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A study on optimizing the electrical load analysis for modifying the avionics equipment in an aged aircraft

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Abstract

In the management of aged aircraft, used avionics equipment is replaced with new ones to improve the performance and extend the life cycle of the aircraft. In this case, considering airworthiness, it is necessary to check whether the aircraft has sufficient electricity in the electric generator or the electrical distribution system, in accordance with the maximum electricity consumption of the new avionics equipment. Accordingly, this paper reviews a few airworthiness standards and guidelines associated with the electrical load analysis when an avionics equipment is upgraded in an aged aircraft, and proposes an optimization method for the electrical load analysis. In addition, it verifies the validity of the proposed method via the QFD theory, and is currently available for upgrading the performance of aged aircraft.

Key Words : Electric Load Analysis Optimization Method, Avionics Equipment, Aged Aircraft, Aircraft Performance Upgrade

1. Introduction

When replacing or installing avionics equipment to improve the performance of an aging aircraft and extend its life cycle, the new or installed equipment must be connected to the existing power system of the aircraft. At this point, it is necessary to determine whether the new or installed avionics equipment can be operated within the power capacity of the aircraft generator, considering the airworthiness of the aircraft via the electric load analysis (ELA).

This study defines two ELA method for an aircraft: the bottom-up method, which is an analytical approach to designing aircraft system, and the top-down method for aircraft modification. First, the bottom-up ELA method is a method of analyzing the amount of available margin, based on the maximum power consumption of the aircraft generator's power capacity, which is calculated by examining all maximum power consumption data for each operating condition of the aircraft, and for each load time of numerous avionics equipment, according to the US military specification, MIL-E-7016F [1], as illustrated in Fig. 1. This bottom-up analysis method is adopted when designing the entire aircraft generator capacity during aircraft system development, which requires the design source data related to power consumption for each avionics equipment, provided by the aircraft manufacturer. Fig. 1 is a conceptual diagram that illustrates the design of the aircraft power system in a very simplified manner, excluding details such as wiring route design and electrical component selections, considering military regulations related to electrical system installation and airworthiness certification standards. There have been cases in South Korea where such an aircraft system design was applied to the design and manufacture of military aircraft [2], as well as other cases where unmanned aerial vehicles were applied [3].

Second, the top-down ELA method is applied when modifying an aircraft. This method aims at verifying that no problem exists with the operation

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of new avionics equipment within the permissible capacity of the converter or inverter in the power bus of the existing generator of the aircraft. Although this top-down approach also follows MIL-E-7016F, it is significantly simpler than the bottom-up method applied in aircraft system design, as illustrated in Fig. 2. Specifically, it is performed by examining the permissible capacity of the converter in the power bus of the existing aircraft power system, and by analyzing whether the maximum power consumption (load) value of the new avionics equipment to be installed can be operated within the power capacity of the converter. Nevertheless, in general, the manufacturer does not provide the design source data for each avionics device with the release of an aircraft. Because it is impossible to apply the aforementioned bottom-up ELA method to the modification of an aged aircraft, the second top-down ELA method is generally applied.

