A Markov Process-based Approach for Reliability Evaluation of the Propulsion System in Multi-Rotor Drones

Koorosh Aslansefat, Francisco Marques, Ricardo Mendonça and José Barata

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Applications of Drones

Agricultural

Search and Rescue

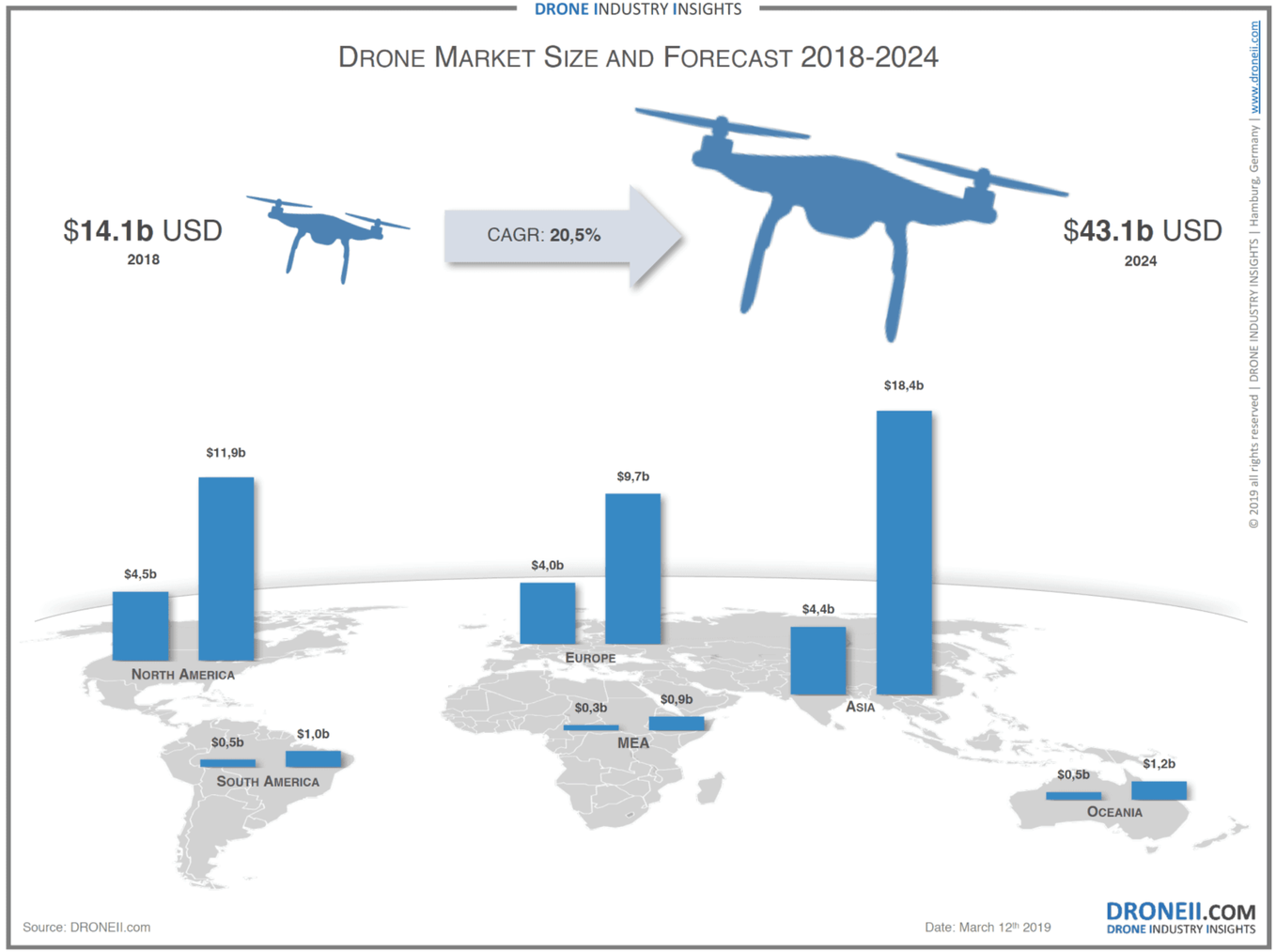
Cargo Delivery

Entertainment

Reliability Definition: The quality of being trustworthy or of performing consistently well.

