Preliminary Fault tree Analysis of Landing Gear Control and Warning for LSA 02 Motorized Glider Type Aircraft

Adi Wirawan[1], Fuad Surastyo Pranoto[2]

[1, 2]Aeronautic Technology Center, National Institute of Aeronautics and Space (LAPAN), Indonesia

e-mail: adi.wirawan@lapan.go.id

Received: 23-03-2021. Accepted: 07-10-2021. Publishied: 30-12-2021

Abstract

This paper presents a reliability analysis of landing gear control and warning system installed on LSA-02 aircraft. The reliability analysis is essential to minimize the fatal effect of a malfunction by defining the possible causal factors of an accident. In this work, the fault tree analysis is used to investigate the undesired events that occurred on the landing gear control and warning system. The construction of fault tree analysis offers a framework privileged to the deductive analysis, which consists of seeking the various possible combinations of events, leading to the occurrence of a top undesired event. The fault tree analysis shows that the top undesired events are the landing gear is not extended, and the warning system is fails to operate.

Keywords: *LSA-02, FTA, Landing gear.*

Nomenclature

DC	=	Direct Current
FTA	=	Fault Tree Analysis
IC	=	Integrated Circuit
LED	=	Light Emitting Diode
$LGCWS$	=	Landing Gear Control and Warning System
LSA	=	LAPAN Surveillance Aircraft

1. Introduction

The landing gear is one of the most critical systems in the aircraft. The landing gear is needed by aircraft to perform takeoff and landing operations. Without landing gear, takeoff and landing is nearly impossible and have a probability of a caused catastrophic event if forced to do. Therefore, reliable components installed in the landing gear system are mandatory for safe aircraft operation. The LSA-02 aircraft belong to one of them; the aircraft is basically equipped with retractable landing gear. When performing takeoff and landing operations, the pilot shall know that the landing gear is in the correct position and locked. All of the statuses of the landing gear shall be known by the pilot onboard. If the pilot receives wrong information about the landing gear status, it will make the pilot make a wrong decision.

To assist pilot during takeoff and landing operation, the landing gear control and warning system is developed. The LGCWS main function is to inform the pilot about the condition of the landing gear position, by driving three indicating light (bi-color LED) and a piezo horn installed in the cockpit.

In the process of designing the LGCWS in LSA-02 aircraft, system safety and reliability are key requirements. Although the landing gear is only one small system in the aircraft, the criticality status during the landing phase if fail to operate is important to be considered. Therefore, the top event such as a malfunction for primary landing gear control and warning, the main function is must be analyzed. If this function fails, the pilot will not get the information about the landing gear status, or the hydraulic pump will not get the signal to extend the landing gear. Both of them can cause hazardous or event catastrophic events in the landing phase. To identify and analyze the top level event, the fault tree analysis will be used.

The possible cause factors of the accident can be obtained by adopting the risk source identification method. At present, many researchers have put forward several risk source identification methods. One of the identification methods is fault tree analysis (FTA). The work in Schweitzer & Anderson, 1997 used FTA to analyze the reliability of transmission line protection. While Brik & Ammar, 2008 used FTA to investigate the factors that lead the loss of battery capacity. Kornecki & Liu, 2013 used FTA to Analyze the Safety/Security Verification in Aviation Software. Samuel et al., 2013 developed FTA for the protection scheme of the 150km-long 132-kV transmission line in Northern Nigeria. Mahfoud et al., 2014 used FTA to estimate the failure probability of B737 pneumatics system. Popovi & Gligorijevi, 2013 used FTA to analyze the causes and modes of failure of air conditioners and automotive DC electro-ventilator. Alkhaledi et al., 2015 used FTA to identify the risk source and type in three gas explosion accidents that occurred in AI-Ahmadi, Kuwait. While Ding et al., 2017 used FTA to conducted quantitative calculations and analysis on the tunnel diseases of Shanghai Subway. Yuan et al., 2018 applied FTA method to the analysis of cause factors in the emergency process of two practical accident cases, in Oil-Gas Storage and Transportation. While Yuan et al., 2018 used FTA to analyze the fault tree of secondary accidents of Fire Accident in Oil-Gas Storage and Transportation. Takahashi, Anang, & Watanabe, 2020 proposed an analytic method that clarifies the causes of troubles by applying FTA to the embedded control software. Jiang et al., 2021 used a dynamic fault tree of explosive production system for the BCZH-15 explosive vehicle. Markulik et al., 2021 used FTA to Calculate the Probability of the Failure of the Pressure Leaching Process. While Ahn, Yu, & Kim, 2021 used FTA to identify the cause of fire and explosion accidents in tankers. Mou et al., 2021 conducted the research to identify the key factors affecting the operational safety of offshore wind farms. Baek & Heo, 2021 used dynamic FTA to adequately capture accident scenarios of electric power systems in nuclear power plants. While Kang & Song, 2021 designed a fault tree that reflects the operational characteristics of an improved hybrid submodule of a high-voltage direct current (HVDC) system and calculates the failure rate by using FTA method. Li et al., 2021 used FTA to performed to identify the weak links of hydraulic system, the results show the critical basic events affecting the safety and reliability of a hydraulic system. Shafiee et al., 2021 used FTA and failure mode and effects analysis (FMEA) to analyze mission-critical failure of unmanned aerial drones for inspection of offshore wind turbines. The article from UKEssays, 2017 discussed FTA analysis for primary landing gear systems. The article focused on mechanical failures analysis of landing gear.

