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Resonance Analysis of the UAV Rotor-arm part

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Abstract: *- The study of Aerial-photography by Unmanned Aerial Vehicle(UAV), becomes more and more important especially for disaster countermeasures. The Vibration from rotor part has an influence on sensors which measures flight parameters. It was found that resonant with natural frequency of arm part and vibration of rotor part gave rise to problems to the flight-stability of UAV. The sensor values from resonance will increase the amount of aircraft control. It is considered to cause overturn and hunting motion of the aircraft. Based on the thrust generated from the propeller, was determined natural frequency of the rotor-arm part by Rayleigh method. Design to understand the natural frequency of aircraft parts, it is important to avoid the resonance. Therefore, the risk of resonance verified with the frequency of rotor rotation speed of propeller.*

Keywords: – *UAV, flight-stability, Resonant, Natural Frequency, Rayleigh method*

I. INTRODUCTION

The authors are developing small UAV and studying flight stabilization control. To understand the characteristics of the aircraft is important for the flight control. The authors are developed small-scale quadrotor [1] UAV shown in Fig.1 Attitude of the UAV the detection of air-frame angular velocity [2] are controlled by the PD control. The vibration from rotor part has an influence on sensors which measures flight parameters. The frequency of vibration changes proportion to the number of motor rotation. Cause of the vibration is unbalance of the propeller. Measures to unstable dynamic behavior [3], it is important to the design of the rotor.

The authors measured the resonant with natural frequency of arm part and rotor vibration. The resonant has an influence on sensors which measures flight parameters. The sensor values from resonance will increase the amount of aircraft control. It is considered to cause overturn and hunting motion of the aircraft. The natural frequency of the rotor-arm part is focused on preventable to resonance. The rotor-arm part simple model is consider to the cantilever [4] with concentrated load. Based on the thrust generated from the propeller, was determined natural frequency of the rotor-arm part by Rayleigh method [5]. Design to understand the natural frequency of aircraft parts, it is important to avoid the resonance [6]. Therefore, the risk of resonance verified with the frequency of rotor rotation speed of propeller.

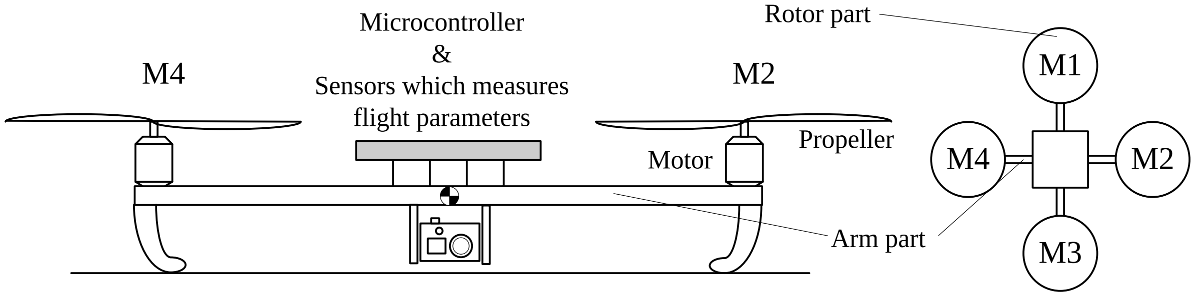


Fig.1 Quad type Unmanned Aerial Vehicle

II. THE ROTOR-ARM PART MODEL

The authors develop the experimental device that reproduces to situation of single rotor-arm part. The flexibility axis of pitch is prepared in the center of arm part. Arm part moves like seesaw. Propellers, motors, and amplifiers are arranged to the both sides ends of arm part, and both side weight is adjusted with them. The thrust is changed to lift of the mass. Loadcell measures the thrust of left-side propeller by leverage. Microcontroller and sensors are placed in the center of arm part, sensors measures gyro, acceleration, posture, etc. It was found that resonant with natural frequency of arm part and vibration of rotor part gave rise to problems to the flight-stability of UAV. Resonance is to influence to the sensor value of to measure the flight parameters. Therefore, the natural frequency of the rotor and the arm part calculate of the quadrotor UAV. Experimental device and simple rotor-arm part model is shown in fig.2.

