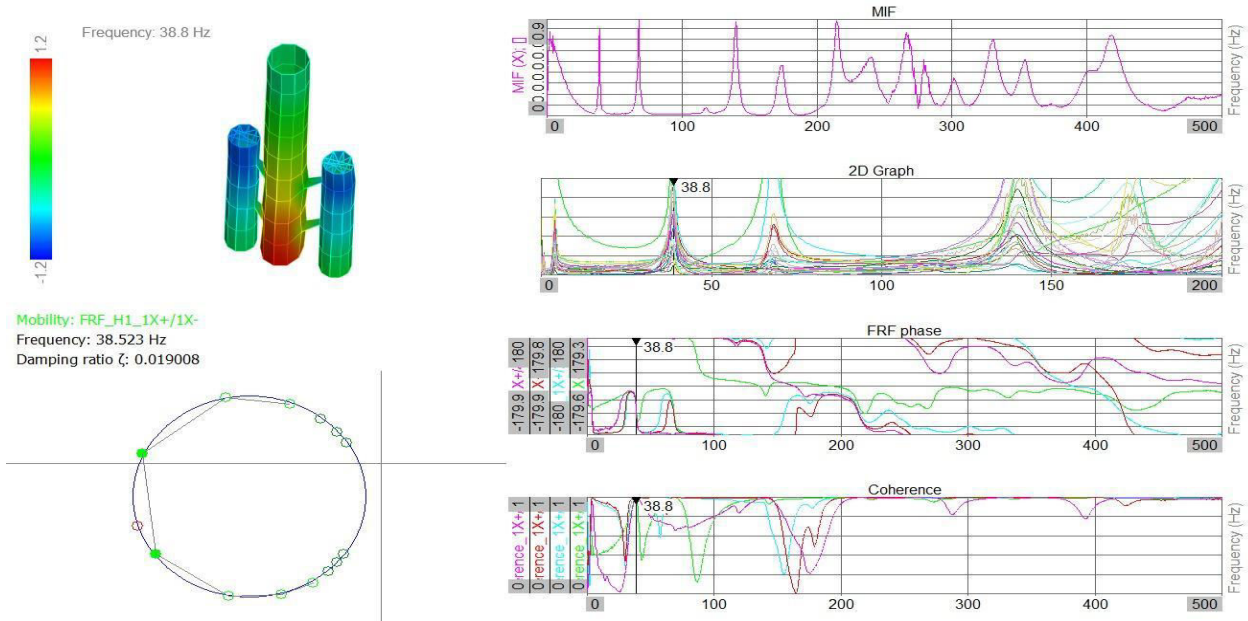


Figure 5: Mode Shape (1) , Natural Frequency and Damping Ratio

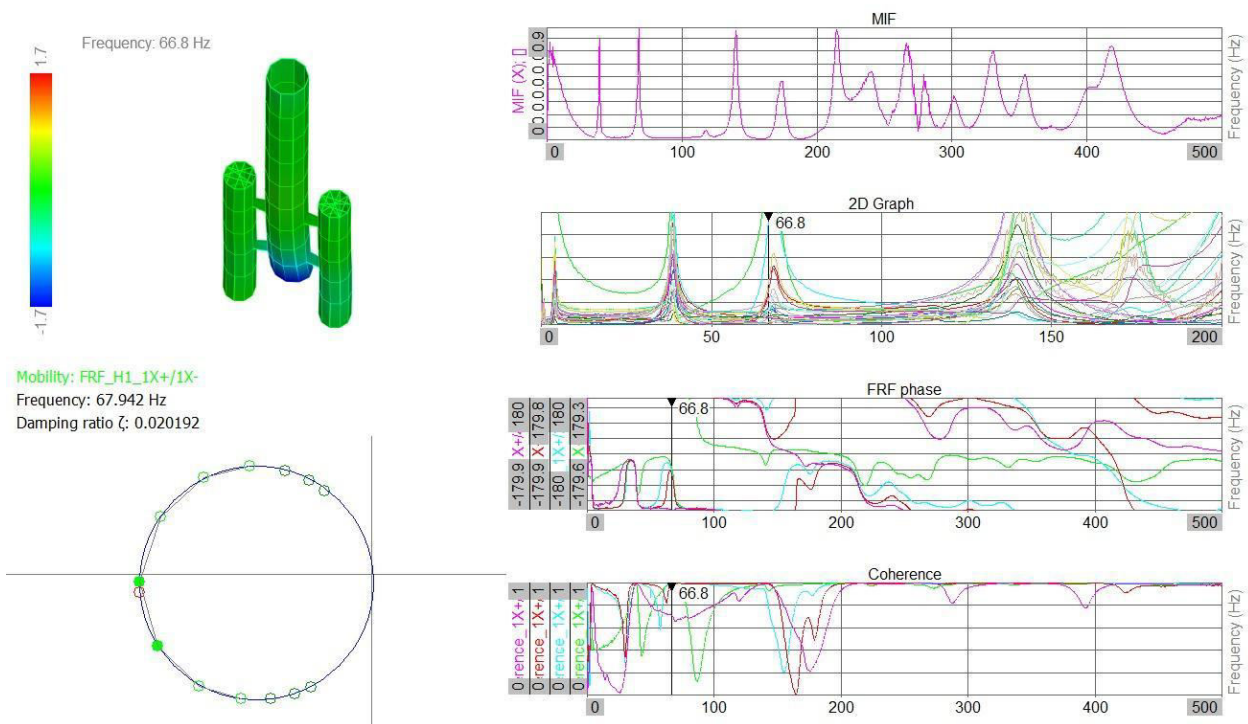


Figure 6: Mode Shape (2), Natural Frequency and Damping Ratio

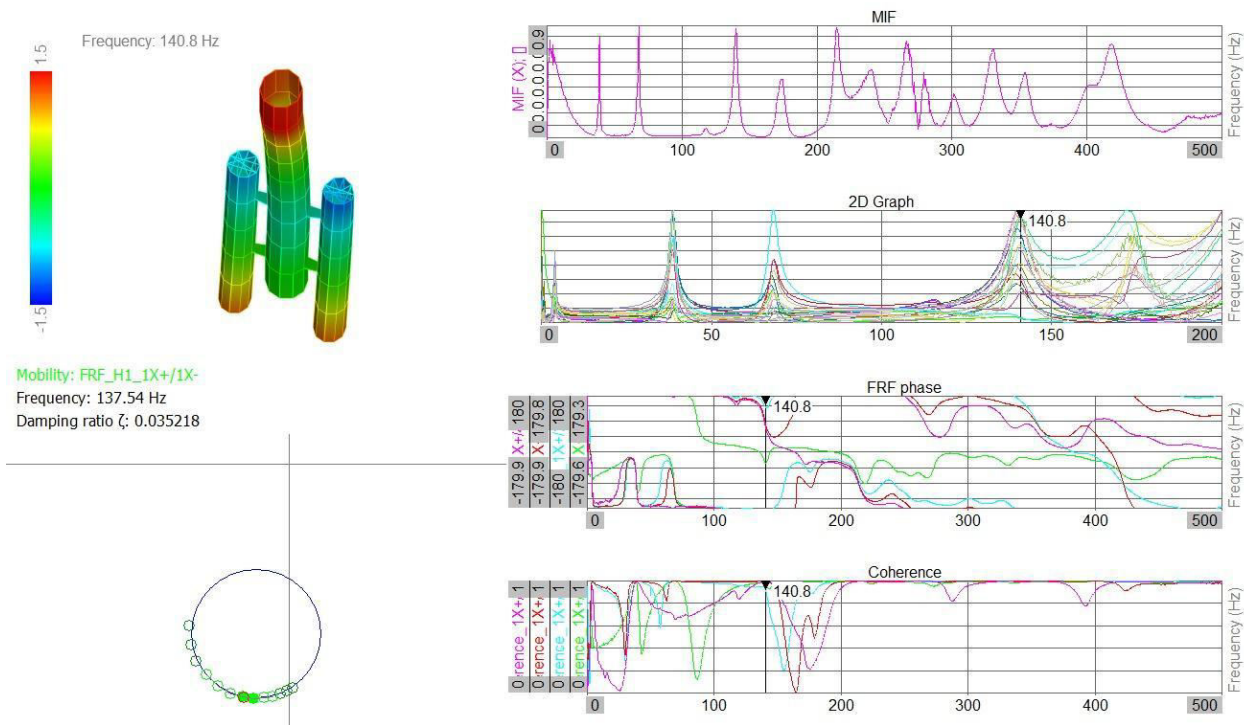


Figure 7: Mode Shape (3) Natural Frequency and Damping Ratio

Mode Shape	Natural Frequency (Hz)	Damping Ratio
First Mode	38.5	0.01900
Second Mode	67.9	0.02019
Third Mode	137.54	0.00352

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