Currently, no specific research focuses on FTA for the LGCWS, specifically on the electronics component. Therefore, the objective of this work is the feasibility of evaluating risk and the impact of failure in specific components, regardless of where in the system the component is located for LGCWS LSA-02.

2. Fault tree analysis concept

The fault tree analysis method was originally developed for the analysis of security systems for the launch of rockets "minuteman" for the purposes of the air force of the United States. The creator of this method is Watson from the company "Bell Telephone Laboratories" (Popovi & Gligorijevi, 2013).

FTA is a top-down deductive analysis in which the causes of an event are deduced. It gives a visual model of how equipment failure, human error, and external factors have contributed towards an accident or event. It uses logical gates and small events to present the path of an accident through different steps, and hence a fault tree is constructed for the particular event. The technical failures can be represented as basic events, while human errors can be represented as intermediate events that may intensify to become a technical failure (Baig, Ruzli, & Buang, 2013).

A deductive model resolves the causes for an event. Before the causes can be resolved, the undesired event must be defined first. The number of undesired events is only one. The undesired event will be resolved into immediate causal events. The undesired event is related to the causal events by using appropriate logic. The immediate causal events will be resolved further into the basic causes. The FTA is a logical diagram that showing the logical relationships between the undesired event and basic causes in deductive approaches. Figure 2-1 shows the schematic of deductive approaches.

Figure 2-1: The Style Box.

The main function of FTA is identifying causes of a failure. After the failure is known, the weakness of the system also can be investigated. Then, based on those results, the design of the system can be modified to increase reliability and safety. The other functions of FTA are identifying the effect of human errors on the system, developing the tests and maintenance procedure of the system, and reduce the system price by modifying the system design.

In the FTA, the important point is defining precisely the failure mode of the system. The FTA will produce the fault tree. Figure 2-2 shows the schematic of the fault tree. The fault tree will consist of Top event, logic gate, intermediate events, and basic events.

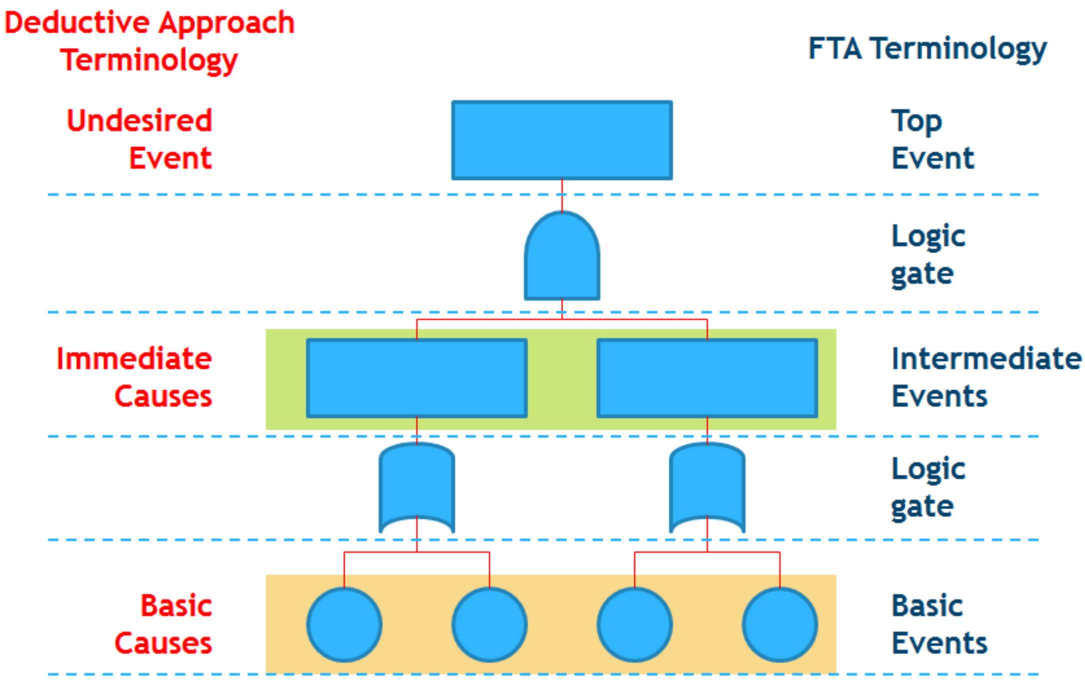
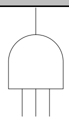
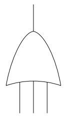
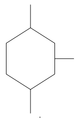
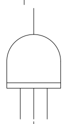
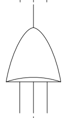
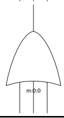


Figure 1-2: The fault tree schematic

The logic gate expresses the causal relation between events and consists of 6 types of gates. Table 2-1 shows the explanation of the causal relation of the logic gate.