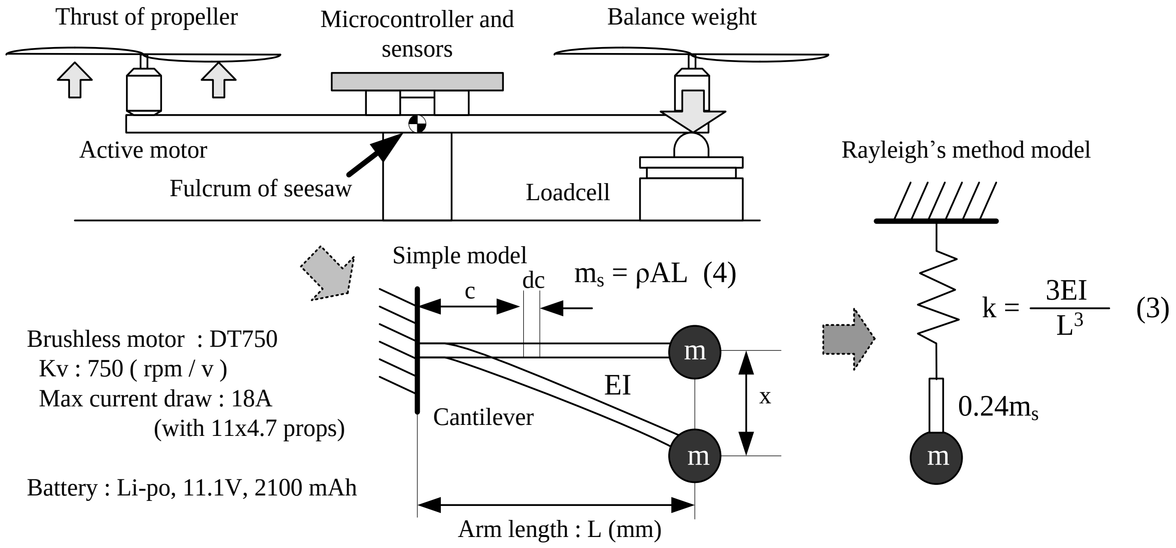


Fig.2 Experimental device and simple rotor - arm part model

The single rotor-arm part is same as cantilever (fixed end and free end).

The single rotor-arm part is same as cantilever (fixed end and free end). The rotor-arm part simple model is considered to the cantilever [4] with concentrated load. The natural frequency "Fn" is formulated from (1).

$$F_n = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{K}{M}} \qquad (1)$$

$$M = m + \frac{33}{140}m_s = m + 0.24m_s \qquad (2)$$

Rayleigh method collects the mass of the cantilever and concentrated load from all kinetic energy. Total mass "M" is formulated from (2). The arm part of a small UAV such as wood, aluminum, carbon material is selected. Yang modulus and density of arm material is shown in table.1.

Table.1 Yang modulus and density of arm material

	Young modulus : E (GPa)	Density : ρ (kg/m^3)
Aluminum : A6063	70	2700
Carbon fiber reinforced plastics (CFRP)	140	1600
Wood : White cedar	9	440

Cross-sectional shape of the arm, circle, circle pipe, square, square pipe, and square timber is selected. The moment of inertia of area "I" in useful type of UAV is shown in fig.3, and formulated from (5 - 8). This model is simplified of relationship between mass and the spring. Spring constant "k" can adjust in length and material of the arm. The authors investigated by balance or non-balance propeller that relationship to number of revolutions between thrust and current. The mass of concentrated load "m" is used from the propeller thrust of the experimental results.