Drones Market

A quick report



Reference: www.droneii.com

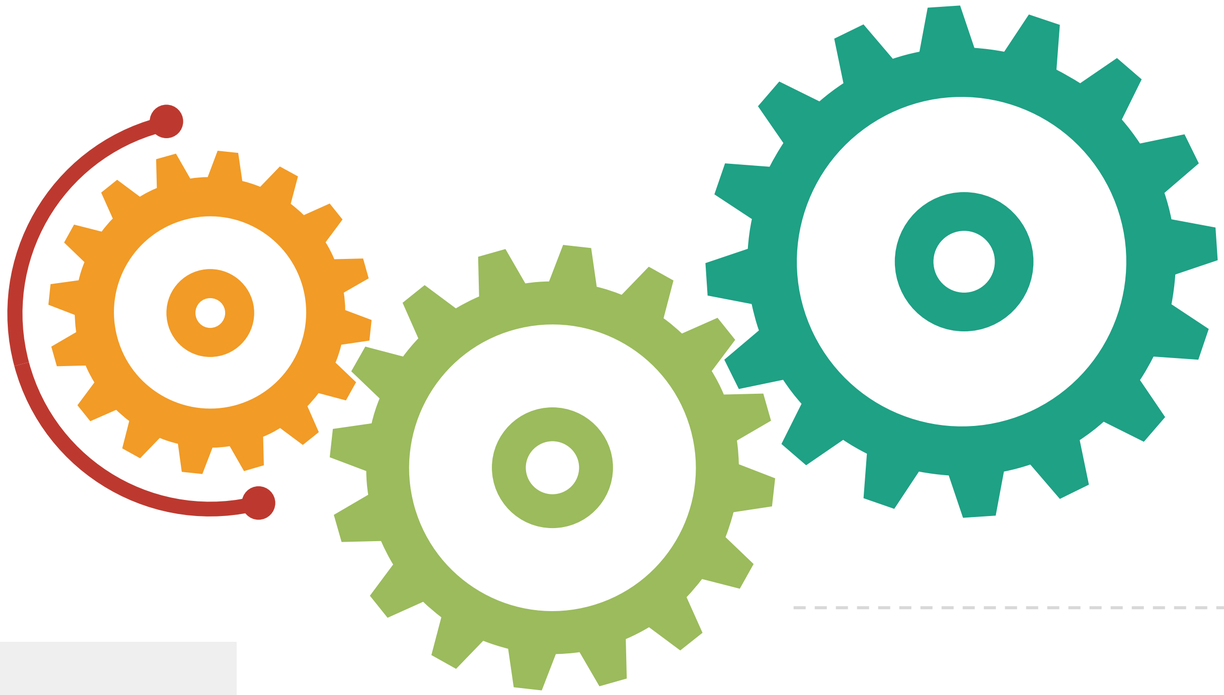
Assumptions

CFP Dissemination

At the beginning, system is always operational

There is no common cause failure in the system

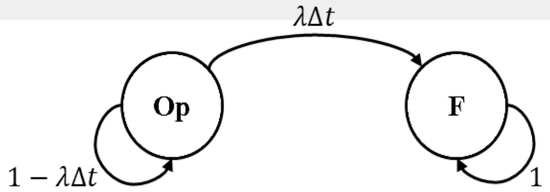
During the mission repair is not possible



- **Probability Distribution Function of Failures**

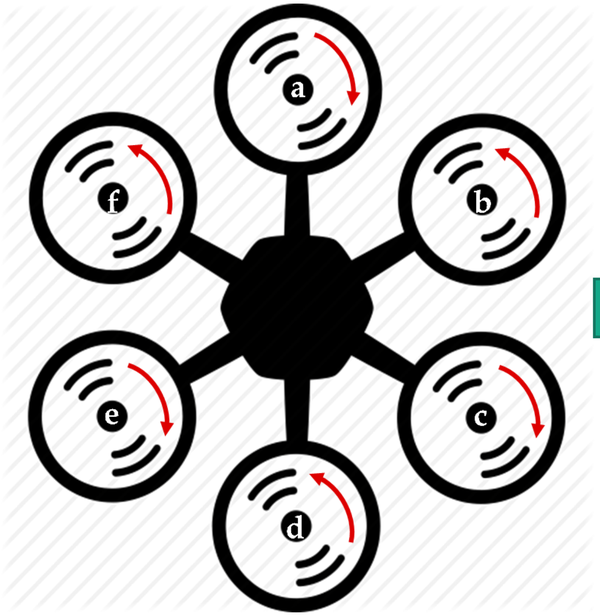
The failure rates of the components obey an exponential probability distribution function.

