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Design of a Flap Stand Tool for Maintenance on a Super King Air Model 350i Aircraft at the Center for Flight Facilities Calibration

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Abstract— Balai Besar Kalibrasi Fasilitas Penerbangan (BBKFP) is an Approved Maintenance Organization (AMO) responsible for performing aircraft maintenance. One of their tasks is the special inspection of inboard and outboard flaps on Super King Air Model 350i aircraft, conducted every 36 months or 3000 cycles. This requires specialized tools, such as a flap stand tool for removing, installing, and storing flaps. Inadequate equipment can create unsafe conditions for technicians, as the manual flap containment process has led to incidents like Teflon washers falling into flaps held with short tires. To address this, a flap stand was designed using the VDI method. This tool is intended to enhance the maintenance process at BBKFP. Testing revealed that the designed tool can lift a flap weighing 7.89 kg using a thread with a 6-ton capacity and ASTM A36 material.

Keywords—Aircraft Maintenance; Flap Stand Design; Safety Enhancement; VDI 2221 Method; Static Load Analysis

I. INTRODUCTION

The Approved Maintenance Organization (AMO) is responsible for aircraft maintenance, covering the body, engine, propeller, equipment, and components as per CASR 43. This ensures the aircraft remains airworthy to prevent incidents that could compromise flight safety [1][2]. All aviation companies aim for zero accidents. Achieving this requires a balance between available tools and maintenance technicians to manage maintenance costs, as continuous inspection and upkeep of aircraft are necessary. Increased maintenance and inspection demands have led to excessive workloads and a shortage of tools, resulting in a decrease in the workforce due to heightened safety issues related to human error in maintenance and inspection processes. This problem is further complicated by effects on the aviation system, such as non-compliant procedures that can impact flight safety and potentially lead to accidents [3].

Defective maintenance and inspection contribute to 14% to 21% of civil helicopter accidents in the US. Of these, 31% occur within the first 10 flight hours after maintenance due to incorrect or incomplete reassembly or installation of parts, such as incorrect torque on B-nuts and incomplete assembly of critical connections [4]. An unsafe condition was identified during the Special Inspection LH/RH Flap Assy Inboard and Outboard of the King Air 350i aircraft with registration PK-CAP by the Balai Besar Kalibrasi Fasilitas Penerbangan (BBKFP). Personnel were performing tasks that risked human error during aircraft maintenance, with flaps not placed properly, potentially causing defects. Flaps are the most frequently used lift-modifying devices for both small and large aircraft, installed on the leading or trailing edge to increase lift and drag at any given angle of attack. Flap and slat actuators operate during takeoff and before landing, making them critical parts of the high-lift device system on an aircraft's wing, functioning in an uninsulated environment. Flap actuator failure during flight can create an emergency situation

[5]. To address this issue, a flap stand tool was designed using the VDI 2221 method. This design considered concepts, efficiency, shape, dimensions, and material strength calculations to support the maintenance of the Super King Air Model 350i at the Balai Besar Kalibrasi Fasilitas Penerbangan. This tool aims to facilitate the maintenance process and reduce human error.

II. METHODOLOGY

This research employs a quantitative approach to designing a tool. The design process is guided by the VDI 2221 method, which involves several stages: task clarification, conceptual product design, embodiment design, and detailed design. The design criteria are based on established theories, including design theory, load theory, static load theory, material theory, and thread theory.

VDI 2221 Method

The VDI 2221 method, developed by Gerhard Pahl and Wolfgang Beitz [6], is a systematic design approach intended to assist designers in creating products in a structured and methodical manner. This method encompasses several key stages as described below.

Clarification of the Task

This initial stage involves collecting information or data regarding the requirements and limitations that the tool's design must meet. The outcome of this stage is formalized in the form of specifications, which provide a clear framework for the design process.

Conceptual Design

In this stage, the focus is on abstracting the problem, developing a functional structure, and identifying appropriate principles for problem-solving. These principles are then combined into various concept variants. The result of this stage is a set of key solutions or concepts that address the design problem effectively.

Embodiment Concept

During this stage, sketches combining solution principles are developed into initial layouts. These layouts are evaluated and refined based on technical and economic criteria. The selected initial layout is then transformed into a final layout, which includes detailed elements of the product, such as the form, static material strength calculations, material selection, and size determination. This ensures that the design meets both the functional requirements and practical constraints.

Detail Design

The final design stage involves presenting the detailed design in comprehensive documentation. This includes detailed tool drawings, component lists, material specifications, operating systems, tolerances, and other relevant documentation. A thorough evaluation is conducted to ensure the design meets all specified criteria and requirements.

Design Theory Method

According to Nur and Suyuti [7], several criteria must be established by a designer during the design process. These criteria are essential to ensure the functionality and success of the final product with the criteria that can be shown below.

