Load and Stress Analysis of POD Part on LSA (LAPAN Surveillance Aircraft)

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Abstract. LSA (LAPAN Surveillance Aircraft) is the aircraft which be used for doing the surveillance mission especially with the requirement of high endurance, long-distance, and high altitude. LSA (LAPAN Surveillance Aircraft) as an aircraft consists of several general whole parts as, fuselage which fit for two passengers include the pilot, inner wing, outer wing, main landing gear, and propeller. Payload; can be a camera, sensor, antenna, or transmitter; is the key to a surveillance mission. There is a part that has an important role related to the surveillance mission on LSA (LAPAN Surveillance Aircraft) and payload system. That part named POD part occupied on inner wing LSA (LAPAN Surveillance Aircraft). The structural analysis needed to assure and guaranteed LSA (LAPAN Surveillance Aircraft) can borrow such payload while doing surveillance missions. Stress analysis by 3D model on POD and threaded bar has given such stress contribution value with FEM as processing structural analysis. On the POD part, the maximum principal value to be considered at 112 MPa while operation, and on the threaded bar, the maximum principal value to be considered at 288 MPa.

INTRODUCTION

LAPAN (*Lembaga Penerbangan dan Antariksa Nasional*) as part of the government body has the responsibility in the public service field. Surveillance mission is one of LAPAN tasks in the public service area. Surveillance missions are usually related to mapping areas, disaster mitigation, weather, etc.[1] Aeronautics Technology Center as part of LAPAN become one government body who have to do some task in aircraft surveillance. Aircraft surveillance can be done by unmanned or manned aircraft vehicles, depends on endurance, distance, altitude, or mission requirement.[2]

In the category of manned aircraft vehicle surveillance, there is LSA (LAPAN Surveillance Aircraft) as the aircraft which will be used for doing the surveillance mission especially with requirement long-endurance, long-distance, and medium altitude.[3,4] LSA (LAPAN Surveillance Aircraft) as an aircraft consists of several general whole parts as, fuselage which fit for two passengers include the pilot, inner wing, outer wing, main landing gear, and propeller. The payload, which is the key to a surveillance mission, can be in the form of a camera, sensor, antenna, or transmitter. Aircraft takes part as a carrier for the payload surveillance. In this experiment/ examination, we will take the part of structure examination of main part on inner wing LSA (LAPAN Surveillance Aircraft) which its main function as hold payload during surveillance mission that we called POD Part and its structural system. POD is part that is connected to the inner wing by a bolted joint and holds the payload and payload pad by the threaded connecting bar.[5-8] STEMME-Germany as a constructor of LSA (LAPAN Surveillance Aircraft) made an assurance of their aircraft part load capacity, stated in their technical description document, that the inner wing still can hold the payload as 75 kg on each wing. So, we can assume that value becomes our boundary on examined and structure analysis of the POD structure system. The POD structure system examined by this experiment consists of finding the combination of position POD threaded bar that contributed at minimum stress reaction on POD part, stress reaction POD part when to be operated at assuming maximum load service condition and cause by maneuver position such as taxi, pitch, and roll, yaw and stress reaction on POD threaded bar when operated at assuming maximum load service condition and cause by maneuver position such as taxi, pitch, and roll, yaw while yaw condition can assume to be eliminated for both.

The examination and analysis stage was done by making a 3D simplified and nearly representative model both for the POD part and threaded bar for load and stress analysis. There are several steps for validating and assure the value of simulation FEM, both for POD part stress analysis and threaded bar stress analysis as conducted in Refs.

The 8th International Seminar on Aerospace Science and Technology – ISAST 2020
AIP Conf. Proc. 2366, 040002-1–040002-13; https://doi.org/10.1063/5.0060081
Published by AIP Publishing. 978-0-7354-4123-1/$30.00

9 and 10, ABAQUS be nearly convergent while FEM was involved by meshing parametric both number element of mesh and mesh element itself. The principal maximum stress value (MPa) for both the POD part and threaded bar concluded from the FEM load-stress simulation result. This examination hopefully can guide us about the plan tightening strategy, consideration about payload weighting, and consideration about the range of allowable maneuver conditions related to structure load capacity. Maneuver condition defined as a taxi (park/while block on), pitch and roll condition while being on air mission. On this experiment, assumed that both for pitch and roll degree extremely at 5 degrees while climb up/down and roll left/right.