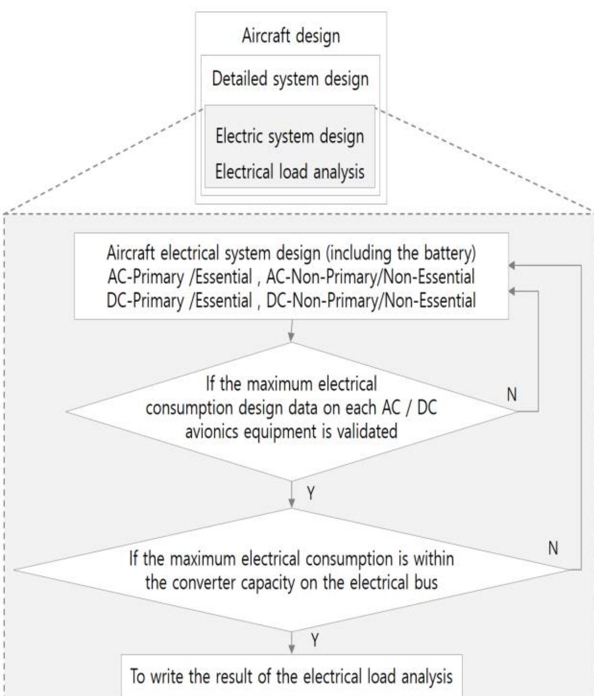

Fig. 1 Bottom-up method of the electric load analysis

However, even with this top-down method, practical difficulties emerge when applying all of the aircraft operating conditions according to MIL-E-7016F during the actual on-site aircraft modification.

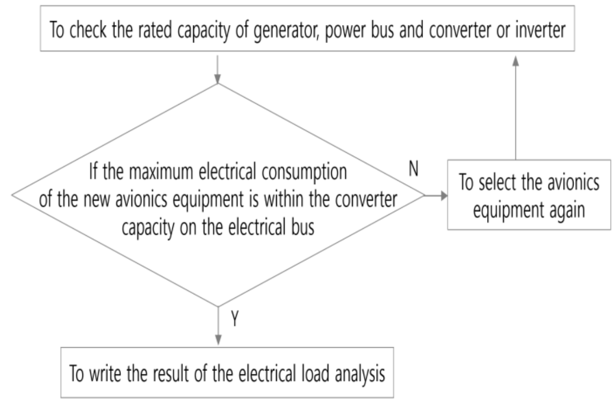

Fig. 2 Top-down method of the electric load analysis

First, although most of the modification work is carried out in the garage, to start the engine, the aircraft must be moved to a hangar or another place where the engine can be started, according to the procedures and regulations requiring cooperation with related organizations and departments beforehand, as well as compliance with safety guidelines. Second, it may be necessary to conduct flight tests without acquiring airworthiness certification after observing possible influencing factors after installing the new avionics equipment in the aircraft, although the mounted equipment may have already passed the applicable tests based on the US military standards, such as the MIL-STD-810G environmental engineering considerations and laboratory tests against conditions that include vibration, temperature, altitude, humidity, lightning, falling water, as well as complex environments [4], the MIL-STD-461G electromagnetic compatibility test [5], and MIL-STD-704F aircraft electrical power characteristics test [6]. To address this paradoxical problem, a temporary special airworthiness certification system [7] has been introduced. Nevertheless, it also requires essential planning and managing the active participation of numerous stakeholders and required time for processes, including the creation of the review data on the verified test results, review by related institutions, including government agencies, and revisions after review, a complex approval process, selection and approval of applicable aircraft based on the mission of the aircraft, and pre-flight maintenance. If a required test has not been performed, the task of performing the test should be included to the list of tasks after arranging the test site, schedule, and procedure, which may also be followed by certain tasks, including the scheduling of a review. This makes it impossible to meet the entire project schedule for modification, such as flight test schedules. Accordingly, this study attempted to address the practical difficulties of applying these aircraft operating conditions to the top-down analysis for the modification and installation of new avionics equipment in an aged aircraft by devising an optimization method for ELA that can be adopted on site.

2. Body

2.1 Related Case Studies

As an overseas study related to the optimization of ELA proposed in this study, a study [8] on the Design Data Sheet (DDS) 310-1 Revision 1, a guideline for the power capacity analysis method when selecting the capacity and size of a generator in the design of a surface ship for the US Navy. After checking the data measured for loads sensitive to environmental conditions, such as an electrical load list and temperature, as a guideline for selecting a generator for a naval surface ship, modeling and simulation analysis, as well as stochastic load analysis, are performed to analyze load factors. Based on the analysis results, a more detailed zonal load factor analysis, quality of service load analysis, required load factor analysis, and 24-hour average load analysis are performed as guidelines for selecting a power converter and transformer. This is a study related to the capacity selection of generators applied to the design of naval surface ships, which deals with the conventional bottom-up analysis method described in the introduction. This method is not suitable for the modification and installation of new avionics equipment on an aged aircraft. The ELA for selecting the generator of the power system is not appropriate, as the aircraft for modification is in operation with the already verified power system components.