Function (Usage)

The tool must perform its intended function effectively and efficiently. This involves ensuring that the tool can handle the expected operational conditions and deliver the desired performance consistently.

Safety

The design must ensure the safety of users and the environment that includes incorporating safety features that prevent accidents and mitigate risks during the tool's operation. Compliance with relevant safety standards and regulations is also a critical aspect.

Reliability

The tool should function consistently over time without failure, involving designing for durability and robustness and ensuring that the tool can withstand repeated use and adverse conditions without significant degradation in performance.

Cost

The design should be cost-effective and within budget constraints by selecting materials and manufacturing processes that balance performance with cost, ensuring the tool is affordable to produce and maintain.

Manufacturability

The tool must be feasible to produce with available manufacturing processes and resources and designed for ease of manufacturing, considering factors such as material availability, production complexity, and assembly processes.

Marketability

The design must align with market demands and be commercially viable. This requires a thorough understanding of market needs and preferences, ensuring the tool provides features and benefits that attract potential customers.

Additional criteria and considerations, especially related to product safety and potential failure, are also integrated into the design process. This includes analyzing potential failure modes and incorporating design features to prevent or mitigate these failures. In designing machine components, there are no fixed rules, and various solutions can address design challenges. Flexibility and creativity in the design process are essential to developing innovative and effective solutions.

Load Theory and Static Load Theory Method

A load is defined as an external force acting on an object. There are three primary types of loads: dead loads, live loads, and impact loads. The foundational aspects of loading on machine elements include axial load, pure shear force, torque, and bending. Each type of force induces stress and deformation in machine elements, which are categorized as normal and shear stress [7]. A static load is a continuous force applied to a structure, developing gradually and defined by steady-state variables [8]. The five components of a static load are:

Compressive Stress: Stress occurring when an object is subjected to axial forces in opposing directions, leading to a reduction in the object's length.

Bending Stress: Stress resulting from forces applied at a midpoint on a load-bearing element, causing the element to bend. This type of stress is critical in determining the structural integrity of components subjected to transverse loads.

Allowable Stress: The maximum stress value used to determine the dimensions of a component during design. This value ensures that the component can withstand operational loads without failing.

Equilibrium: The state in which all forces acting on a structure are balanced, ensuring that the structure remains stable under load.

Power Thread: Threads designed to transmit significant power or withstand high loads, essential in applications requiring secure and robust connections.

Material and Thread Theory Method

Threads, or screws, are used to connect and disconnect machine parts without causing damage, facilitating adjustments during assembly, repair, and maintenance [7]. The strength of a thread is determined by selecting appropriate materials based on design calculations and the specific application requirements. This includes considering factors such as material strength, durability, and compatibility with other components.

Data Analysis Method

Threads, or screws, are used to connect and disconnect machine parts without causing damage, facilitating adjustments during assembly, repair, and maintenance [7]. The strength of a thread is determined by selecting appropriate materials based on design calculations and the specific application requirements. This includes considering factors such as material strength, durability, and compatibility with other components.

III. RESULTS AND DISCUSSION

The load analysis for the flap removal process, using the specifications of the flap in Table 1 and the design of the flap stand in Figure 2, was conducted to ensure alignment with the validated design for the King Air 350i flap shown in Figure 1 and the specifications for demand (D) and wishes (W) listed in Table 2.

Table 1. Flap Specifications

No	Flap Part	In cm	In mm	In inches
1	Flap Length	250	2500	98.42
2	Flap Width	50	500	19.68
3	Flap Height	100	1000	39.37

Figure 1. King Air 350i Flap

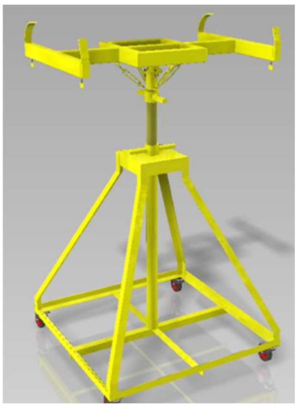

Figure 2. Design Plan

Table 2. Flap Specifications

Parameter	Specification	D/W
Geometry	Correct placement of the test object	D
	Tool height 100 cm	D
	Maximum tool width 75 cm	W
Kinematics	Unidirectional loading	D
	Up and down movement (screw)	D
Force	Compressive loading	D
Material	Iron	D
	Wheels	D
	Material easily obtainable	W
Safety and Ergonomics	Safe and easy to operate	D
Assembly	Simple construction and easy-to-assemble	W
	Uses standard components	W
Transportation	Easy to move	D
Operation	The operator does not require special training	D
	Can withstand the load from the flap	D
Maintenance	Low maintenance cost	D
Cost	Low manufacturing cost	W
	Low operating cost	W

The conceptual design phase involved abstraction and creating a functional structure (comprising the lower frame, drive screw, upper frame drive, and upper frame). Various combinations were explored and selected for further design development. During the design phase, the static load was determined based on the flap's weight of 7.89 kg. This resulted in a load distribution of 77.3 N on the support frame and 115.64 N on the lower support frame from a total load of 11.27 kg. The planned load, derived from the factor of safety and working or design load, was calculated to be 11.83 kg, with the stress on the flap stand totaling 0.10 MPa. This led to the embodiment design, including material strength calculations and material selection for constructing the upper frame, as outlined in Table 3.