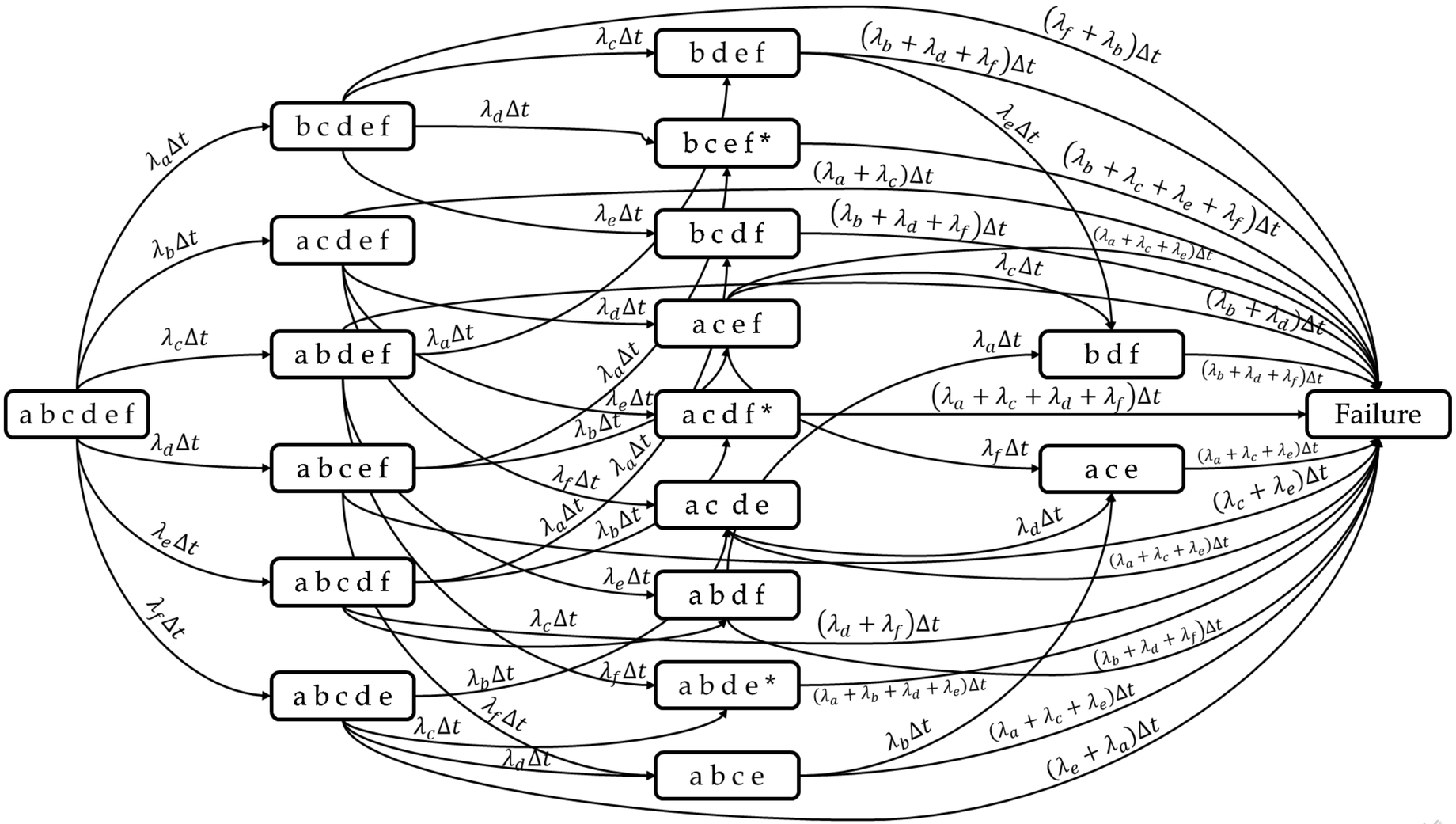
$$F(t) = 1 - e^{-\lambda t}$$



Markov Modelling

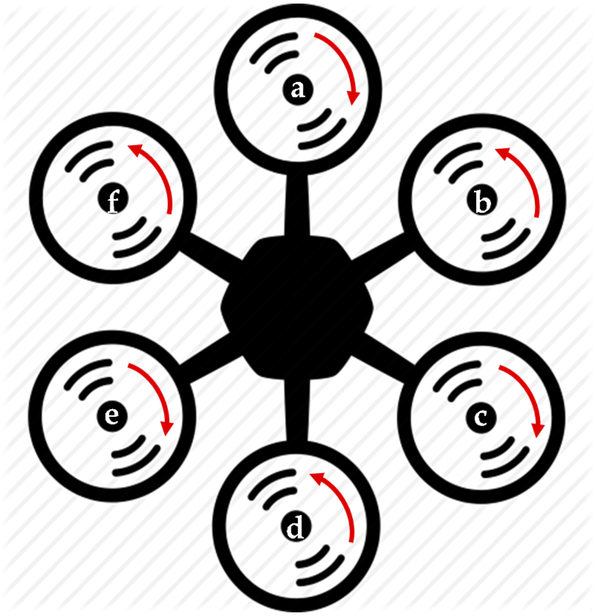
Hexa-Copter PNPNPN Configuration



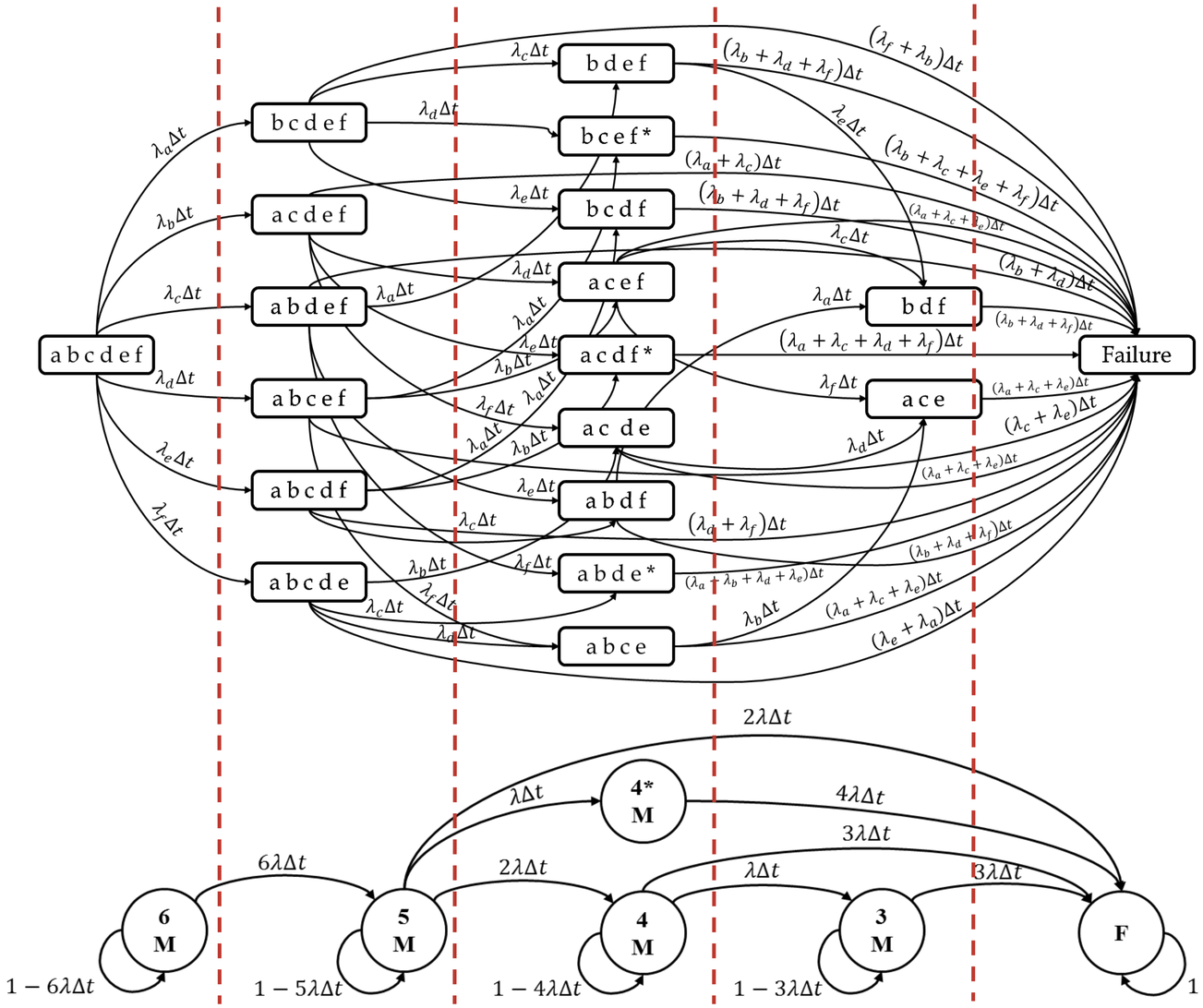