Table 2-1: the causal relation of logic gate

Gate symbol	Gate name	Causal relation
	AND gate	Output event occurs if all input events occur simultaneously
	OR gate	Output event occurs if any one of the input events occurs
	Inhibit gate	Input produces output when a conditional event occurs
	Priority AND gate	Output event occurs if all input events occur in the order from left to right.
	Exclusive OR gate	Output event occurs if one, but not both, of the input events occur
	m-out-of-n gate	Output event occurs if m-out-of-n input events occur

3. Landing gear control and warning system description

The LSA-02 aircraft will use Stemmed S15 aircraft as a basis. This aircraft has a retractable tricycle configuration landing gear with a steerable nose gear. The mechanism for retraction and extension of landing gear are driven hydraulically. The hydraulic actuator is used for the extension and retraction of landing gear legs. The main and nose landing gears are driven by a separate hydraulic actuator. The hydraulic system for actuation is pressurized by a hydraulic drive unit, installed in the rear section of the center fuselage steel-frame. The unit consists of the electrically powered hydraulic pump, including a controller for the pressurization of the complete hydraulic system and a pressure reservoir (or pressure accumulator) for an emergency extension of the main and nose landing gear.

In the extended end position, the supporting struts of the nose and main landing gear legs are secured by a deadlock blocking and additional springs independent from hydraulic pressure. The extension and retraction are operated by one combined lever switch for the nose and main landing gear. The switch is located in the area of the control elements of the instrument panel on the left side of the propeller pitch control unit.

The lever switch provides two settings, which are UP and DOWN positions. In the UP position, the landing gear will be in RETRACT condition; while in the DOWN position, the landing gear will be in EXTEND condition.

The landing gear control and warning system will provide control and warning functions. The control function in the landing gear control and warning system gives the pilot the ability to control the landing gear condition. There are two possible conditions of landing gear condition, extending or retracting. The control function is done by controlling the rotation direction of DC motor inside the hydraulic pump as the hydraulic pump is connected directly to the hydraulic actuator, which is attached on the landing gear. The warning function in the landing gear control and warning system gives the pilot information about the landing gear status and warns the pilot if landing gear does not extend whenever is needed. The warning function is done by turning on the LED indicator in the cockpit. The LED will turn on, depending on the position of landing gear and airbrakes. There are three possibilities of LED which are:

Each landing gear LED is turned on with one continuous green light. This LED status happens when each landing gear is extended, then locked, and the airbrake is extended.

Each landing gear LED is turned on with one continuous red light. This LED status happens when the hydraulic pump motor is running, and the landing gear legs are moving.

Each landing gear LED is flashing red light, and the interrupted horn signal is sound. This LED status happens if only one landing gear is not extended or extended but not locked.

The landing gear control electronic circuit is connected to the landing gear lever switch in the cockpit. The main function of the landing gear control electronic circuit is controlling the direction of rotation from the electric motor inside the hydraulic pump. The hydraulic fluid flow direction depends on the rotation of the electric motor. If the landing gear lever in the cockpit is in the UP position, then the electric motor rotates in a clockwise (CW) direction. Therefore, the hydraulic pump puts the landing gear in the retracted position. On the contrary, the landing gear will be in an extended position if the electric motor rotates in a counter-clockwise (CCW) direction.

The landing gear control electronic circuit is consists of three main circuits, which are: [1] Protection circuit for input, [2] Logical IC to process the electric signal and decide a decision from that, and [3] H-Bridge circuit to determine the rotation direction of an electric motor inside the hydraulic pump. Figure 3 shows the electrical circuit for landing gear control.

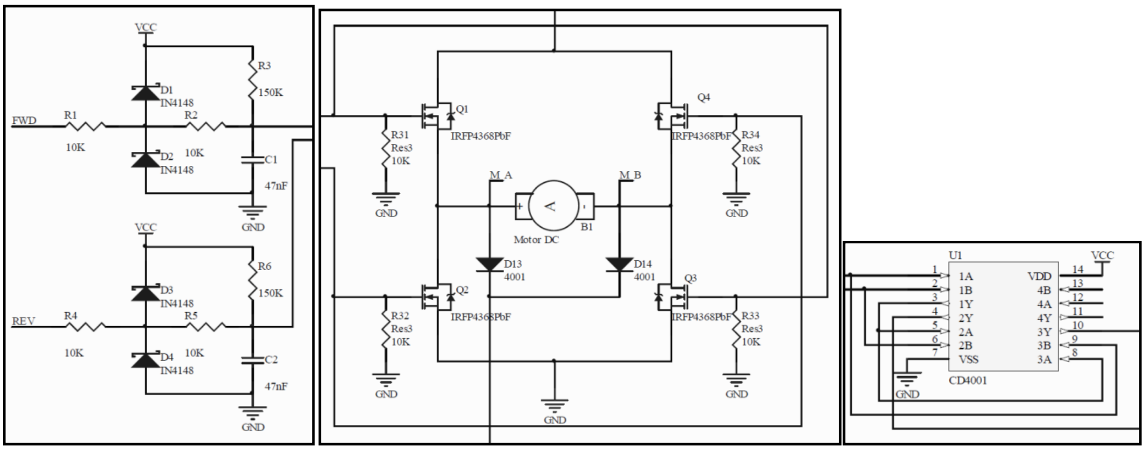


Figure 2-1: Electrical circuit for landing gear control, from left to right: protection circuit, H-bridge circuit, logical IC circuit (Author's personal document)

The example of how the system in Figures 3-1 work is described as follows. Whenever the landing gear lever which is located in the cockpit is in the down position, the landing gear control electrical circuit rotates the DC motor in the H-Bridge circuit to a clockwise direction. The logical IC circuit is responsible for controlling the electrical signal flow before entering the H-bridge circuit. The protection circuit is responsible for securing the input signal from the "spike".