Table 3. Material Selection

No	Material	Category	Yield Strength	Tensile Strength
1	ASTM A36	Mild steel	250 N/mm^2	400-550 N/mm^2
2	DIN 1700 ST 37.2	High strength steel	235 N/mm^2	340-470 N/mm^2
3	DIN 1700 ST 44.2	High strength steel	275 N/mm^2	410-540 N/mm^2

For this design, ASTM A36 mild steel was selected, with dimensions of 30x30x1 mm, a weight of 1 kg/m, and a total length of 2.38 m. Consequently, the frame's weight is 2.38 kg, which was used to calculate the mass supported by the screw, which must withstand a load of 15.21 kg. Therefore, a screw with a load-bearing capacity of 6116 kg (or 6.74 tons) was chosen. The bending stress calculation for the lower frame resulted in a force of 27.39 N and a moment of 1021.25 N.mm. These values were used to compute the section modulus of 1084.24 mm^3, resulting in a bending stress of 9.47 N/mm^2 (or 9.47 MPa). Further, material strength calculations were conducted using data in Table 4, wheel selection was performed as per Table 5, and the safety factor was determined. The detailed design phase commenced after thorough analysis and calculations, leading to the designs illustrated in Figures 3 through 7. Based on these calculations and analyses, a comprehensive summary is presented in Table 6.

Table 4. Material Strength

Name	Value	Unit
Yield strength	250	MPa
Tensile strength	400-550	MPa

Table 5. Wheel Specifications

No	Wheel	Strength
1	Unico Fixed Wheel 2-inch	45 Kg
2	Swivel Wheel 2 inch	50 Kg
3	Polyurethane Wheel 3 inch	400 Kg