Simplified Markov Model

Hexa-Copter PNPNPN Configuration

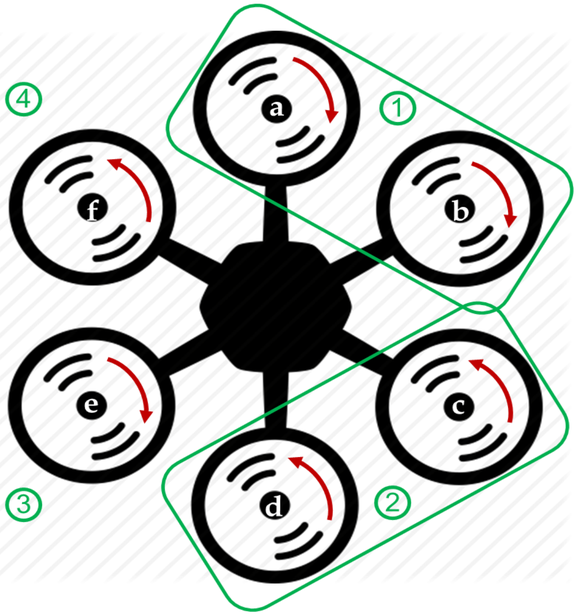


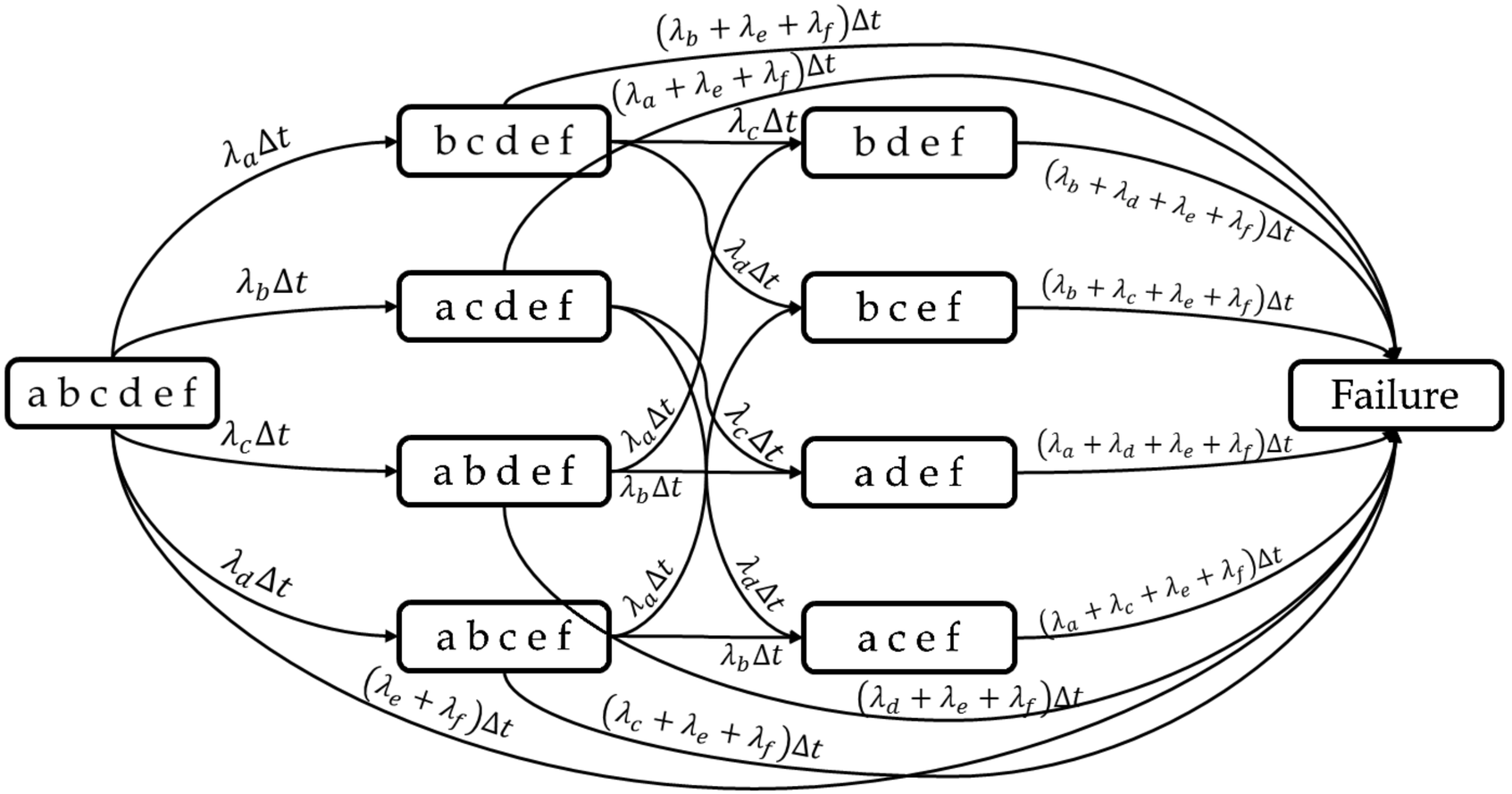
$$\lambda = \lambda_a = \lambda_b = \lambda_c = \lambda_d = \lambda_e = \lambda_f$$



