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FREE VIBRATION ANALYSIS OF RECTANGULAR-PLATE-BASED AIRCRAFT WINGS

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Abstract- Today, plates are widely employed in a variety of engineering disciplines, including aircraft, marine, civil, mechanical, and aeronautical constructions. The presence of an imperfection like a crack will cause to change in natural frequencies of the plate. So that this work aims to study the natural frequency for composite plates with and without crack consideration. finite element simulations are employed to analyze the vibration behavior of rectangular composite wing plates using ANSYS software program to determine the first natural frequency response of epoxy composite wing plates reinforced with various mixing ratios of Aluminum oxide (Al_2O_3) with respect to several parameters, including the mixing percentage of Al_2O_3, boundary conditions, plate thickness, and aspect ratio. The results indicate that all-side simple supported boundary conditions (SSSS) produced the higher natural frequency values. The natural frequency of vibration for wing plate's decreases with the presence of crack, since the stiffness of a cracked plate reduces, also natural frequency is increases as wing plate thickness and aspect ratio (a/b) increases. This study makes it feasible to investigate process vibrations and unplanned failures, which become a financial and technological challenge for the industry.

Keywords: Epoxy Composite, Natural Frequency, ANSYS, Mixing Ratio, Cracked Plate, Wings.

1. INTRODUCTION

In the recent years, there has been a lot of focus on the identification of damages and its location in wing structure using measurements of changes in natural frequencies. Cracks and other flaws alter the structures' dynamic reactivity. In other words, the components like natural frequency and their mode shape are altered by the cracks due to a decrease in local stiffness. Consequently, it is crucial to conduct a thorough analysis of the vibrational characteristics of cracked structures [1].

The influence of the cracks on the dynamic reactions of the structures has been the subject of deserving efforts. J. Simsiriwong and R. Warsi Sullivan examine the vibration testing of two different configurations of the (unmanned aerial vehicle) UAV in full scale carbon composite ultralight wings. Damping coefficients, natural frequencies, and mode forms are included in the modal characteristics, and these findings are contrasted with the vibration characteristics discovered by modelling a cantilever wing on an airplane [2]. S.E. Carry out a free vibration analysis on a thin-walled composite beam-based model of an airplane wing. To account for the effects of various parameters, natural frequencies were estimated based on the ply angle for the wing's NACA symmetrical airfoil sections [3]. R.R. Fernandes, perform a free vibration analysis of curved spars and ribs in composite wing boxes. The top and bottom skins of the wing box are considered as rectangular plates, and the natural frequencies of wing boxes with straight spars and ribs composed of graphite/epoxy were compared with ANSYS models, demonstrating that the suggested plate model can faithfully replicate the free vibration of a wings [4].

Andrzej and Gawryluk Contrasted the modal analysis for the stationary rotor with one composite blade and the cantilever composite beam to the findings of the modal analysis for three composite blades in terms of natural frequencies and mode shapes [5]. K. Ghonasgia, et al. Investigated the variance of the perforated plates' first three natural frequencies as a function of a few key factors. The criteria taken into account include the perforation pattern, perforation form, plate size, aspect ratio, mass remnant ratio, and ligament effectiveness. The plates under consideration have a boundary condition and all of their edges are clamped. Plate thickness was kept constant at 0.002 m for all simulations, and three perforation designs were taken into consideration [6].

Wang, et al. evaluated analyzed numerically the plates' free vibration with thin, square holes. They regarded the hole as a virtual plate by setting mass density and Young's module to zero. The perforations were diagonal and equivalent to the edges. Result showed that the diagonal holes had a greater impact on the mode shapes and natural frequencies as opposed to the parallel holes [7]. K. Kalita and S. Haldar. Analyzed By using the FSDT in the FE approach, plates that are isotropic and have a center cutout have been examined. For plates with different aspect ratios, boundary conditions, and thickness ratios, the non-dimensional frequency parameters have been calculated. Following a preliminary examination of the eigenvalue solutions' convergence, findings were confirmed by comparison with existing experimental & numerical data.