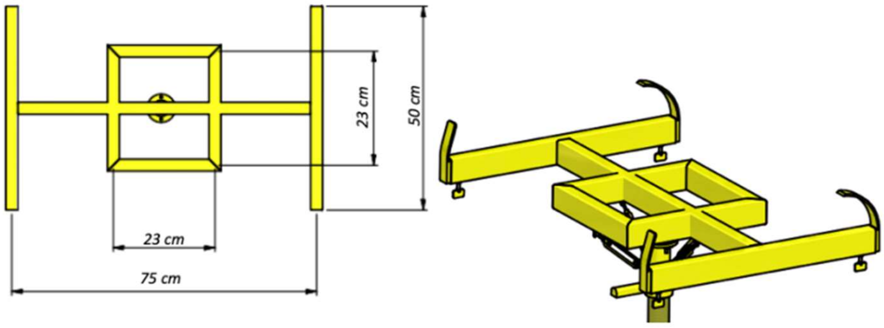

Figure 3. Upper Frame Design

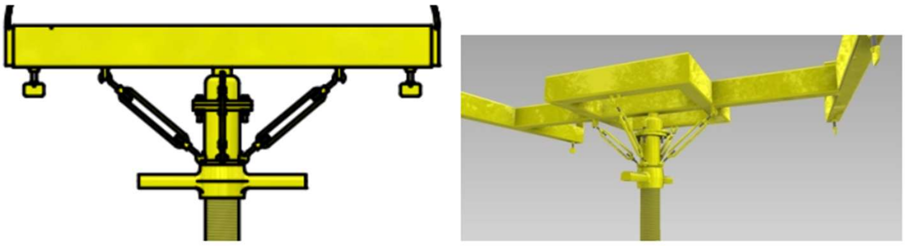

Figure 4. Upper Frame Drive Design

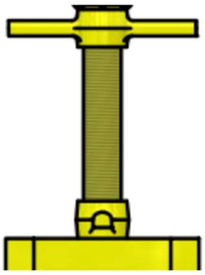

Figure 5. Screw

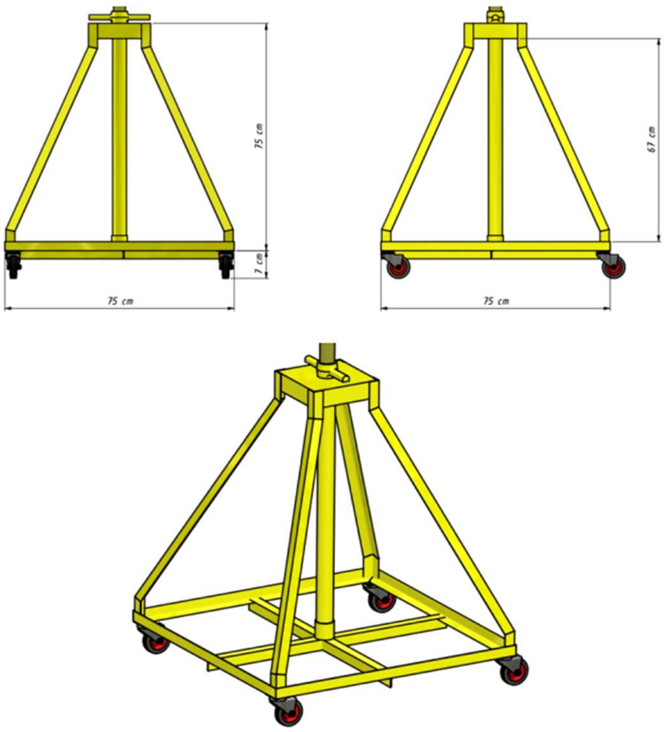

Figure 6. Lower Frame Design

Figure 7. Wheel

Table 6. Calculation Summary

No	Design Block	Indicator	Result	Description
1	Received Load	7.89 kg	11.83 kg	Load multiplied by safety factor 1.5 based on the type of static load
2	Bending Stress	62.5 MPa	9.47 MPa	Below allowable material stress
3	Compressive Stress	62.5 MPa	0.10 MPa	Below allowable material stress
4	Screw	6116 kg	15.21 kg	Suitable
5	Wheel	50 kg	29.65 kg	The wheel can support the load

The detailed design specifications of the flap stand include a minimum height of 1 meter and an upper frame width of 75 cm by 50 cm, padded with 7mm thick insulation foam to prevent flap damage. The stand employs a screw with a major diameter of 33.1 mm and a minor diameter of 32.15 mm, with a crest size of 3.8 mm made of high tensile steel, capable of bearing up to 6116 kg. The design also features L-profile steel for the four-leg frames and 3-inch wheels that can support up to 50 kg. The tool is designed to handle a static load from the flap, which weighs 7.89 kg, and this weight is multiplied by a safety factor of 1.5, resulting in a planned load of 11.83 kg. The frame design consists of a supporting frame and base frame, sustained by a drive screw with a 6-ton capacity, and the upper frame supports the flap's weight. The device's dimensions are a minimum height of 1 meter, with leg width and length of 75 cm each, constructed using L-profile steel and 30x30x1 mm hollow sections. The total frame weight is 19.65 kg, with a maximum frame stress of 9.47 N and an allowable material stress of 62.5 MPa, based on material strength analysis, stress concepts, and safety factors. ASTM A36 hollow steel, with a yield strength of 250 MPa, was selected as the material. The detailed flap stand design includes an upper frame that is 75 cm long and 50 cm wide, made of 3x3 mm hollow steel with a 1 mm thickness, and padded with 7 mm insulation foam. The upper frame uses a ball joint for tilting and a 6 mm turnbuckle for locking the tilt, made of cast iron. The screw has a major diameter of 33.1 mm, a minor diameter of 32.15 mm, and a crest size of 3.8 mm, made of high tensile steel, capable of bearing up to 6116 kg. The lower frame uses four legs made of L-profile steel, 75 cm by 75 cm, with wheels that can support up to 50 kg and are equipped with brakes.

To enhance the design, several recommendations can be considered including dynamic load calculations during the vertical movement of the screw for more accurate results, modifying the upper frame to support flaps from various aircraft models, using a diverse range of materials to improve flap support and enhance safety, and incorporate additional safety features. By implementing these recommendations, the design can be further refined to enhance performance, safety, and versatility, ensuring the flap stand meets the rigorous demands of aircraft maintenance.

IV. CONCLUSION

The flap stand design for the Super King Air Model 350i employs a systematic approach, ensuring functionality, safety, and reliability. Using ASTM A36 mild steel, the tool can support a static load of 7.89 kg, with a planned load of 11.83 kg after applying a safety factor of 1.5. Material strength and stress calculations are within acceptable limits, guaranteeing safety and durability. Incorporating features like padded upper frames and high-tensile steel screws, the tool is both practical and functional.

Recommendations for further enhancements include dynamic load calculations and additional safety features. Overall, the flap stand design meets rigorous aircraft maintenance demands, reducing human error and improving operational efficiency.

V. ACKNOWLEDGMENT

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