As a representative domestic aircraft ELA study, a study [3] exists on the design of the electrical system of an unmanned aerial vehicle through ELA. This study analyzes the loads of AC and DC generators, including batteries under five UAV operating conditions from the ground to takeoff, cruising, and landing after the ground inspection. Subsequently, the design of the electrical system is verified by performing the final flight test. This study case is also a bottom-up design study that analyzes power data for avionics equipment mounted on an unmanned aerial vehicle, based on MIL-E-7016F. Several other studies are related to the load analysis applied to aircraft design; however, there is an insufficiency in the availability of studies on the optimization of ELA performed during modification.

2.2 Review of Application Criteria for Electrical Load Analysis

The standard applied to ELA for a military aircraft is the US military specification MIL-E-7016F, which specifies the report format of ELA, as presented in Table 1.

Table1 MIL-E-7016F Electric Load Analysis Report [1]

Chapter	Details
I. Title	Title of the report
II. Table of contents	Table of contents
III. Introduction	A. Mission statement (optional) B. Operating Conditions C. Electric Bus Wiring Diagram D. Description of Electric System Operation E. Generator Mounting and Drive Data F. Power Source Output Data
IV. AC Load Analysis	A. Connected Load Chart B. Load Analysis Chart C. Transient Analyses D. Power Source Utilization Analysis Chart E. Power Source Utilization Graph F. Adjusted Power Source Graph
V. DC Load Analysis	A. Connected Load Chart B. Load Analysis Chart C. Transient Analyses D. Power Source Utilization Analysis Chart E. Power Source Utilization Graph F. Adjusted Power Source Graph G. Battery Analysis
VI. Starting Load Data	A. Engine Starting Requirements Data B. Starting Power Source Data

VII. Ground Power Analysis	Ground Power Analysis
VIII. Summary and Conclusion	Summary and Conclusion A. Summary of System Analysis B. Conclusions
IX. Notes	Notes

According to Table 1, the ELA for an aircraft should be prepared in a report by analyzing the power consumption of the generator for all operating conditions of the aircraft. Based on MIL-E-7016F, there are 10 aircraft operating conditions, which include:

G1	Ground Maintenance
G2	Calibration
G3	Loading and Preparation
G4	Start and warm up
G5	Taxi
G6	Take off & Climb
G7	Cruise
G8	Cruise combat
G9	Landing
G10	Emergency

As another ELA standard, the US ASTM International set up the Standard Guide for Aircraft Electrical Load and Power Source Capacity Analysis, F2490-05 [9], as presented in Table 2. In ASTM F2490-05, the procedure and calculation method for analyzing the electrical load, considering the electrical load time of the avionics equipment are comprehensively presented, according to the operating conditions of the aircraft, with reference to the provisions of 14 CFR Part 23 Normal Category Airplanes, the Aeronautics and Space Airworthiness Standards of the Federal Aviation Administration (FAA). However, unlike MIL-E-7016F, ASTM F2490-05 presents a guide that describes all assumptions and design criteria of avionics equipment.

Table 2 ASTM F2490-05 Report [9]