The results clearly fall within a fair range of agreement with the available literature [8]. D.S. Ganiyev, examine one of the dynamic strength properties, the natural vibration frequency of a vertical support made of three Ortho-tropic, soil filled cylindrical panels reinforced with discretely spaced longitudinal rods, determining the vibrational frequencies of a vertical support. With more rods, retaining wall frequencies naturally vibrate at higher frequencies. [9]. A. Moukhliss, et al. used the discrete model to handle un-cracked tapered beams and look at the free vibrations of a cracked tapered beam supported by a variable elastic Winkler foundation. Making a modest adjustment to the stiffness matrix also enables the calculation of the frequencies of any tapered beam with fractures distributed among distinct locations. The findings of this study may be utilized to locate and measure the size of a fracture in a tapering beam under an elastic Winkler foundation. [10]. S.A. Nama, using Solid works simulation add-ins, Free vibrations of the rectangular plates with a flange's aperture was numerically studied. The effects of flange parameters on the fundamental frequency of the plate were estimated. The findings indicate that cutting an around area and turning it into a flange can increase the fundamental frequency of the all-side clamped boundary conditions CCCC plate by more than 1.7 times that of the bare plate and the SSSS plate by more than 1.5 times [11].

According to the prior researches, it is crucial to investigate how cracks affect the vibration behavior of composite plates. The study of natural frequencies and crack diagnosis can both benefit from vibration analysis. In the current research, free vibration analysis of an epoxy composite wing plate with and without a crack has been investigated utilizing finite element analysis ANSYS 15.0 software. Different wing plate parameters, such as mixing ratio of Al_2O_3, boundary conditions, plate thickness, and aspect ratio have been taken into consideration.

2. FINITE ELEMENT ANALYSIS

The finite element analysis was performed, to identify the natural frequency of the cracked wing plate in relation to the effects of various factors. The simulation has been carried out on ANSYS 15.0 APDL software. The computed natural frequencies for two different wing plate configurations (with- and without crack). Crack dimensions used in this study was (25 mm long, 1 mm width, and 1, 2, 3 mm in penetration depth, according to the three types of plate's thickness. For studying thin to moderately thick shell structures, SHELL281 [12] is appropriate. The element comprises 8 nodes, each one has 6 degrees of freedom, allowing for translations along the *x*, *y*, and *z* axes along with rotations about these axes. The element only has translational degrees of freedom when the membrane option is selectedSHELL281 is ideally suited for linear, large rotational, and/or big strain nonlinear applications.

Nonlinear analyses account for variations in shell thickness. The component considers how the follower is impacted by various pressures (load stiffness). Since a smaller mesh size often leads in more accurate modeling output, mesh refinement research should be carried out to determine an acceptable level of accuracy while still preserving computing effectiveness. The total number of elements for each plate are 400, while the number of nods is 1281. Finite element mesh and boundary conditions for crack plate are shown in Figure 1. It is assumed that the plate made by epoxy composite material reinforced with Al_2O_3. Table 1 presents plate properties with different mixing percentage, where E is the young modulus and σ_y yield stress of the material, σ_{Ult} ultimate tensile stress and ρ material density.

Table 1. Mechanical properties of composite rectangular wing plate

Mix. Per. %	E MPa	σ_y MPa	σ_{Ult} MPa	ρ g/cc
0	1504	17.25	33.2	1.2
2	1534	27.5	32.55	1.2169
4	1598	20.2	30.55	1.2342
6	1660	20.5	29.23	1.2523

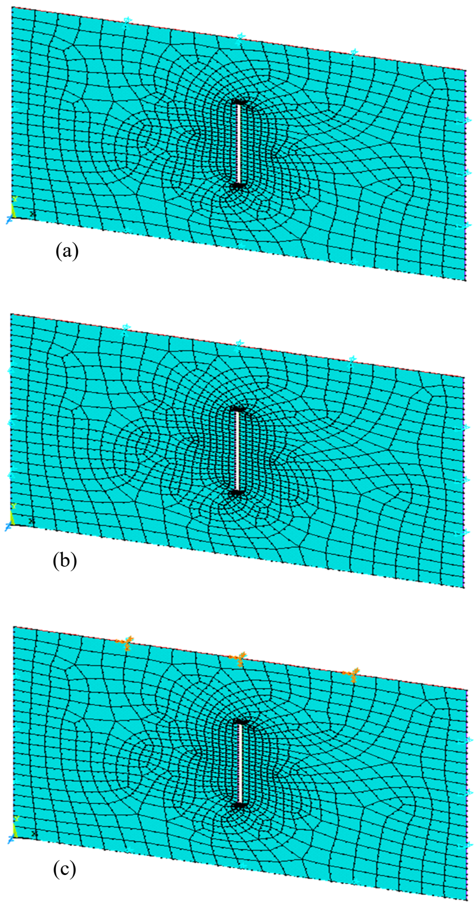

Figure 1. Mesh and boundary condition of crack rectangular wing plate (a) SSSS, (b) SSSF, (c) SFSC