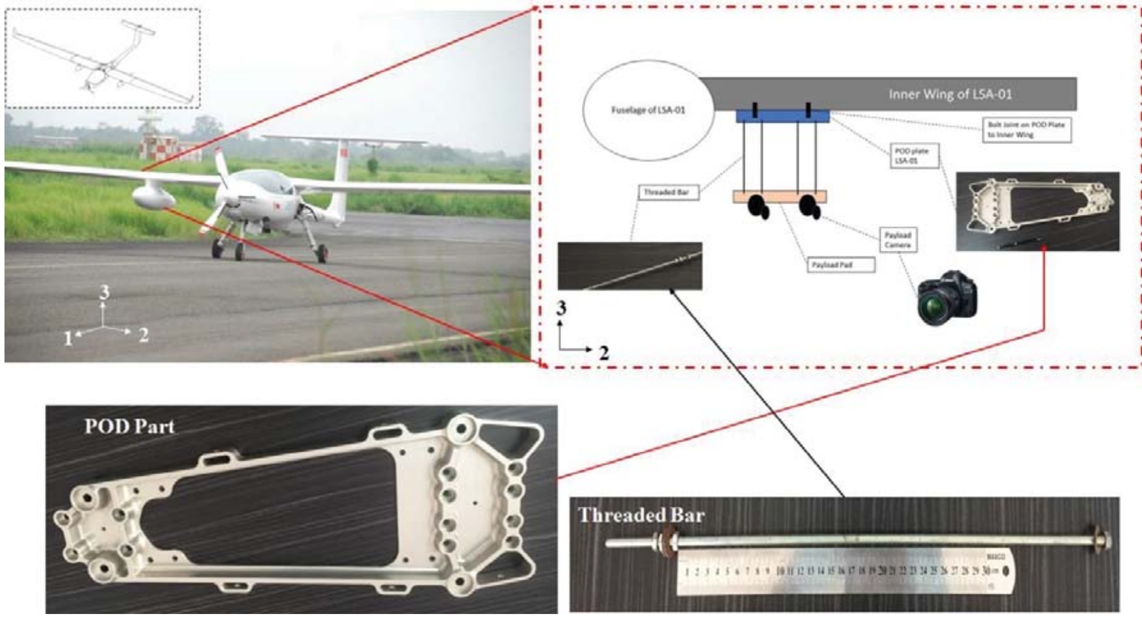

FIGURE 1. Scheme of POD part on LSA.

Figure 1 shows the LSA (LAPAN Surveillance Aircraft) as LAPAN-Republic of Indonesia property for the manned aircraft surveillance system and scheme POD part system and payload system on LSA (LAPAN Surveillance Aircraft). POD part system consists of a threaded bar, four-bolt joints to the inner wing, four threaded bar that is connected to the payload pad and hold the total payload weight load, and POD part itself. Figure 1 shows that the LSA (LAPAN Surveillance Aircraft) POD part has several holes that consist of a big hole defined as 8 mm in diameter and four in number while a small hole defined as 6 mm in diameter and twelve number. Big hole occupied for bolt POD-Inner wing while small hole for occupied four threaded bar that connected POD-payload pad.

The main purpose of this examination is to find a combination of position POD threaded bar from all possible combination that contributed at minimum stress reaction on POD part at 75 kg payload weight. With the best combination that founded before from step a), then analyze the stress distribution reaction of POD part when be operated at assuming suggested/ allowed maximum service condition at 75 kg payload weight with maneuver or aircraft condition/ position while taxiing, pitch and roll. Stress distribution reaction on the threaded bar of POD when be operated at assuming suggested/ allowed maximum service condition at 75 kg payload weight with maneuver or aircraft condition/ position while taxiing, pitch and roll.

EXAMINATION METHOD

First of all, examination starts by observation the POD part and its system. The model is represented by the 3D model made based on data, dimension, interconnection/ joining, boundary condition, material, external load, several inputs about loading condition. More detailed information gained so more sharpening the analysis and examination. POD part model and threaded bar model made with the simplified model without neglected the essential parameter that influenced the result. The threaded bar model is simplified as a smooth bar without thread and bolt head that related to stress concentration. It is assumed that load comes purely from loading conditions without stress concentration factor caused by contour morphology of part. After the model is gained, the load analysis stage is separated in two ways. First, load analysis focused on find POD and its tightening possible combination. And second, analysis threaded bar both for load and stress analysis. Finding a tightening strategy that makes stress reaction at minimum stress distribution starts with finding eight possible tightening strategies. Every eight possible combinations checked one by one for their stress distribution while loaded 75 kg of payload. the best combination bar position or tightening strategy which made minimum stress distribution on the POD part while loaded payload weight. Then, that best tightening combination is used as a reference and guide while tightening threaded bar on POD-payload pad and as reference for next load and stress analysis of POD while pitch and roll condition. Figure 2 illustrates the examination process.