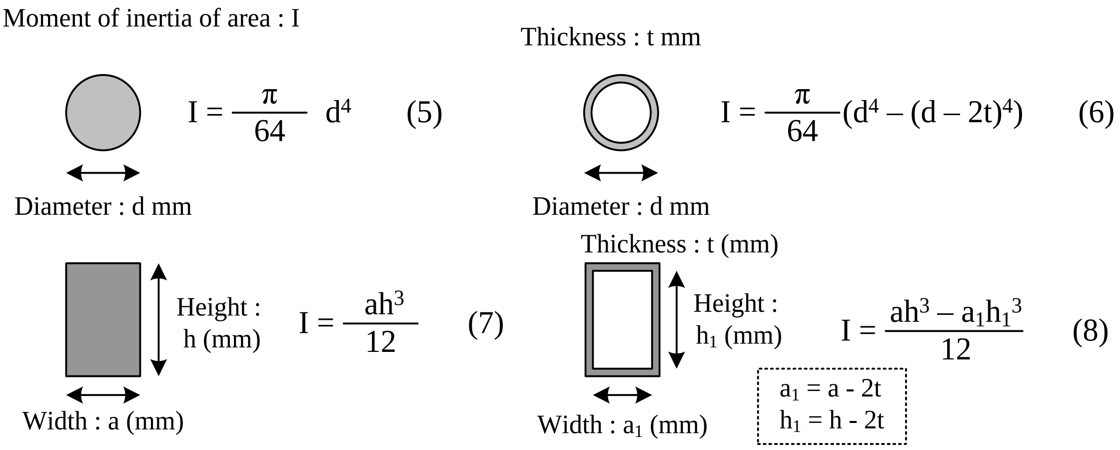


Fig.3 Arm cross-sectional shapes and moment of inertia of area

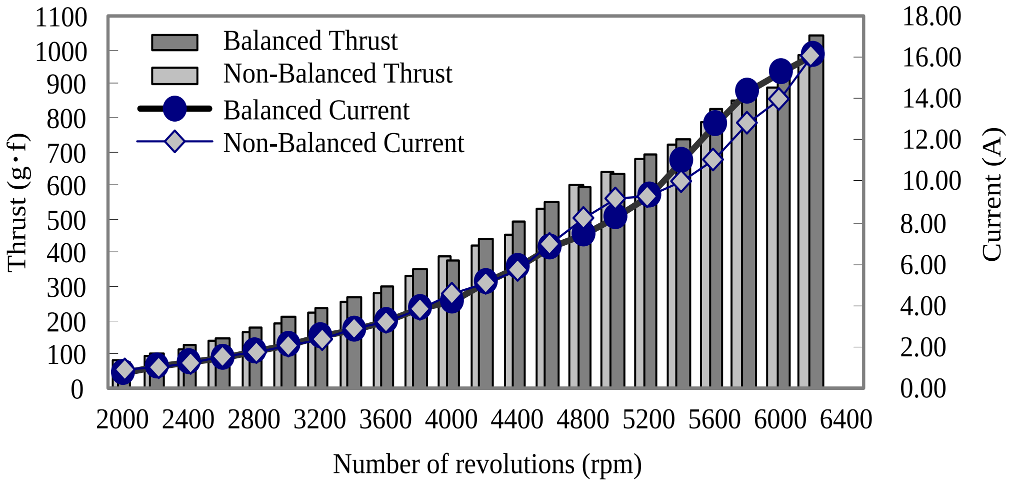
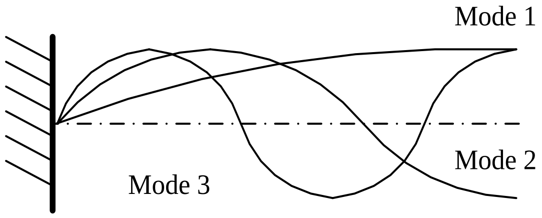


Fig.4 Type "11x4.7" thrust and current

III. THE NATURAL FREQUENCY OF ARM PART

Based on the thrust generated from the propeller, was determined natural frequency "Fn" of the rotor-arm part by Rayleigh method. The compare rotation number "Rn" is 60 times for natural frequency "Fn". The Cantilever has a free end. Therefore, the resonance is generated by the odd multiples of natural frequencies.



Mode 1 : $\lambda_1 = 1/Fn$
Mode 2 : $\lambda_2 = 3\times\lambda_1$
Mode 3 : $\lambda_3 = 5\times\lambda_1$

Mode n : $\lambda_n = (2n-1)\times\lambda_1$

Fig.5 Resonant mode numbers of cantilever

The natural frequency multiple data F1 ~ F12 are computed from the thrust occurred in the number of revolutions of propeller. Natural frequency was calculated under the same conditions as the experiment in fig.4 ("11x4.7" trade edition propeller, wood: white cedar, square timber 9×9mm, arm length: 0.438m). Table 2 shows the part of calculation result. The smaller the absolute value of the difference between the "Rn" and the rotor rotational speed "Crisis rate", means that the easy-to-resonance. Low mode1 value of natural frequency is easy to resonate. So, multiple is narrow step, because. The factors of determine the natural frequencies of the arm is the arm length, material, and moment of inertia. In particular, the highest usage of rotor rotational speed is near the hovering thrust in the UAV. It is necessary to design to avoid resonance at near hovering number of revolutions.