Chapter	Details
1.Introduction	. Brief description of aircraft type . Electrical system operation . A copy of the bus wiring diagram or electrical schematic. . Generator, alternator, and other power source description and related data . Operating logic of system . List of installed equipment
2. Assumptions and Criteria	. Most severe loading conditions and operational environment . Momentary/intermittent loads . Motor load demands are shown for steady-state operation and do not include starting inrush power . Intermittent loads such as communications equipment . Maximum continuous demand of the electrical power system . Cyclic loads such as heaters, pumps, and so forth(duty cycle) . Estimation of load current, assuming a voltage drop between bus bar and load.
3. Load Analysis-Tabulation of Values	Aircraft Bus, Condition of Power Sources, Aircraft Operating Phases, Permissible Non-serviceable Conditions, Circuit Breaker, Load at Circuit Breaker [Ampere], Operating Time, Condition of Aircraft Operation
4. Emergency and Standby Power Operation	. Where standby power is provided by non-time-limited sources, the emergency loads should be listed and evaluated, such that the demand does not exceed the capacity of the standby power source. . When a battery is used to provide a time-limited emergency supply, an analysis of battery capacity should be undertaken. . 5 Min of Electrical Power Requirement by 14 CFR 23.1351(g) . 30 Min of Electrical Power Requirement by 14 CFR 23.1353(h) . A review of aircraft operating rule equipment requirements . Calculation including battery capacity
5. Summary and Conclusion	. Summary : should provide evidence that for each operating condition, the available power can satisfy the loading requirements with adequate margin for both peak and maximum continuous loads. This should consider both the normal and abnormal (including emergency) operating conditions. For AC power systems, these summaries should include power factor and phase loadings. . Conclusion: should include statements that confirm that the various power sources can satisfactorily supply electrical power to necessary equipment during normal and abnormal operations under the most severe operating conditions, as identified in the analysis. : should confirm that the limits of the power supplies are not exceeded

In addition, the European Union Aviation Safety Agency (EASA) provides an electrical load analysis report form [10], based on the ASTM standard F2490-05, where it is recommended to describe the normal, abnormal, and emergency conditions of the aircraft separately. The format for this is presented in Table 3.

Table 3 EASA Electric Load Analysis Report [10]

Chapter	Details
0. Introduction	Objections
1. References	Certification Program, FAA Advisory Curricular, AC43.13, ASTM F2490-05
2. Abbreviations	Aircraft equipment abbreviations
3. List of requirements	Requirements of the electric load analysis such as ASTM F2245-12d, ASTM F2490-05
4. Electrical System General Description	General Description of the electrical system such as primary DC electrical source, electrical schematic diagram, including battery, etc.
5. Load Analysis	
5.1 Electrical power sources	Summary about all the electrical power sources by tabulation
5.2 Analysis	Electrical consumption (electrical current rates) analysis
5.3 Emergency conditions assessment	Calculation of the battery consumption
6. Compliance statements	Compliance Statements along with the requirements

The application criteria in terms of aircraft airworthiness certification related to ELA is the Standard Airworthiness Certification Criteria (Part 1) [12] following the US Department of Defense Handbook: Airworthiness. Certification Criteria, MIL-HDBK-516C [11].

Table 4 Airworthiness Standards Criteria [12]

Chapter	Criterion
12.1.1 Power quantity	Verify that sufficient power is available to meet the power requirements during all modes of operation, mission profiles, failure conditions, and malfunction recovery procedures. Verification of sufficient power requires the consideration of all sources, and includes the evaluation battery rate(s) of discharge.

As presented in Table 4, it is necessary to ensure that sufficient power is available to satisfy the power requirements during all modes of operation, mission profiles, failure conditions, and malfunction recovery procedures in Subsection 12.1.1 Power Quantity of Section 12.1 Electrical System. Even for commercial aircraft, the power generation capacity, as well as the number and type of the electrical power sources, should be determined according to ELA, as stipulated in Subsection 25.1351 General Standards on Electrical System and Equipment under Section 25 Technical Standards for Airplanes with Airworthiness Classification of Transport (T) in the Korean Airworthiness Standards (KAS) by the Ministry of Land, Infrastructure and Transport [13]. In addition, the Ministry of Land, Infrastructure and Transport Ordinance No. 879 Guidelines for Approval of Repair and Modification of Aircraft, etc. [14] states that ELA data must be submitted according to the repair and modification approval checklist in the attached Table 3, with no specific mention of the ELA data format and procedure.