3. RESULTS AND DISCUSSION

The objective of the numerical modal analysis is to identify the dynamic characteristics of the composite wing plate, such as the natural frequency of the system setup during testing [13]. Natural frequency was measured using a modal analysis of rectangular composite wing plate reinforced with various mixing percentage of Al_2O_3 and different plate thickness and aspect ratio, under three distinct boundary conditions that is (Simply-Supported) SSSS, (Simply-Supported-Free) SSSF, and (Simply

Supported-Free-Clamped) SFSC, investigated with and without crack effect. Table 2 displays the average value of the first natural frequency (mode 1) of rectangular plates for each parameter used in this study.

Table 2. Natural frequency of rectangular wing plates at different parameter

B.C	a/b	Thick. mm	un-crack / crack	Frequency (Hz) Mixing percentage % 0	2	4	6
SSSS	1	1	un-crack	107.04	107.35	108.8	110.09
			crack	102.61	103.09	104.48	105.71
		2	un-crack	212.99	213.61	216.49	219.05
			crack	204.1	204.68	207.44	209.89
		3	un-crack	317.58	318.5	322.79	326.61
			crack	303.8	304.68	308.78	312.43
	1.5	1	un-crack	176.33	176.84	179.22	181.34
			crack	170.74	171.23	173.54	175.59
		2	un-crack	350.45	351.47	356.2	360.41
			crack	338.79	339.77	344.34	348.41
		3	un-crack	521.81	523.31	530.36	536.63
			crack	503.74	505.19	512	518.05
	2	1	un-crack	267.55	268.32	271.94	275.15
			crack	259.75	260.5	264.01	267.13
		2	un-crack	531.49	533.02	540.2	546.59
			crack	515.21	516.7	523.65	529.85
		3	un-crack	531.49	792.79	803.47	812.97
			crack	765.33	767.54	777.88	787.07
SSSF	1	1	un-crack	62.951	63.133	63.983	64.74
			crack	61.092	61.268	62.093	62.828
		2	un-crack	125.42	125.78	127.48	128.99
			crack	121.53	121.88	123.52	124.98
		3	un-crack	187.34	187.88	190.41	192.66
			crack	181.27	181.8	184.25	186.42
	1.5	1	un-crack	73.765	73.978	74.974	75.86
			crack	71.367	71.573	72.537	73.395
		2	un-crack	146.56	146.98	148.96	150.72
			crack	141.52	141.93	143.84	145.54
		3	un-crack	218.29	218.92	221.87	224.49
			crack	210.43	211.04	213.88	216.41
	2	1	un-crack	85.927	86.175	87.336	175.12
			crack	83.178	83.419	84.542	85.542
		2	un-crack	170.28	170.77	173.07	175.12
			crack	164.5	164.97	167.2	169.17
		3	un-crack	252.93	253.66	257.08	260.12
			crack	243.93	244.63	247.92	250.86
SFSC	1	1	un-crack	68.265	68.462	69.384	70.205
			crack	67.057	67.251	68.157	68.962
		2	un-crack	135.99	136.38	138.22	139.86
			crack	133.46	133.84	135.65	137.25
		3	un-crack	203.07	203.66	206.4	208.84
			crack	199.13	199.7	202.39	204.79
	1.5	1	un-crack	90.938	91.201	92.429	93.522
			crack	89.985	90.244	91.46	92.541
		2	un-crack	180.78	181.3	183.75	185.92
			crack	178.75	179.26	181.68	183.82
		3	un-crack	269.31	270.09	273.73	276.97
			crack	266.11	266.88	270.47	273.67
	2	1	un-crack	122.14	122.49	124.14	125.61
			crack	121.63	121.98	123.62	125.08
		2	un-crack	242.55	243.25	246.53	249.45
			crack	241.4	242.1	245.36	248.26
		3	un-crack	360.83	361.87	366.75	371.08
			crack	358.96	360	364.85	369.16

First, the fluctuation in natural frequencies for plate composites with and without crack effect was noticed from the table above, where the values of the cracked plates are contrasted with the values of an un-cracked plate. According to the findings, all cracked plates have lower natural frequencies than un-cracked one.