The landing gear warning electrical circuit is conducted two main tasks generates warning tone and LED flashing signal. The landing gear warning tone signal generator electrical circuit is consists of three main circuits, which are: [1] Protection circuit for input, [2] Logical IC to process the electric signal and decide a decision from that, and [3] circuit to generate the warning tone. The landing gear LED flashing signal generator electrical circuit also consists of three main circuits, which are: [1] voltage sensing circuit, [2] voltage regulation circuit, and [3] protection circuit. Figures 3-2 and 3-3 show the electrical circuit for landing gear warning.

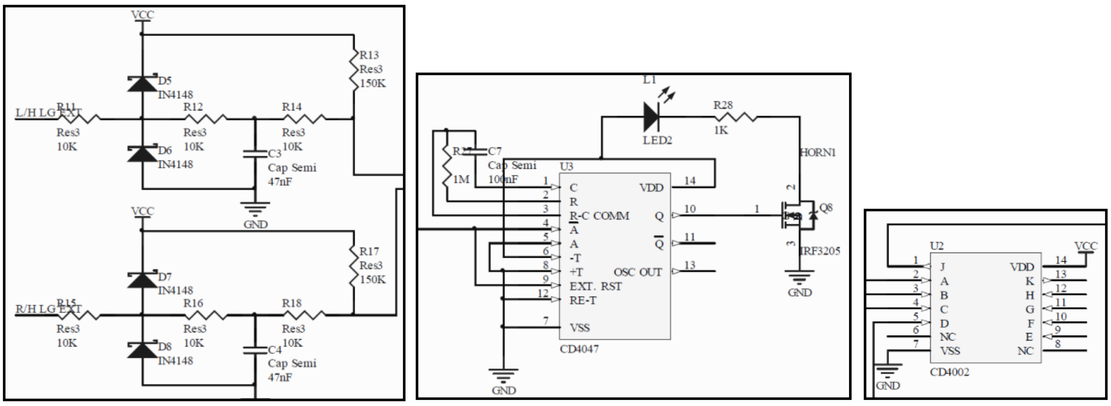


Figure 3-2: Electrical circuit for landing gear warning (warning tone signal generator), from left to right: protection circuit, warning tone signal generator circuit, logical IC circuit (Author’s personal document)

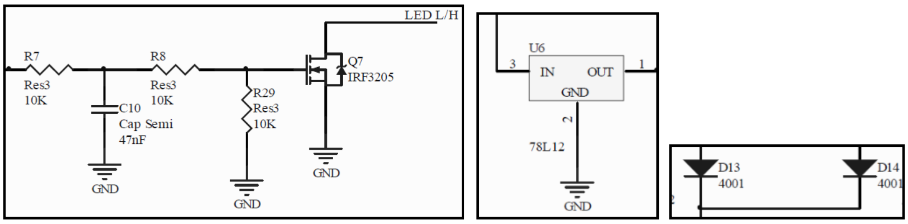


Figure 3-3: Electrical circuit for landing gear warning (LED flashing signal generator), from left to right: protection circuit, voltage regulator circuit, voltage sensing circuit (Author’s personal document)

The example of how the system in Figures 3-2 works is described as follows. Whenever the landing gear lever, which is located in the cockpit, is in the down position, the logical IC circuit checks the input signal from the protection circuit for landing gear (main + nose) and the air break. This circuit should generate tone during the extended process of the landing gear. If all three landing gear is extended and lock plus air brake is deployed, the warning tone stops sounding.

The example of how the system in figure 3-3: works is described as follows. The voltage sensing circuit will sense the voltage from the H-Bridge circuit to determine the landing gear status. Whenever the landing gear lever which is located in the cockpit is in the down position, the voltage sensing circuit provides the signal logic for LED to light up Continuous red light on all three landing gear LED, if the hydraulic pump motor is running and the landing gear legs are moving. After the landing gear is fully extended and locked, the voltage sensing circuit provides the signal logic for LED to light up a continuous green light for each landing gear LED.

4. Fault tree analysis of the landing gear control and warning system Preparation

In the preparation phase, the top event and the system boundary must be defined. The top event for this system is: landing gear not extended or warning system is failed to operate when the lever in the down position. The system boundary is: the circuit containing the DC Motor, resistor, capacitor, Zener, voltage regulator, IC NOR, IC signal generator, and Mosfet. The initial state of the system is: landing gear is in retract position due to landing gear lever in the cockpit is in up position.