Markov Modelling

Hexa-Copter PPNNPN Configuration





Simplified Markov Model

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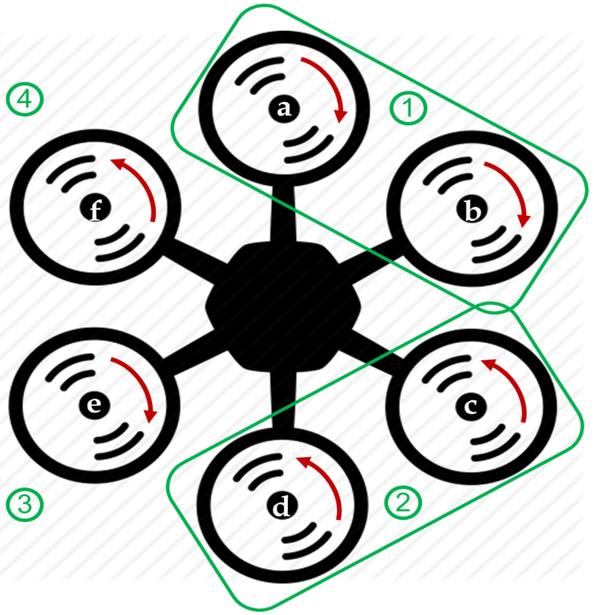

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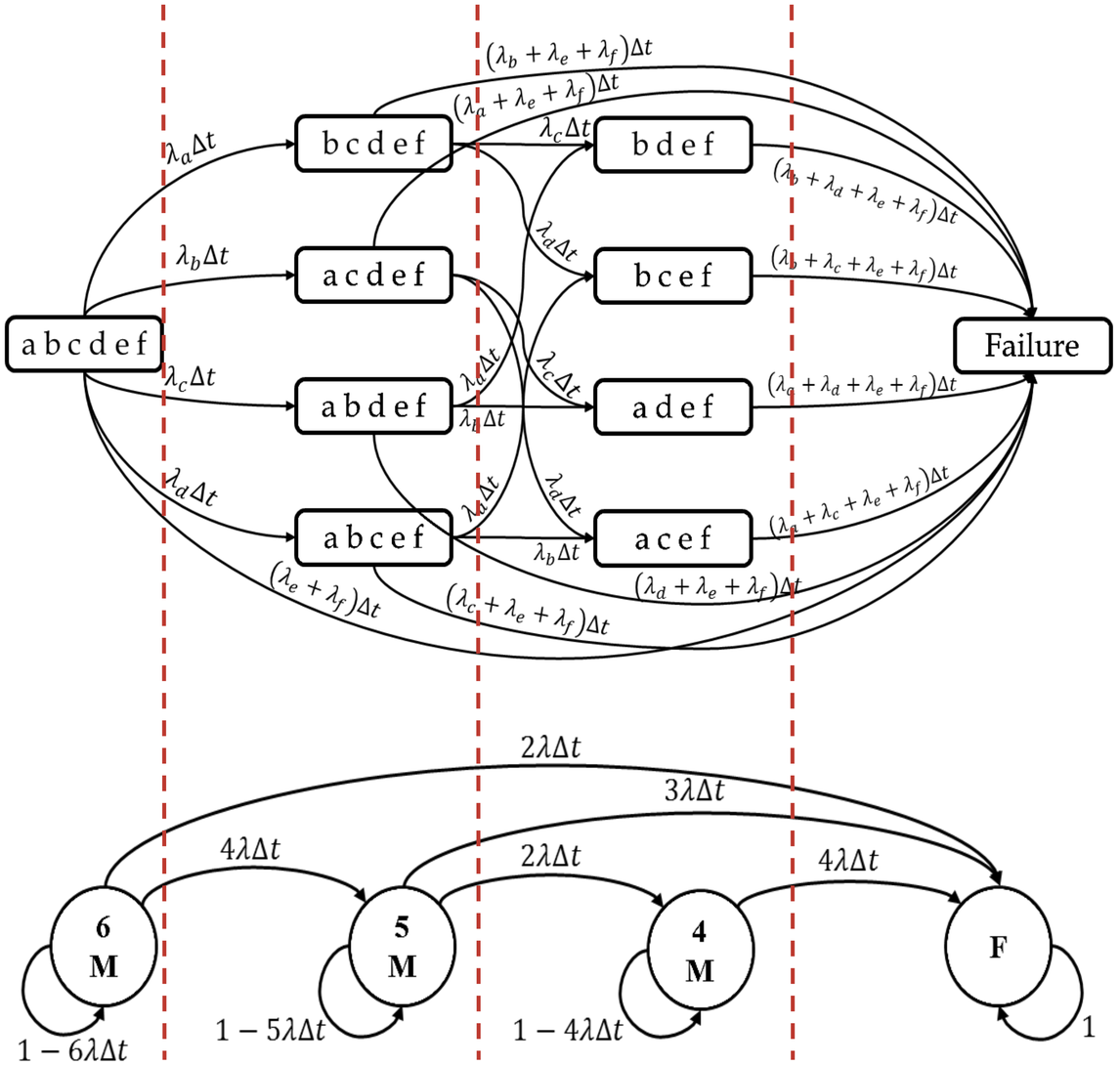
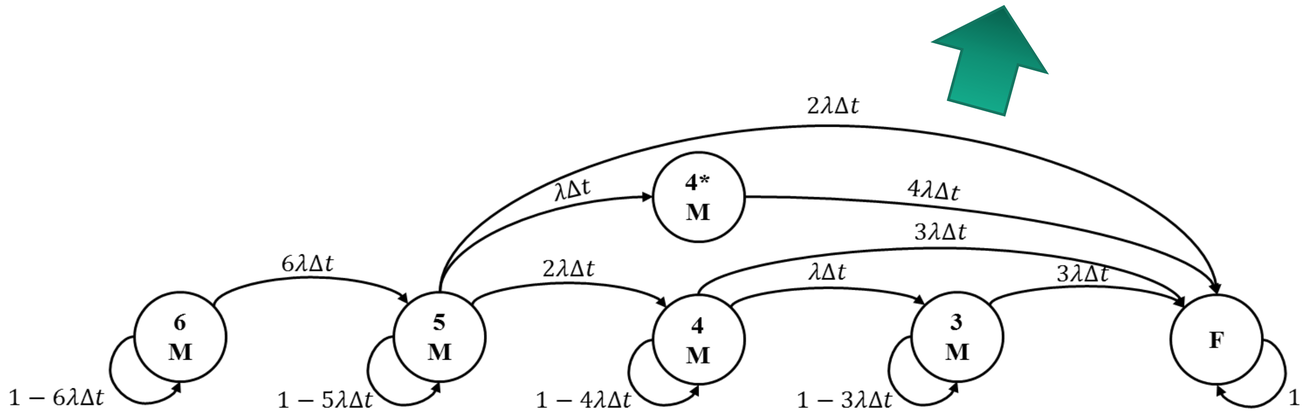