Al_2O_3 reinforcement have a significant affect the fundamental natural frequency of epoxy rectangular wing plate as shown in Figure 2. It is true that frequencies are increased with the increasing mixing percentage of Al_2O_3, Because Al_2O_3 has a high elasticity modulus, and increasing mixing ratios made the composite stiffer and consequently raises the plate's natural frequency. Natural frequency of the un-cracked plate with 6% Al_2O_3, a/b=2 and 3 mm plate thickness under SSSS type is 812.97 Hz, and 787.07 Hz. cracked plate, while for pure epoxy (0% Al_2O_3) The natural frequency was 531.49 Hz. for un-cracked and 765.33 Hz. for cracked wing plate under same conditions. As a result, the frequency increased about 52.96% for un-cracked plate and 2.84% for cracked plate as compared to pure epoxy.

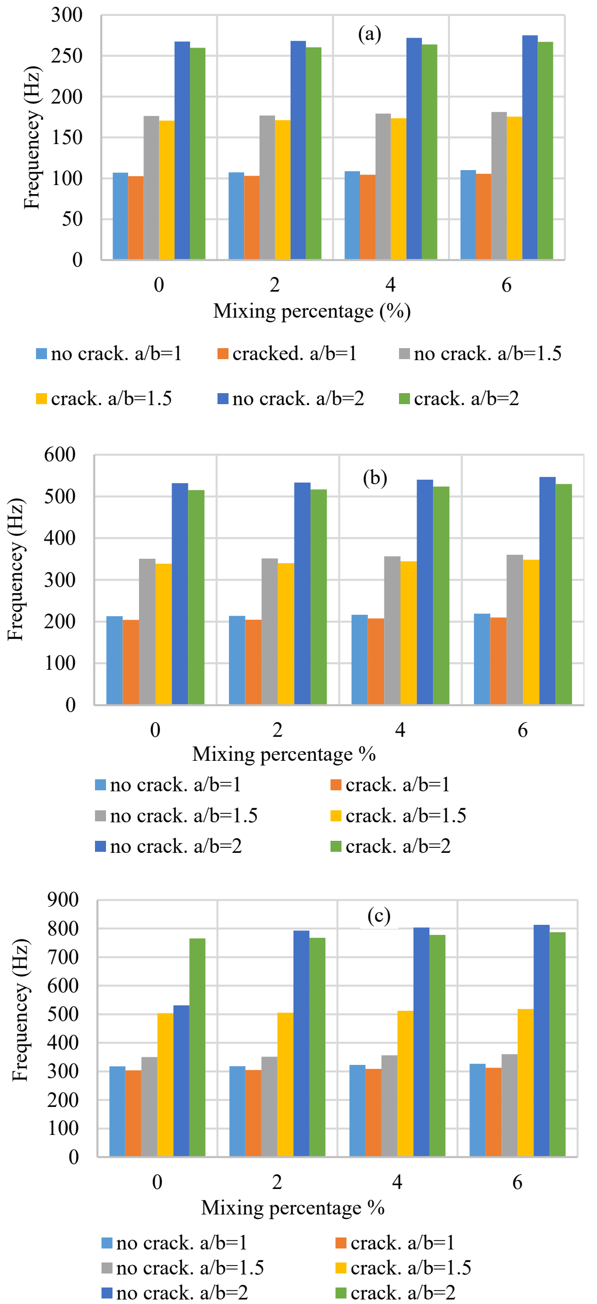

Figure 2. A comparison between mixing percentage and natural frequency with and without crack effect at various aspect ratio under SSSS B.C with wing plate thickness, (a) 1 mm, (b) 2 mm, (c) 3 mm

Additionally, several aspect ratios (a/b) of the same rectangular plate were analyzed (1, 1.5 and 2). Aspect ratio's effect on natural frequency is seen in Figure 3. It has been discovered that as the aspect ratio increases, so does the fundamental frequency's fluctuation. For cracked plate, the natural frequencies may be slightly increased to approximately 33.9% when a/b = 2 compared to a/b= 1.5 and 59.8% when a/b = 1, whereas for un-cracked plate, they rise by 34.17 % when a/b = 2 compared to a/b=1.5 and 60.3% when a/b = 1.