Fault Tree Structure - Top Level

The fault tree structure on top-level contains the top event description and what is the cause of the top event. Figure 4-1 show the fault tree top-level structure

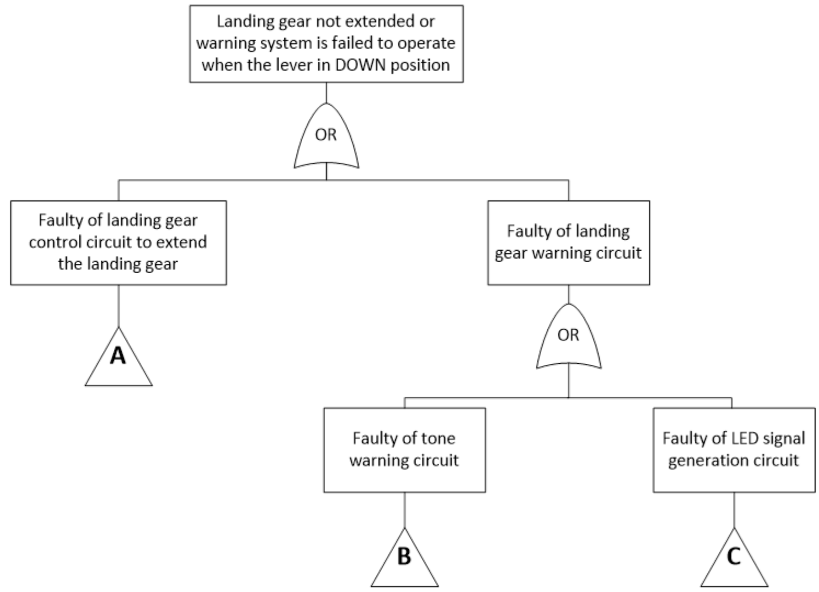


Figure 4-1: fault tree structure – top level

Fault Tree Structure in A Level

The fault tree structure in A level identifies the cause of landing gear control circuit fault. Figures 4-2 show the relationship between basic event and intermediate event in A level.

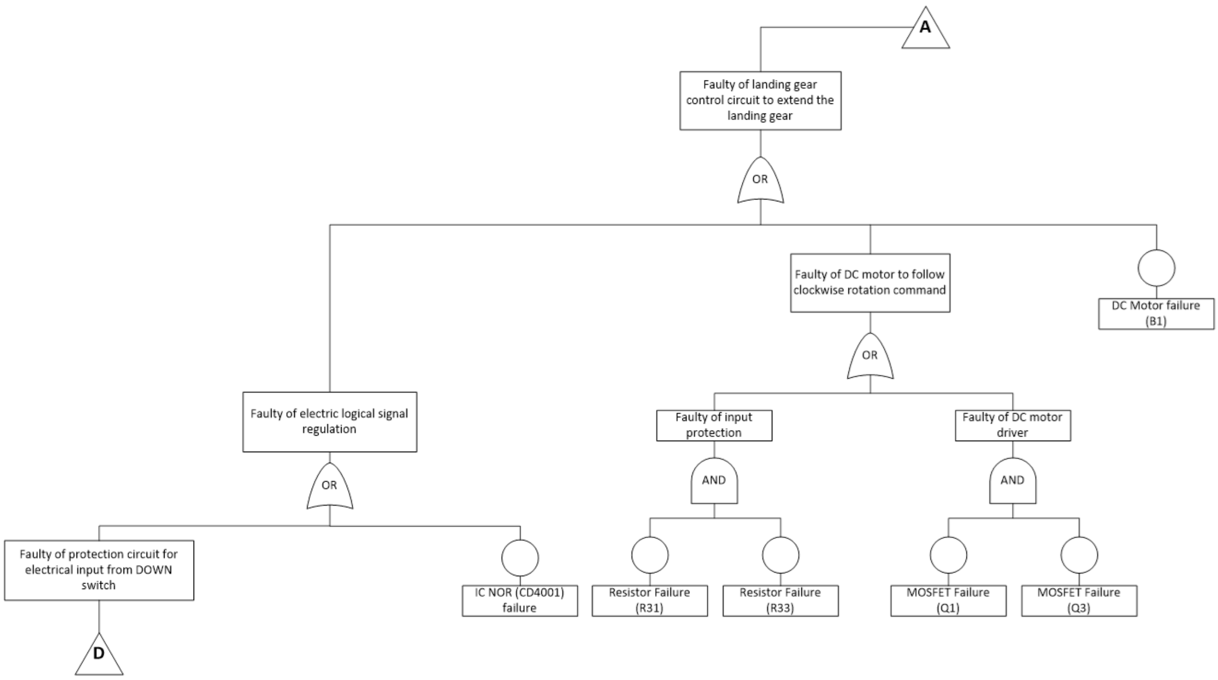


Figure 4-2: fault tree structure – A level

Fault Tree Structure in B Level

The fault tree structure in B level identifies the cause of landing gear warning tone generator circuit fault. Figure 4-3 show the relationship between basic event and intermediate event in B level.