Model Validation Through Monte Carlo Simulation

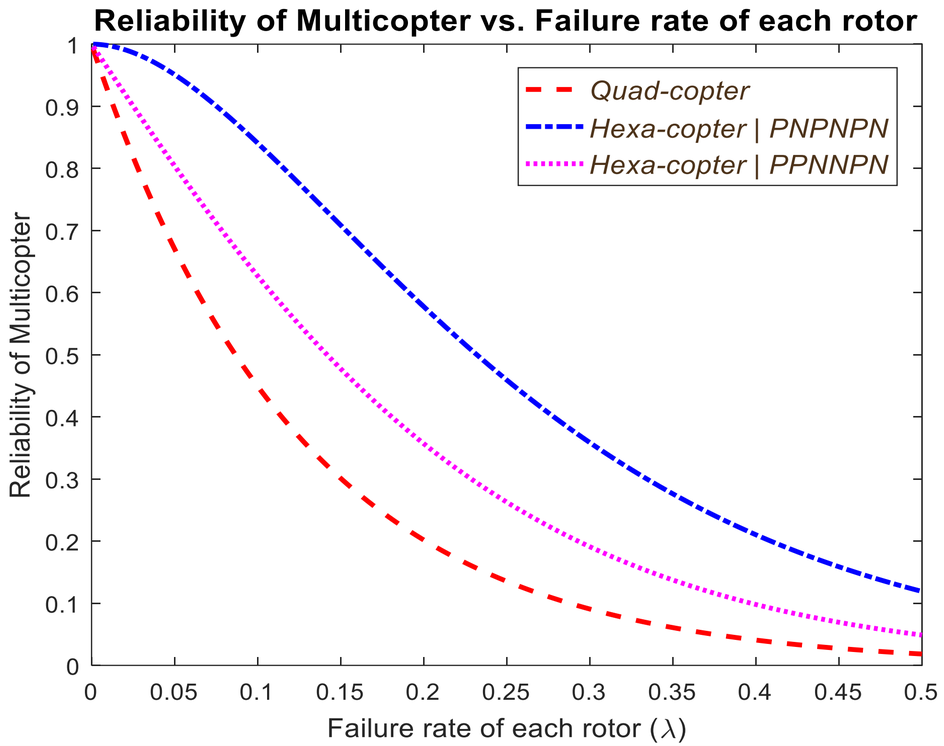
Hexa-Copter PNPNPN Configuration

Reliability (Mission Time)	Monte Carlo (1e06 Iteration)		Markov Solution
	Mean	Variance	
R(5)	0.841404	1.32e-3	0.840721
R(10)	0.578312	1.32e-3	0.577502
R(15)	0.357543	1.32e-3	0.358676
R(20)	0.211128	1.32e-3	0.210288
R(25)	0.117153	1.32e-3	0.119051
R(30)	0.066433	1.32e-3	0.065957
R(35)	0.036925	1.32e-3	0.036063