Table 5 KAS(Korean Airworthiness Standards) 25.1351 General Standards on Electrical Systems and Equipment of [13]

Chapter	Standards
25.1351 General	(a) Electrical system capacity : The required generating capacity, and number and kinds of power sources must. (1) Be determined by an electrical load analysis

2.3 Optimization Method for ELA

Optimization of ELA to apply the modification of aged aircraft follows up the report format of MIL-E-7016F, which has been adopted as the standard for the ELA of military aircraft, but it performed via the simulation of the maximum load during aircraft missions, not to all of the operating condition of the aircraft.

The procedure carried out as shown in Fig. 3, and the format of the ELA report is presented in Table 6.

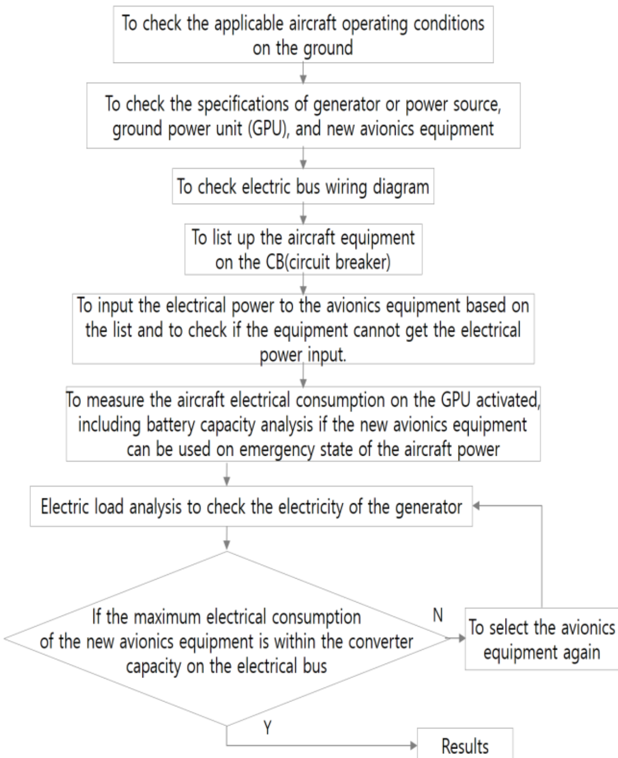

Fig. 3 Proposed procedure for the optimization method of the electric load analysis

Table 6 Proposed Electric Load Analysis Report

Chapter	Details
1. Title	The title of this document
2. Contents	Table of Contents
3. Introduction	The standards and guideline names, main mission of the aircraft and the object of the electric load analysis, and aircraft electrical system for the electric load analysis, including the battery if needed
4. Electric load analysis	A. The required aircraft operating conditions and assumptions for this document. B. Specification: Generator, Power sources, GPU(Ground Power Unit), New avionics equipment, including battery if the avionics equipment is connected to the battery bus C. Aircraft electrical wiring diagram and avionics equipment D. Electric load analysis-including battery capacity analysis if the avionics equipment can be used in the emergency state of the aircraft power
5. Conclusion	Electrical power capacity description for aircraft maximum power electricity based on the result of the electric load analysis