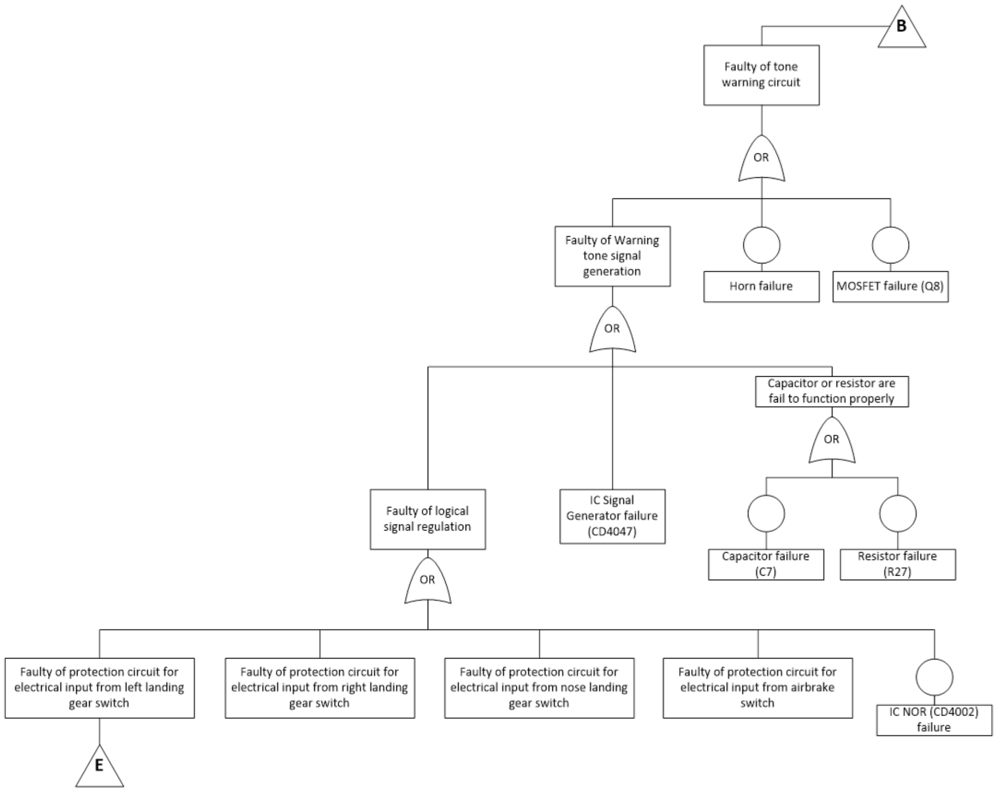


Figure 4-3: fault tree structure – B level

Fault Tree Structure in C Level

The fault tree structure in D level identifies the cause of landing gear LED flashing signal generator circuit fault. Figure 4-4: show the relationship between basic event and intermediate event at C level.

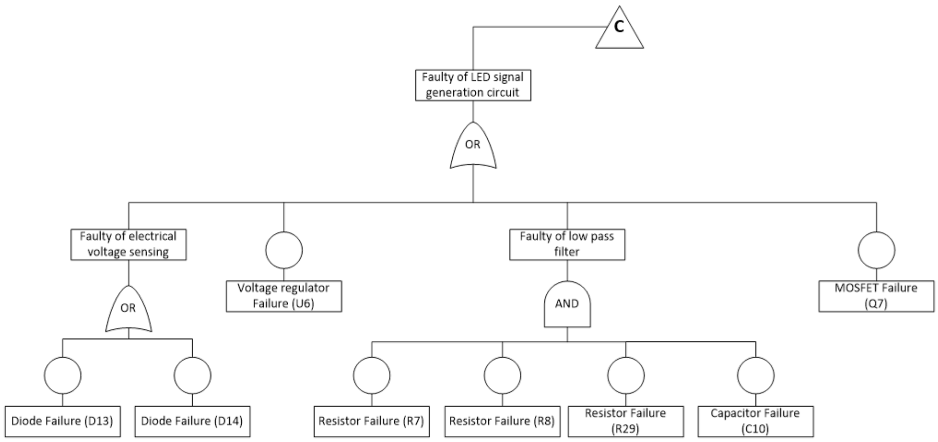


Figure 4-4: fault tree structure – C level

Fault Tree Structure in D Level

The fault tree structure in D level identifies the cause of protection circuit fault inside the landing gear control circuit. Figure 4-5 show the relationship between basic event and intermediate event in D level.