Table.2 Resonance risk of the rotor rotational speed

Rotor (RPM)	Thrust (g･f)	R1	R2	R3	R4	R5	R6	R7	R8	Crisis rate
2000	80	646	***1939***	3231	4524	5816	7109	8401	9694	***61***
2200	92	605	***1816***	3026	4237	5447	6658	7868	9078	384
2400	113	549	1647	***2745***	3843	4941	6039	7137	8236	-345
2600	136	502	1507	***2512***	3517	4522	5527	6532	7537	***88***
2800	162	462	1386	2309	***3233***	4157	5080	6004	6928	-433
3000	188	430	1289	2149	***3008***	3868	4727	5586	6446	***-8***
3200	216	402	1205	2008	***2812***	3615	4418	5222	6025	388
3400	250	374	1122	1870	2618	***3366***	4114	4862	5610	***34***
3600	275	357	1071	1785	2499	3212	***3926***	4640	5354	-326
3800	321	331	993	1654	2316	2978	***3639***	4301	4963	161
4000	375	306	919	1532	2145	2758	3371	***3984***	4597	***16***
4200	405	295	885	1475	2066	2656	3246	3836	***4426***	-226
4400	440	283	850	1416	1983	2549	3116	3682	***4249***	151
4600	512	263	788	1314	1840	2365	2891	3417	3942	132

IV. COMPARISON WITH THE RESULTS OF SENSOR WHICH MEASURE FLIGHT PARAMETERS

Fig.6 shows the results of sensor which measure flight parameters.

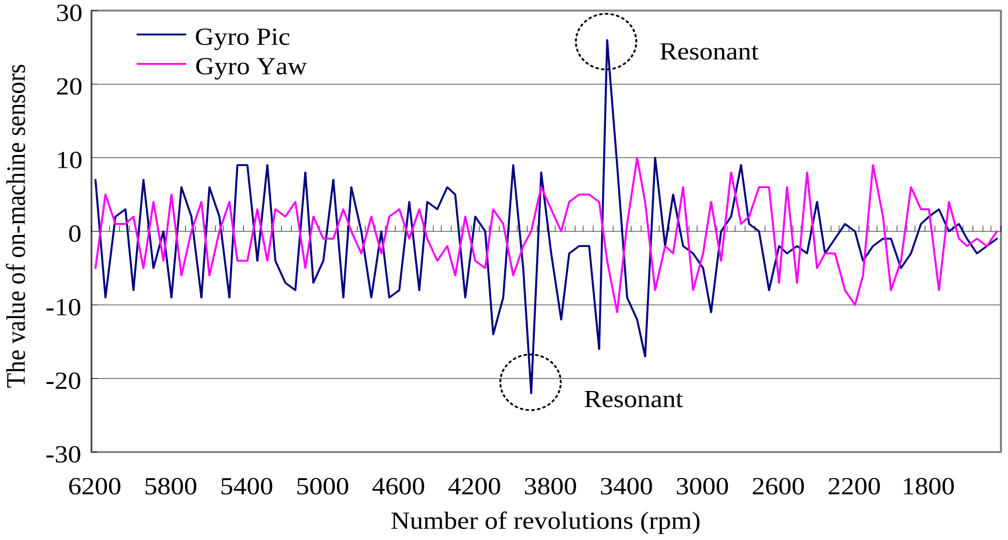


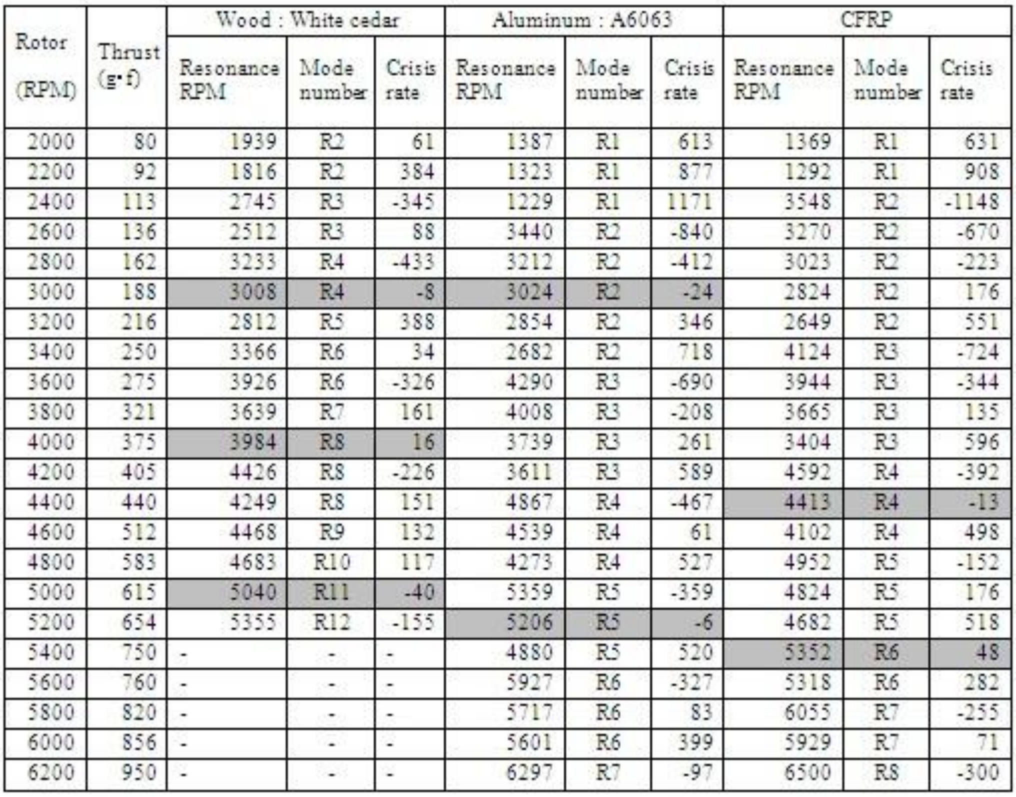
Fig.6 Sensors data in type "11x4.7" trade edition propeller