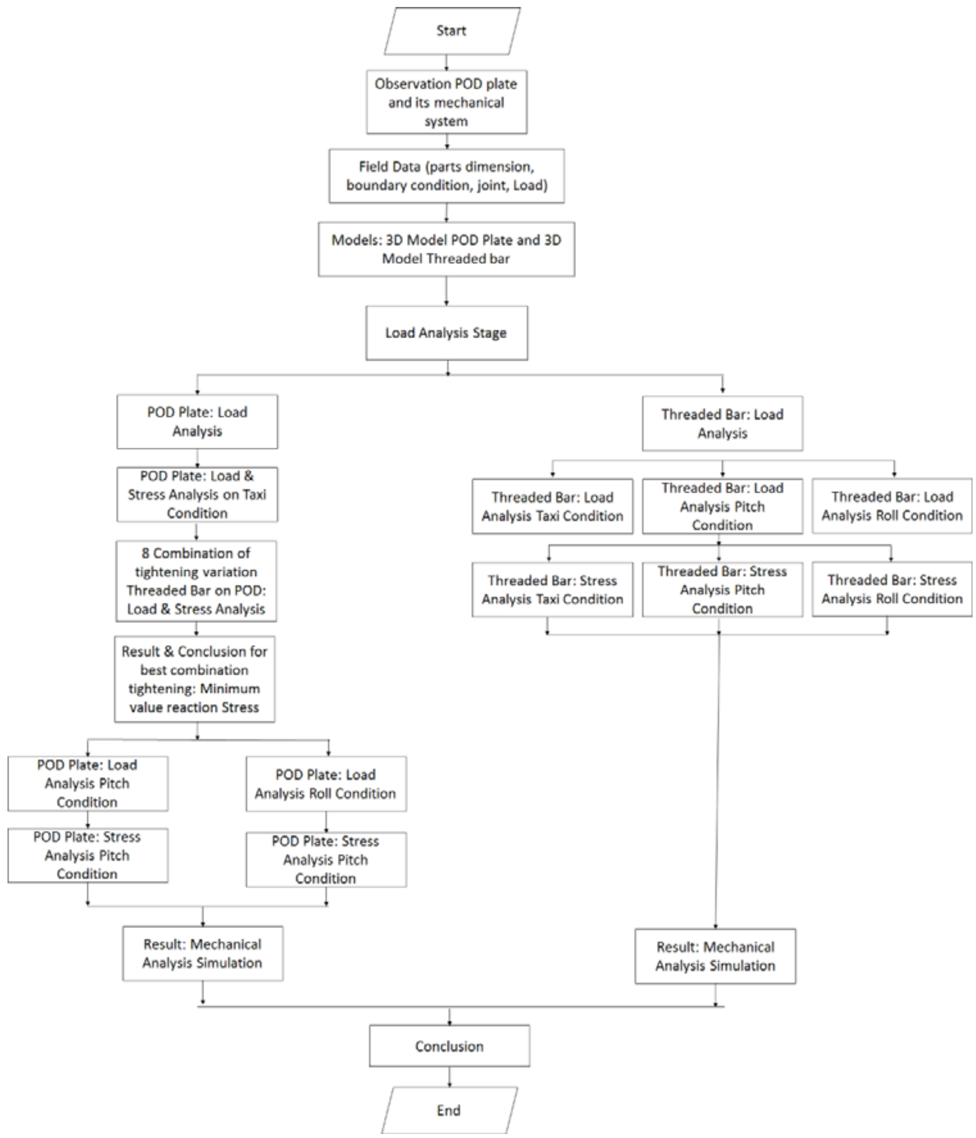

FIGURE 2. Examination methodology.

TIGHTENING COMBINATION ANALYSIS

There are several methods to tighten the threaded bar to the POD part. There is eight possible combination method to tighten. Identification hole joint by name and number are needed on process analysis stage and making model. The hole joints on the POD part of LSA (LAPAN Surveillance Aircraft) were identified as hole A, hole B, hole C, hole D, or can be called HA, HB, HC, HD, which are bolted joint hole that connects to the inner wing of LSA. Aside from that, there are also hole 1, hole 2, hole 3, hole 4, hole 5, hole 6, hole 7, hole 8, hole 9, hole 10, hole 11, and hole 12 or can be called H1, H2, H3, H4, H5, H6, H7, H8, H9, H10, H11, dan H12, which are bolted joint hole that connects to payload pad which that surveillance camera on.

Meanwhile, the condition and some information that we use and assume to proceed in this examination are maximum service condition for inner wing holds the payload as 75 kg or 735,75 N (gravity as 9,81 m/s^2) and assume that contributed to every four threaded bars and four-bolt joints. The analysis model uses a 3D model as a representative model for mechanical analysis with identifying the thickness of the POD part at 24 mm based on the real item. The diameter of bolted that joint POD part to inner wing identify as 8 mm and diameter of bolted that joint POD part to POD Pad and payload identify as 6 mm. Mechanical stress analysis software using ABAQUS®.