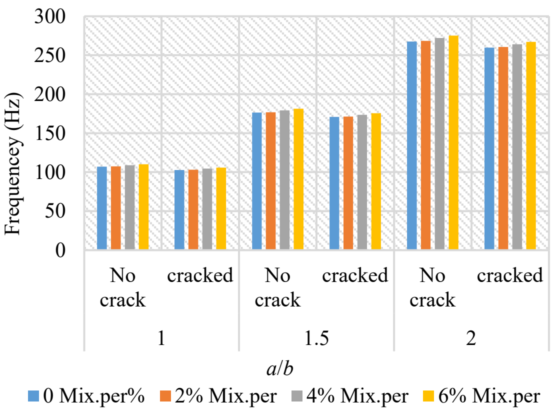

Figure 3. Effect of aspect ratio on natural frequency for SSSS support type and 1 mm wing plate thickness

Figure 4 displays the fluctuations on natural frequency with wing plate thickness (1, 2, 3 mm) for cracked and un-cracked plates under SSSS type boundary conditions as an example. The values of cracked plates are compared with the value of an un-cracked plate. The results indicate that as plate thickness increased natural frequency also increased, beside; the natural frequencies of all cracked plates are lower than those of un-cracked one.

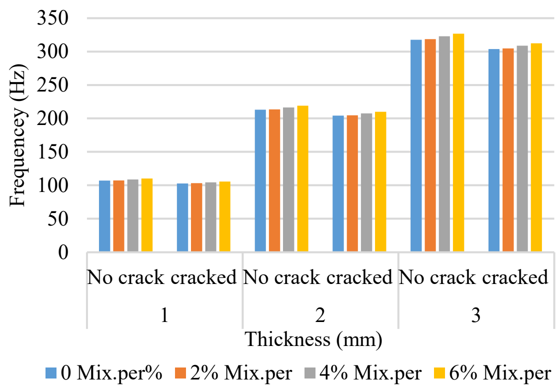

Figure 4. Effect of plate thickness on natural frequency for SSSS support type with wing plate thickness (1, 2, 3 mm) for cracked and un-cracked plates

To analysis the effect of boundary conditions on the natural frequency of epoxy reinforced Al_2O_3 composite rectangular wing plate, three types of boundary conditions, (SSSS, SSSF, and SFSC) are implemented. Figure 5 represent the effect of different boundary conditions on natural frequency for 1 mm wing plate thickness and a/b=2 with different mixing percentage.

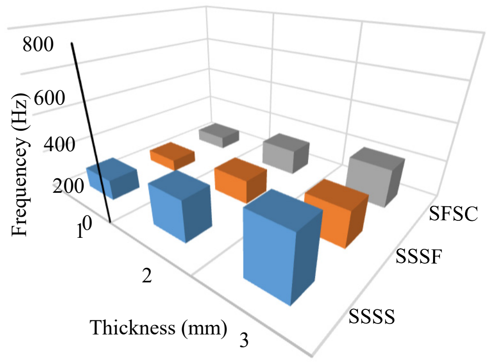

Figure 5. Effect of boundary condition on natural frequency at various aspect ratio and wing plate thickness for 6% mixing percentage of Al_2O_3

Additionally, the reached results obviously demonstrate that frequency variables increase if more restrictions are included. For instance, SSSF and SFSC have lower frequencies than SSSS as show in Figure 5 related to simply support on all four sides in the later. SSSS boundary conditions presents the highest natural frequencies. This indicates that when the limitations on the edges increases the bending rigidity also increase. Consequently, the frequency has increased.

In general, maximum natural frequency was found at 6% Al_2O_3, with 3 mm plate thickness and a/b=2 which results in natural frequencies are (787.07 Hz) and (812.97 Hz) for crack and un-cracked plate, respectively as shown in Figure 6 under SSSS B.C; while minimum natural frequency located at 0% Al2O3 with 1 mm plate thickness and a/b=1 which results in natural frequencies are (61.092) and (62.951) for crack and un-cracked wing plate, respectively as shown in Figure 7 under SSSF B.C.