Sensors measure cycle is period of about 10 ms. The authors were measured to -200rpm step from 6400rpm. The Graph values are average ten points max and min values for each rotational speed. There is a point sensor values greatly disturbed in Fig.6. At those points the rotor and the arm on the experimental device that was vibrated together. Therefore, the authors can predict the risk of specific resonance frequency calculations using the Rayleigh method.

V. DIFFERENCES OF MATERIALS

A similar calculation do in table 2 and square timbers pipe used in aluminum and carbon to small UAV. Differences of materials are shown in table.3. Crisis rate is stressed the value of 50 or below. In the case of aluminum and carbon, interval of the multiple is wide by Young's modulus. The arm length "L" is also significantly affects the result. Changes in the design parameter can be carried out in a prediction of the resonance.

Table.3 Differences of materials



Rotor (RPM)	Thrust (g·f)	Wood : White cedar			Aluminum : A6063			CFRP		
		Resonance RPM	Mode number	Crisis rate	Resonance RPM	Mode number	Crisis rate	Resonance RPM	Mode number	Crisis rate
2000	80	1939	R2	61	1387	R1	613	1369	R1	631
2200	92	1816	R2	384	1323	R1	877	1292	R1	908
2400	113	2745	R3	-345	1229	R1	1171	3548	R2	-1148
2600	136	2512	R3	88	3440	R2	-840	3270	R2	-670
2800	162	3233	R4	-433	3212	R2	-412	3023	R2	-223
3000	188	3008	R4	-8	3024	R2	-24	2824	R2	176
3200	216	2812	R5	388	2854	R2	346	2649	R2	551
3400	250	3366	R6	34	2682	R2	718	4124	R3	-724
3600	275	3926	R6	-326	4290	R3	-690	3944	R3	-344
3800	321	3639	R7	161	4008	R3	-208	3665	R3	135
4000	375	3984	R8	16	3739	R3	261	3404	R3	596
4200	405	4426	R8	-226	3611	R3	589	4592	R4	-392
4400	440	4249	R8	151	4867	R4	-467	4413	R4	-13
4600	512	4468	R9	132	4539	R4	61	4102	R4	498
4800	583	4683	R10	117	4273	R4	527	4952	R5	-152
5000	615	5040	R11	-40	5359	R5	-359	4824	R5	176
5200	654	5355	R12	-155	5206	R5	-6	4682	R5	518
5400	750	-	-	-	4880	R5	520	5352	R6	48
5600	760	-	-	-	5927	R6	-327	5318	R6	282
5800	820	-	-	-	5717	R6	83	6055	R7	-255
6000	856	-	-	-	5601	R6	399	5929	R7	71
6200	950	-	-	-	6297	R7	-97	6500	R8	-300

VI. CONCLUSION

Based on the thrust generated from the propeller, was determined natural frequency of the rotor-arm part by Rayleigh method. The risk of resonance verified with the frequency of rotor rotation speed of propeller. Compared with the experimental results in the experimental device, it was confirmed that the resonance point and the calculated values are consistent. The authors can predict the risk of specific resonance frequency calculations using the Rayleigh method. Design to understand the natural frequency of aircraft parts, it is important to avoid the resonance. It is necessary to design to avoid resonance at near hovering number of revolutions.

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