As illustrated in Fig. 3, first, the aircraft operating conditions, which can be simulated relative to the aircraft operation without starting the engine under the G1 non-operating ground static condition, are examined. Because the engine does not start, detailed systems related to engine starting, specifically fuel, hydraulic, and landing gear systems, cannot be operated. This limitation is imposed as the avionics equipment is turned on and operated solely by external power input for maintenance, under the G1 ground condition. The aircraft operating conditions from G3 to G10 that can be simulated are examined via this process. Next, the power source of the aircraft and the power specifications of the avionics equipment to be newly installed are examined. Because the new avionics equipment replaced in the cockpit to improve aircraft mission performance generally uses DC bus power, it is described based on the avionics equipment connected to the DC bus in this study. Once the power specifications of the aircraft and new avionics equipment are identified, the power system diagram of the aircraft is examined based on the technical data of the aircraft. This is an essential and important task in modifying an aged aircraft, as it is impossible to connect it to the circuit breaker (CB) panel, which must be passed through in the aircraft, without checking the wiring schematic diagram for the interconnected bus when installing or adding the new avionics equipment. If the new avionics equipment is operated in conjunction with the battery in case of an aircraft emergency, the connection with the battery should also be checked in the power system diagram. Next, while checking the power system diagram, the list of avionics equipment should be identified using the CB panel. When applying power to the external power GPU, consultation with the mechanic in charge of the aircraft based on this equipment list is required to determine the possibility of applying power to each avionics equipment. If power is not applied to each equipment on the list at this time, the reason should be specified. This is to record the measurement conditions for measuring current consumption. After checking all factors to be checked, the external power, GPU is applied to all available avionics equipme nt as checked previously. At this time, the current consumption of the GPU is measured using a current meter such as a clamp meter, which is measured as a value at which the changing current value is stabilized for a certain period of time and converges by measuring for 5 min longer. This current consumption measurement time is based on the continuous operation condition of MIL-E-7016F. In addition, it tends to exclude inrush current, which may be generated before and while performing the power-up built-in-test (PBIT) function after the aircraft avionics are powered on. The current consumption measured in this way must be within the rated power range of the generator, as the aircraft engine is not started. If the measurement result is out of the permissible power range, the aircraft engine should be started to measure all current consumption of the CB panel and ensure that there is no problem with the operating power of the aircraft. If the measurement result is within the permissible power range, the ELA is completed by checking whether the power margin ratio of the existing aircraft generator calculated by adding the maximum current consumption of the new avionics equipment to the measured current consumption is within the maximum power consumption capacity of the generator. If the new avionics equipment is connected to the battery in an emergency, the usable time of the battery is also calculated by measuring the battery current. In this case, the battery consumption time should allow an operation for at least 30 min as specified in the ROK Airworthiness Certification Criteria (Part 1) [12]. The power margin, which may vary depending on the aircraft type and mission, can be calculated, assuming a minimum of 15% margin, considering that up to 85% of the aircraft generator capacity is consumed under the maximum electric load as stipulated by the Advisory Circular [15] of the Civil Aviation Authority of New Zealand (CAA), or assuming a maximum of 30% margin, as it is usually required to have a margin of approximately 30% or more of the generator for aircraft manufacturing [2]. If the power margin is insufficient, it is necessary to trade off by either reselecting the new avionics equipment as the equipment that consumes less power or terminating the use of existing avionics equipment unnecessary for the mission. Based on the actual data measured according to the procedure in Fig. 3, the ELA report is created, as presented in Table 6.

2.4 Feasibility Review for Applying the ELA Optimization Method using QFD

Regarding the optimization method for ELA proposed in this study, it has been described that the standard for ELA, MIL-E-7016F, as well as ASTM F2490-05 and the EASA report format for ELA of commercial aircraft, are applied mutatis mutandis, as presented in Tables 7 to 10. Although the AC load analysis is excluded in Table 7, as it is not covered in this report, it can be applied in the same way as the DC load analysis in this study, provided the avionics equipment is connected to the aircraft AC bus. The engine start-related contents of the starting load data are excluded from the scope of this study because the G1 non-operating ground static condition not involving engine start is applied. The abbreviations in Table 9 and the compliance matrix are also excluded from the report in this study as they are considered non-essential.