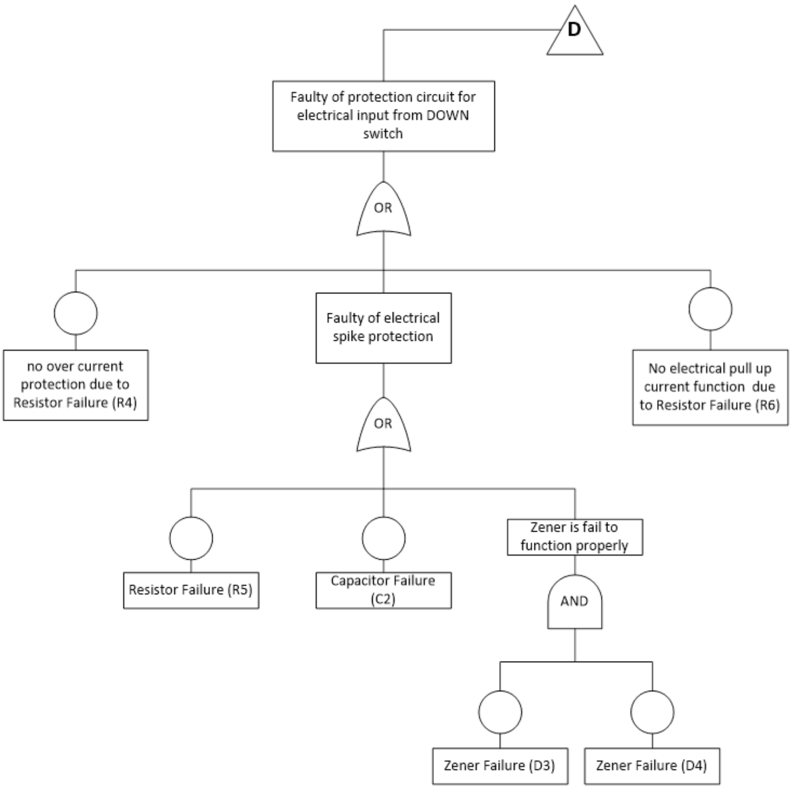


Figure 4-5: fault tree structure – D level

Fault Tree Structure in E Level

The fault tree structure in E level identifies the cause of protection circuit fault inside landing gear warning tone generator circuit. Figure 4-6 show the relationship between basic event and intermediate event at E level.

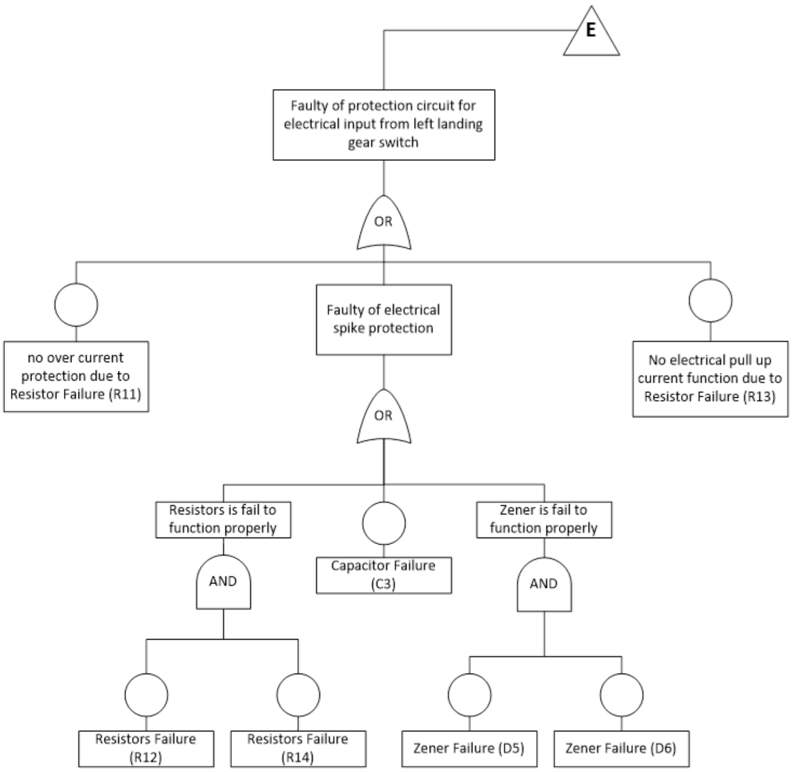


Figure 4-6: fault tree structure – E level

Table 4-1 Causes factor lead to failures of LGCWS

Failures Event	Landing gear not extended	Warning system failed to operate	
Causes factor failures	DC Motor (B1)	Zener (D5)	Zener (D13)
	Zener (D3)	Zener (D6)	Zener (D14)
	Zener (D4)	Resistor (R11)	Voltage Regulator (U1)
	Capacitor (C2)	Resistor (R12)	Mosfet (Q7)
	Resistor (R4)	Resistor (R13)	Mosfet (Q8)
	Resistor (R5)	Resistor (R14)	Capacitor (C3)
	Resistor (R6)	Resistor (R7)	Capacitor (C7)
	Resistor (R31)	Resistor (R8)	Capacitor (C10)
	Resistor (R33)	Resistor (R27)	Horn
	Mosfet (Q1)	Resistor (R29)	
	Mosfet (Q3)	IC NOR (CD4001)	
	IC NOR (CD4001)	IC TONE (CD4047)	

Table 4-1 summarizes the causes factors that led to the failures of LGCWS. According to pictures 4-1, two failures can lead to the failure of LGWCS, they are landing gear not extended, or warning system failed to operate. The event of landing gear not being extended had 12 causes factors of component failures, while the warning system failed to operate had 21 causes factors of component failures..

5. Conclusions

In the initial version of the fault tree structure for Landing gear control, the warning system is developed successfully. The fault tree structure identifies the undesired event for this system: landing gear not extended, and the warning system fails to operate when the lever is in the down position. We analyzed causes that led to landing gear not extended and the warning system was failed to operate. We summarize that 12 cause factors led to landing gear not extended, and 21 cause factors led warning system is failed to operate when the lever in the down position. The future works is carried out the unavailability quantification of the system and optimize the circuit design to increase the system reliability.

Acknowledgements

This research was conducted in the project LSA-02. The author thanks to Mr. Gunawan Setyo Prabowo for the support and opportunity given to the writer. The contents of this paper are authority of the authors and Pustekbang-LAPAN.