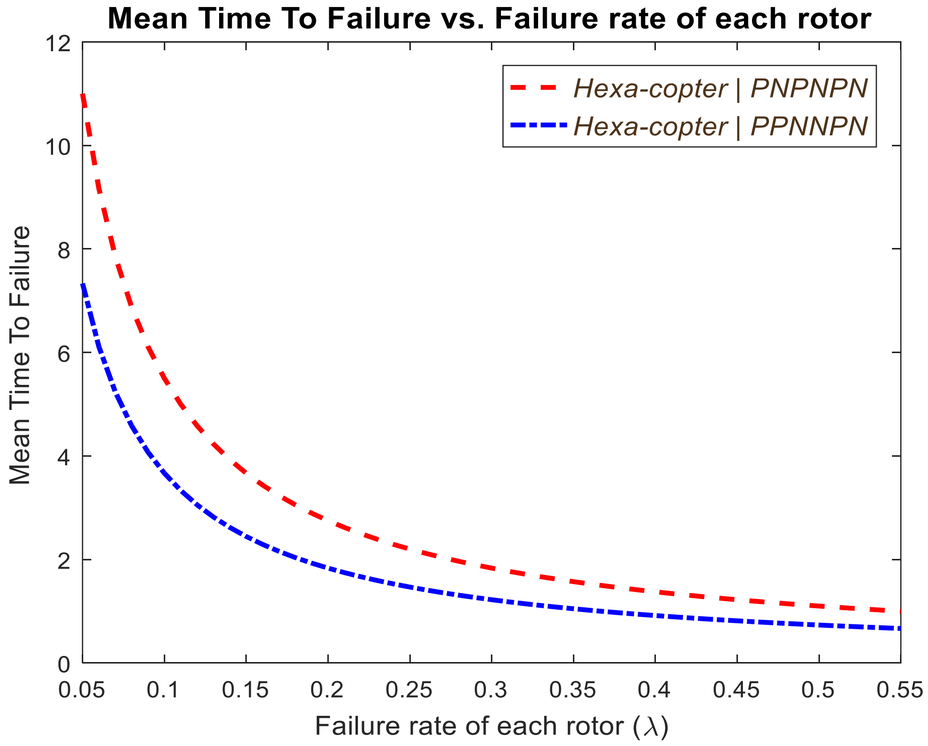


Numerical Results

Reliability and MTTF Evaluation



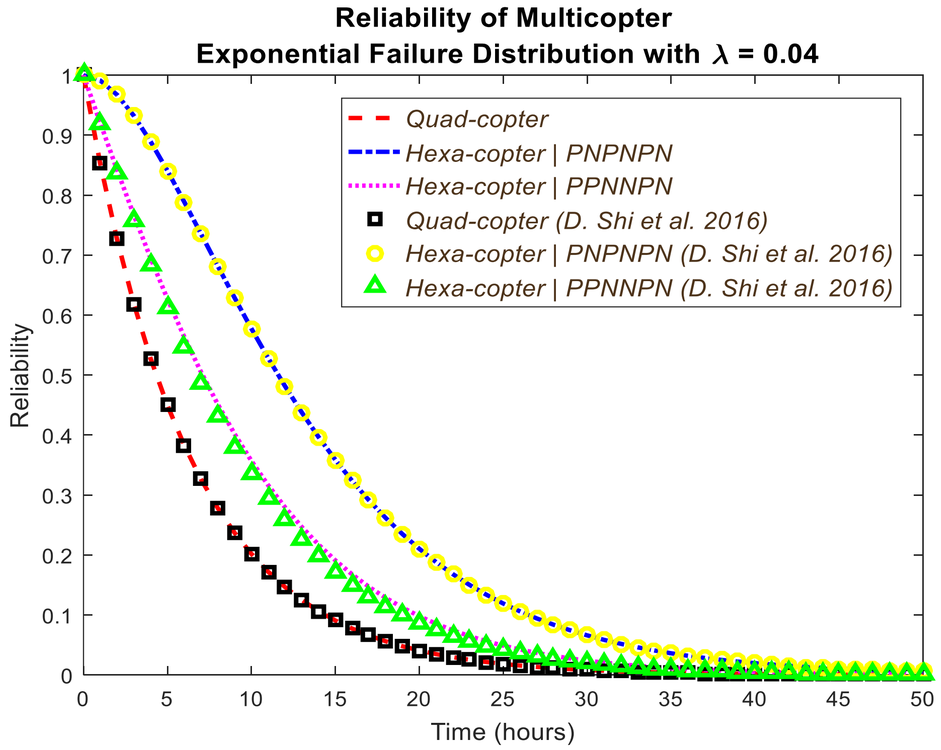
Reliability evaluation of Multirotors (Quadcopter and Hexacopter) vs. failure rate of each rotor at two hours of mission