Table 7 Compliance matrix with MIL-E-7016F

<table>
<tr><th>MIL-E-7016F</th><th>Optimization method for electric load analysis</th><th>Compliance</th></tr>
<tr><td>1. Title</td><td>1. Title</td><td>O</td></tr>
<tr><td>2. Table of Contents</td><td>2. Table of Contents</td><td>O</td></tr>
<tr><td>3. Introduction</td><td>3. Introduction
a. Applicable standard document
b. Aircraft mission and objection of electric load analysis
c. Aircraft electrical power condition including battery</td><td>O</td></tr>
<tr><td>4. AC Load Analysis</td><td rowspan="4">4. Electric Load analysis
a. Applicable aircraft operating conditions and assumptions
b. Generator or Power source specification
c. Ground Power Unit(GPU) specification
d. New avionics equipment electrical specification
e. Electric bus wiring diagram including avionics equipment list
f. Electric load analysis including</td><td>-</td></tr>
<tr><td>5. DC Load Analysis</td><td>O</td></tr>
<tr><td>6. Starting Load Data</td><td>-</td></tr>
<tr><td>7. Ground Power Analysis</td><td>O</td></tr>
</table>

	battery, if avionics equipment connects to the battery.	
8. Summary and Conclusion	5. Conclusion	O

Table 8 Compliance matrix with ASTM F2490-05

ASTM F2490-05	Optimization method for electric load analysis	Compliance
1. Title	1. Title	O
2. Table of Contents	2. Table of Contents	O
3. Introduction	3. Introduction a. Applicable standard document b. Aircraft mission and objection of electric load analysis c. Aircraft electrical power condition including battery	O
4. Assumptions and Criteria	4. Electric Load analysis a. Applicable aircraft operating conditions including assumptions	O
5. Load Analysis-Tabulation of Values	b. Generator or Power source specification c. Ground Power Unit(GPU) specification	O
6. Emergency and Standby Power Operation	d. Electrical specification of new avionics equipment e. Electric bus wiring diagram including avionics equipment list f. Electric load analysis including battery if avionics equipment connects to the battery.	O
7. Summary and Conclusion	5. Conclusion	O

Table 9 Compliance matrix with EASA Report

EASA Report	Optimization method of electric load analysis	Compliance
1. Title	1. Title	O
2. Table of Contents	2. Table of Contents	O
3. References	3. Introduction	O
4. Abbreviations	a. Applicable standard document	-
5. List of requirements	b. Aircraft mission and objection of electric load analysis c. Aircraft electrical power condition including battery	O
6. Electrical System General Description	4. Electric Load analysis a. Applicable aircraft operating conditions including assumptions	O
7. Load Analysis - Electrical power sources - Analysis - Emergency conditions assessment	b. Generator or Power source specification c. Ground Power Unit(GPU) specification d. Electrical specification of new avionics equipment electrical specification e. Electric bus wiring diagram including avionics equipment list f . Electric load analysis including battery if avionics equipment connects to the battery 5. Conclusion	O
8. Compliance		-

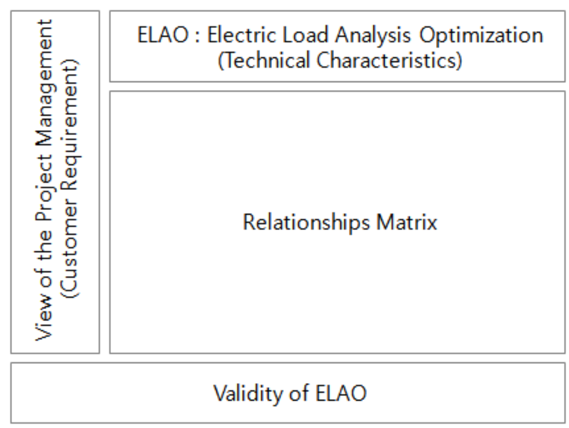

Fig. 4 QFD diagram for the validation of the electric load analysis optimization

In addition, the quality function deployment (QFD) theory [16, 17] was applied and analyzed in terms of project management [18] based on the sixth edition of the Project Management Body of Knowledge (PMBOK) guide. Fig. 4 presents the House of Quality (HOQ) model for the ELA optimization procedure proposed in this study via the QFD theory and the feasibility of applying the report. The correlation matrix of ELAO based on the HOQ of the QFD theory in Fig. 4 analyzes the correlation of ELAO itself. Because it was unnecessary, it was excluded from this analysis. In the QFD theory, analysis is carried out in four stages. Nevertheless, the analysis was performed in the first stage, as this study aims at performing the application feasibility analysis. Table 10 presents the results of the analysis based on Fig. 4.