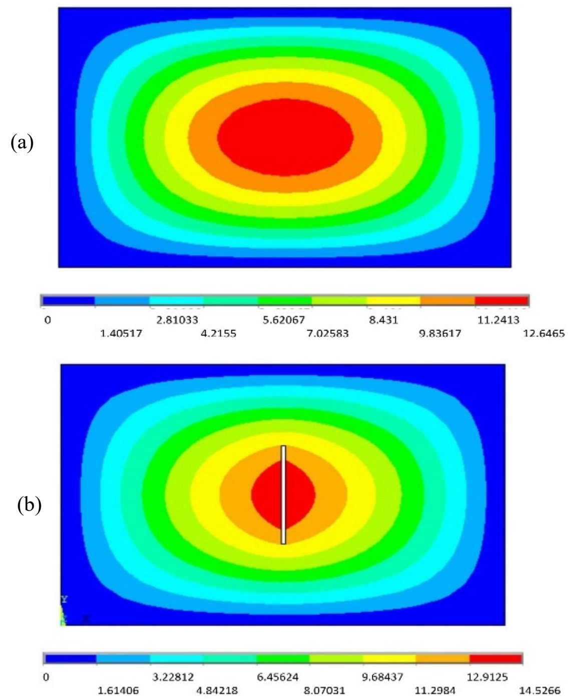

Figure 6. Natural frequency shape (mode 1) of simply supported SSSS B.C at 6% mixing per. and a/b=2, (a) un-cracked plate, (b) cracked wing plate

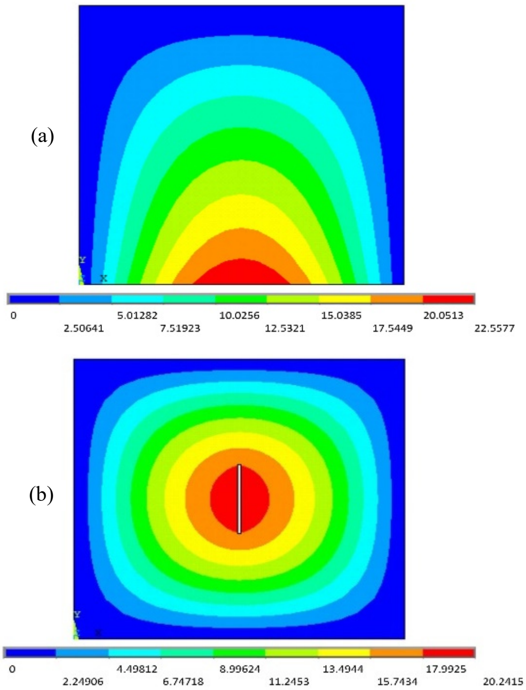

Figure 7. Natural frequency shape (mode 1) of simply supported SSSF B.C at 0% mixing per. and *a*/*b*=1, (a) un-cracked wing plate, (b) cracked wing plate

4. CONCLUSION

This study investigated the effect of Al_2O_3 reinforcement on the natural frequencies of rectangular epoxy composite wing plate with and without crack effect. Numerical simulation was employed to identify first natural frequencies. Al_2O_3 reinforced epoxy composite with various mixing ratios was compared to a pure epoxy. Following conclusions can be drawn from the obtained results.

1. Wing plates with crack have smaller natural frequencies than wing plates without crack, for all boundary conditions, because stiffness of cracked wing plates are decreases.
2. At 6% mixing ratio of AL_2O_3, the plate thickness (3 mm) and *a*/*b*=2 un-cracked wing plate exhibited the highest natural frequency (812.97 Hz) on simply supported (SSSS) boundary conditions.
3. At 0% mixing ratio of AL_2O_3 (pure epoxy), the wing plate thickness (1 mm) and *a*/*b*=1 cracked plate exhibited the lowest natural frequency (61.092 Hz) on simply supported- free (SSSF) boundary conditions.
4. With increase in wing plate thickness the percentage of natural frequency for plates with and without crack are increase
5. The fundamental natural frequency of the wing plate is impacted by the aspect ratio (*a*/*b*). The natural frequency increases in value as the aspect ratio rises.

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