Contributorship Statement

Each author has an equal contribution to the manuscript.

References

Ahn, Y. J., Yu, Y. U., & Kim, J. K. (2021). Accident cause factor of fires and explosions in tankers using fault tree analysis. *Journal of Marine Science and Engineering*, *9*(8). https://doi.org/10.3390/jmse9080844

Alkhaledi, K., Alrushaid, S., Almansouri, J., & Alrashed, A. (2015). Using fault tree analysis in the Al-Ahmadi town gas leak incidents. *Safety Science*, *79*, 184–192. https://doi.org/10.1016/j.ssci.2015.05.015

Baek, S., & Heo, G. (2021). *Application of Dynamic Fault Tree Analysis to Prioritize Electric Power Systems in Nuclear Power Plants*. https://doi.org/10.3390/en14144119

Baig, A. A., Ruzli, R., & Buang, A. B. (2013). Reliability Analysis Using Fault Tree Analysis: A Review. *International Journal of Chemical Engineering and Applications*, *4*(3), 169–173. https://doi.org/10.7763/ijcea.2013.v4.287

Ding, X., Huang, Q., Zhu, H., Hu, H., & Liu, Z. (2017). Subway Tunnel Disease Associations Mining Based on Fault Tree Analysis Algorithm. *Mathematical Problems in Engineering*, *2017*. https://doi.org/10.1155/2017/2621493

Jiang, G. J., Li, Z. Y., Qiao, G., Chen, H. X., Li, H. Bin, & Sun, H. H. (2021). Reliability Analysis of Dynamic Fault Tree Based on Binary Decision Diagrams for Explosive Vehicle. *Mathematical*

Problems in Engineering, *2021*. https://doi.org/10.1155/2021/5559475

Kais Brik; F Ben Ammar. (2008). The Fault Tree Analysis of the Lead Acid Battery's Degradation. *Electrical System*, *4*(2), 1–12.

Kang, F. S., & Song, S. G. (2021). Life-cycle expectation using fault-tree analysis for improved hybrid submodule in HVDC system. *Electronics (Switzerland)*, *10*(2), 1–20. https://doi.org/10.3390/electronics10020133

Kornecki, A. J., & Liu, M. (2013). Fault tree analysis for safety/security verification in aviation software. *Electronics* , *2*(1), 41–56. https://doi.org/10.3390/electronics2010041

Li, S., Yang, Z., Tian, H., Chen, C., Zhu, Y., Deng, F., & Lu, S. (2021). Failure analysis for hydraulic system of heavy-duty machine tool with incomplete failure data. *Applied Sciences (Switzerland)*, *11*(3), 1–18. https://doi.org/10.3390/app11031249

Mahfoud, H., Elbarkany, A., & Elbiyaali, A. (2014). Estimation of failure probability of B737 pneumatics system by fault tree analysis. *Advances in Engineering Mechanics and Materials*, *2*(4), 309–312.

Markulik, S., Šolc, M., Petrík, J., Balážiková, M., Blaško, P., Kliment, J., & Bezák, M. (2021). Application of fta analysis for calculation of the probability of the failure of the pressure leaching process. *Applied Sciences (Switzerland)*, *11*(15). https://doi.org/10.3390/app11156731

Mou, J., Jia, X., Chen, P., & Chen, L. (2021). Research on Operation Safety of Offshore Wind Farms. *Journal of Marine Science and Engineering*, *9*(8), 881. https://doi.org/10.3390/jmse9080881

Popovi, B., & Gligorijevi, J. (2013). Analysis of causes and modes of failure of air conditioner and DC electric - ventilator, as parts of Automotive Air Conditioning System. *International Journal of Engineering and Applied Sciences*, *4*(1), 40–48.

Samuel, I. A., Awelewa, A. A., Katende, J., & Odigwe, I. A. (2013). *Fault Tree-Based Reliability Assessment of a 132-kV Transmission Line Protection Scheme*. (10).

Schweitzer, E. O., & Anderson, P. M. (1997). Reliability analysis of transmission protection using fault tree methods. *Proceedings of the 24th Annual Western Protective Relay*, (October 1997), 1–17. Retrieved from http://www.selinc.com.br/art_tecnicos/6060.pdf

Shafiee, M., Zhou, Z., Mei, L., Dinmohammadi, F., Karama, J., & Flynn, D. (2021). Unmanned aerial drones for inspection of offshore wind turbines: A mission-critical failure analysis. *Robotics*, *10*(1), 1–27. https://doi.org/10.3390/robotics10010026

Takahashi, M., Anang, Y., & Watanabe, Y. (2020). A proposal of fault tree analysis for embedded control software. *Information (Switzerland)*, *11*(9). https://doi.org/10.3390/INFO11090402

UKEssays. (2017). FTA of Main Landing Gear Systems. Retrieved from https://www.ukessays.com/essays/engineering/fta-of-main-landing-gear-systems.php?vref=1

Yuan, C., Cui, H., Tao, B., & Wang, W. (2018). Fault Tree Analysis for Emergency Process of Fire Accident in Oil-Gas Storage and Transportation. *Journal of Hazardous, Toxic, and Radioactive Waste*, *22*(3), 04018011. https://doi.org/10.1061/(asce)hz.2153-5515.0000402