Mean time to failure of hexacopter vs. failure rate of each rotor

Numerical Results

Reliability and MTTF Evaluation

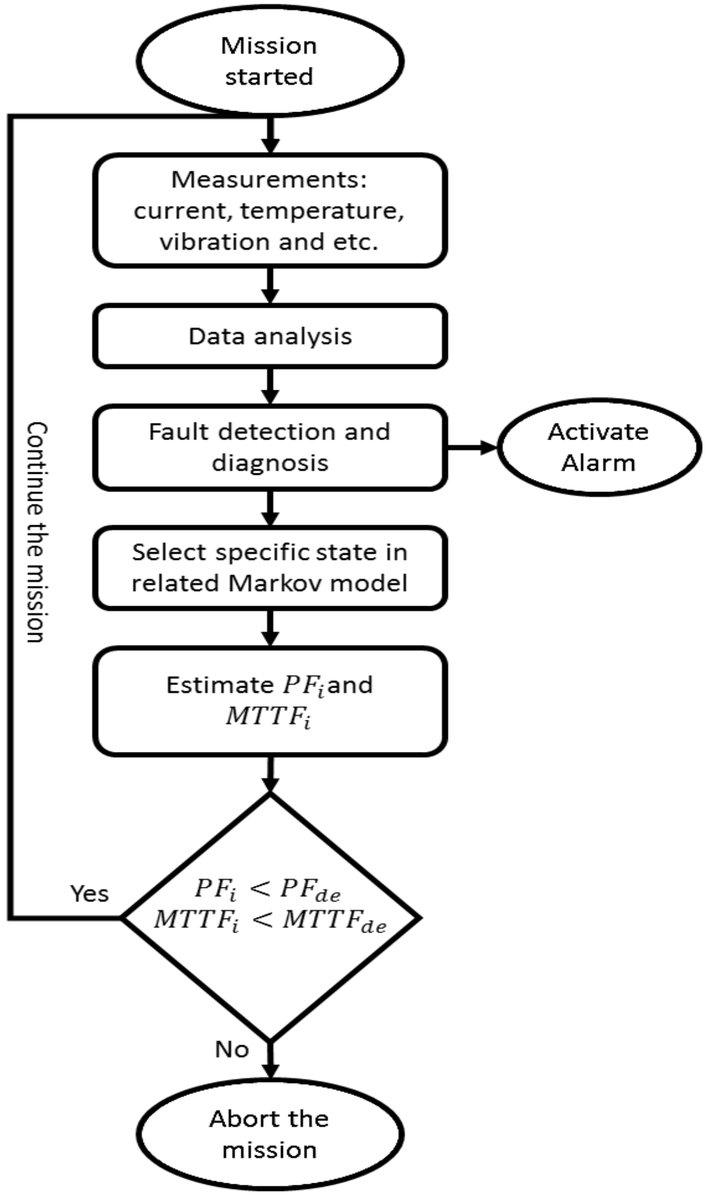


Reliability evaluation of Multirotors (Quadcopter and Hexacopter) vs. time with failure rate of 0.04 failure/hour

	Failure Situations				
	6 M	5 M	4 M*	4 M	3 M
MTTF	13.75	9.58	6.25	8.33	8.33
	6 M	5 M	--	4 M	--
MTTF	9.17	7.50	--	6.25	0

Mean time to failure analysis of quadrotor from each system's states with failure rate of 0.04 failure/hour

Flowchart of the Proposed Markov-based Fault Detection and Recovery System for Multirotors



Conclusion

- For the first time, the Markov models of propulsion system in drones with different configurations and number of rotors have been provided and validated through Monte Carlo Simulation.
- Increasing the number of rotors in drones can improve their reliability and also Mean Time To Failure (MTTF).
- In Hexa-Copters, the PNPNPN configuration is more reliable than PPNNPN configuration and it has a better MTTF.
- A systematic mission avoidance and recovery procedure has been defined to reduce the risk of mission based on MTTF calculation.

References

Barr, L. C., Newman, R. L., Ancel, E., Belcastro, C. M., Foster, J. V., Evans, J. K., & Klyde, D. H. (2017). Preliminary Risk Assessment for Small Unmanned Aircraft Systems. *17th AIAA Aviation Technology, Integration, and Operations Conference.* Denver, Colorado.

Belcastro, C. M., Klyde, D. H., Logan, M. J., Newman, R. L., & Foster, J. V. (2017). Experimental Flight Testing for Assessing the Safety of Unmanned Aircraft System Safety-Critical Operations. *17th AIAA Aviation Technology, Integration, and Operations Conference.* Denver, Colorado.

Belcastro, C. M., Newman, R. L., Evans, J. K., Klyde, D. H., Barr, L. C., & Ancel, E. (2017). Hazards Identification and Analysis for Unmanned Aircraft System Operations. *17th AIAA Aviation Technology, Integration, and Operations Conference.* Denver, Colorado.

De Medeiros, I. P., Rodrigues, L. R., Santos, R., Shiguemori, E. H., & Júnior, C. L. (2014). PHM-Based Multi-UAV Task Assignment. *8th Annual IEEE Systems Conference (SysCon).* Ottawa, ON, Canada.

Dubrova, E. (2013). *Fault-Tolerant Design.* Berlin: Springer.

Juliana de Oliveira Martins Franco, B., & Carlos Sandoval Góes, L. (2007). Failure Analysis Methods in Unmanned Arial Vehicle (UAV) Applications. *19th International Congress of Mechanical Engineering.* Brazil.

Murtha, J. F. (2009). *Evidence Theory and Fault-tree Analysis to Cost-effectively Improve Reliability in Small UAV Design.* Virginia, USA: Virginia Polytechnic Institute & State University.

Olson, I., & Atkins, E. M. (2013). Qualitative Failure Analysis for a Small Quadrotor Unmanned Aircraft System. *AIAA Guidance, Navigation, and Control (GNC) Conference.* Boston, MA.

Sadeghzadeh, I., Mehta, A., & Zhang, Y. (2011). Fault/Damage Tolerant Control of a Quadrotor Helicopter UAV Using Model Reference Adaptive Control and Gain-Scheduled PID. *AIAA Guidance, Navigation, and Control Conference.* Portland, Oregon.

Shi, D., Yang, B., & Quan, Q. (2016). Reliability Analysis of Multicopter Configurations Based on Controllability Theory. *IEEE 35th Chinese Control Conference.* Chengdu, China.

Thanks for Your Attention

If you have any question please fill free to ask