Table 10 QFD assessment for the electric load analysis optimization

Relationships Matrix MAX : 9 MED : 3 MIN : 1			Electric load analysis optimization report							PM Wight Min 1 Max 5	PM Relative Weight
			ELAO1	ELAO2	ELAO3	ELAO4	ELAO5	ELAO6	ELAO7		
			3.a. Applicable standards	3.b. Aircraft mission	3.C Object of ELA	4.a Required aircraft operating conditions	4.b Specifications	4.c Aircraft electrical wiring diagram	4.d Electric load analysis including battery		
Management Factor of the electric load analysis on modifying the aged aircraft	PM 1	Integrated management	3	1	3	3	9	9	9	3	0.083
	PM 2	Detailed and applicable requirements of the electric load analysis on modifying the aged aircraft	1	1	9	9	9	9	9	5	0.139
	PM 3	Schedule management of measuring and reporting the electrical consumption	1	1	3	3	3	3	3	5	0.139
	PM 4	Applicable resources and other cost management e.g. human resources and instrument device	-	-	-	-	3	3	3	2	0.056
	PM 5	Quality management of the electric load analysis report	3	3	3	9	9	9	9	4	0.111
	PM 6	Other applicable resources management, e.g. GPU oil, instrument calibration date	-	-	3	9	1	3	9	3	0.083
	PM 7	Communication management to the mechanic engineer about the available avionics equipment	-	-	9	1	3	9	3	3	0.111
	PM 8	Risk management to the working environment, aircraft damage, safety and other potential problems	-	-	9	9	3	3	3	4	0.111
	PM 9	Procurement management of the instruments and other tools	-	-	3	3	1	1	1	2	0.056
	PM 10	Stakeholders management to cooperate working with the related division	-	-	9	3	9	9	9	4	0.111
VELAO (Validity of the electric load analysis optimization)			0.861	0.694	5.667	5.278	5.389	6.222	6.056		

As presented in Table 10, the feasibility of application was analyzed by mapping the correlation between PM 1 to 10, elements of project management, and report items proposed in this study, into strong correlation as 9, medium correlation as 3, and weak correlation as 1, similar to the basic HOQ model, and providing weights accordingly, as shown in Table 10.

The project management relative weight (PMRW) applied in the rightmost column of Table 10 was calculated by Equation (1).

$$PMRW_i = \frac{PM_i}{\sum_{i=0}^{n} PM_i} \tag{1}$$

The validity of the ELA optimization report (VELAO) was calculated by Equation (2).

$$VELAO_i = \sum_{i=0}^{n} (ELAO_i \times PMRW_i) \tag{2}$$

As presented in Table 10, the validity scores of reports ELAO3 to ELAO7 of the ELA optimization method were from 5.567 to 6.056, this indicating that the contents of Sections 3.C to 4.D of the report, according to the procedure in Fig. 3 described above, should be prioritized in terms of project management. This also seems to be applicable in terms of the 10 knowledge areas of the PMBOK guide, sixth edition.

3. Conclusion

Because there is no data on the maximum load of each avionics equipment for an aged aircraft, there is no analysis data on the power consumption from the total power generation capacity of the aircraft and power margin. Therefore, this study attempted to propose an optimized ELA method using the electric load measurement procedure without operating the engine on the ground, and verifying the application feasibility via the QFD theory. The optimization of ELA proposed in this study will facilitate meeting the aircraft operation schedule via flight tests, after modifying an aircraft in aircraft modification projects for commercial aircraft such as passenger, cargo, light-weight, or transport aircraft, as well as military aircraft such as fighter jets, with different electric load margins according to the aircraft missions while applying MIL-E-7016F and the ELA requirements for commercial aircraft mutatis mutandis.

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