This mechanical stress analysis examination is identified as HA, HB, HC, and HD as a boundary condition (Ux=Uy=Uz=Rz=0) on the model. Identification of possible combination on the POD part are:

Trial/ Combination #1 is H1, H2 & H9, H12
Trial/ Combination #2 is H1, H2 & H10, H11
Trial/ Combination #3 is H1, H2 & H5, H8
Trial/ Combination #4 is H1, H2 & H6, H7
Trial/ Combination #5 is H3, H4 & H9, H12
Trial/ Combination #6 is H3, H4 & H10, H11
Trial/ Combination #7 is H3, H4 & H5, H8
Trial/ Combination #8 is H3, H4 & H6, H7.

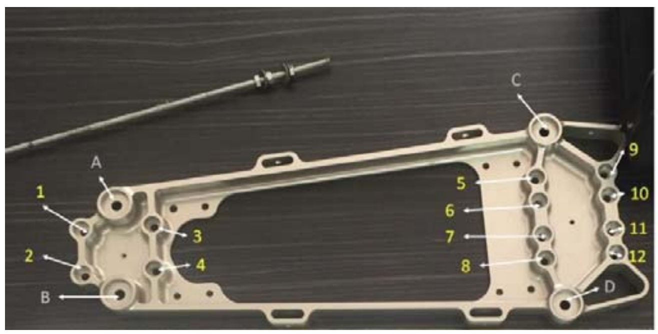

FIGURE 3. Hole numbering designation on POD part.

From scheme POD load system, HA, HB, HC, and HD (hole for joint POD part to inner wing joint) take place as the boundary condition while H1 until H12 take place as load transfer media from the weight of the payload. As per dimension information from observation, model 3D was made for analyzing stress distribution by simulation FEM. The model approach was made as part metal without optimization consideration. Eight possible combinations/trial from trial or combination#1, H1, H2 & H9, H12, to trial or combination#8 H3, H4 & H6, H7 analyze for each model. Figure 4 shows the 3D model of POD description that use in this examination, model while meshed and given boundary condition and load applied point. The boundary condition for every model was the same while the load applied the point varied as detailed in Trial/combination#1 until Trial/combination#8 as shown in Fig. 3.

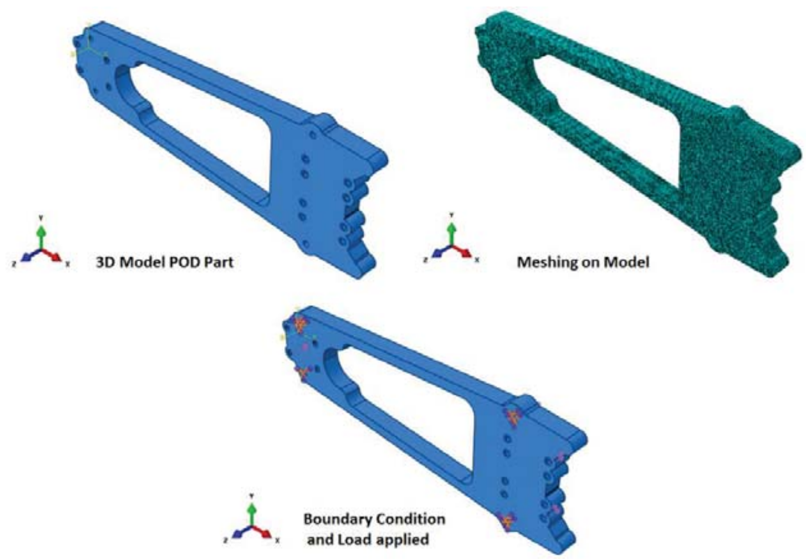

FIGURE 4. Model 3D for POD part.

The result from FEM stress analysis is shown that trial/ combination#7 gain minimum max. principal stress value. Maximum principal stress gain while tightening condition on trial/ combination#2. Detailed information about maximum principal stress varied with trial number tightening informed in Table 1. Stress distribution along model information provided in Fig. 5 for stress distribution on high-stress trial at trial#2 vs low-stress trial at trial#7.

TABLE 1. Maximum principal stress for each tightening combination.

No.	Trial/ Combination Name	Hole Combination	Max. Stress Value (MPa)
1	Trial-1	H1, H2 | H9, H12	203
2	Trial-2	H1, H2 | H10, H11	214.9
3	Trial-3	H1, H2 | H5, H8	127.6
4	Trial-4	H1, H2 | H6, H7	127.4
5	Trial-5	H3, H4 | H9, H12	196.9
6	Trial-6	H3, H4 | H10, H1	208.7
7	Trial- 7	H3, H4 | H5, H8	112.7
8	Trial-8	H3, H4 | H6, H7	117.9

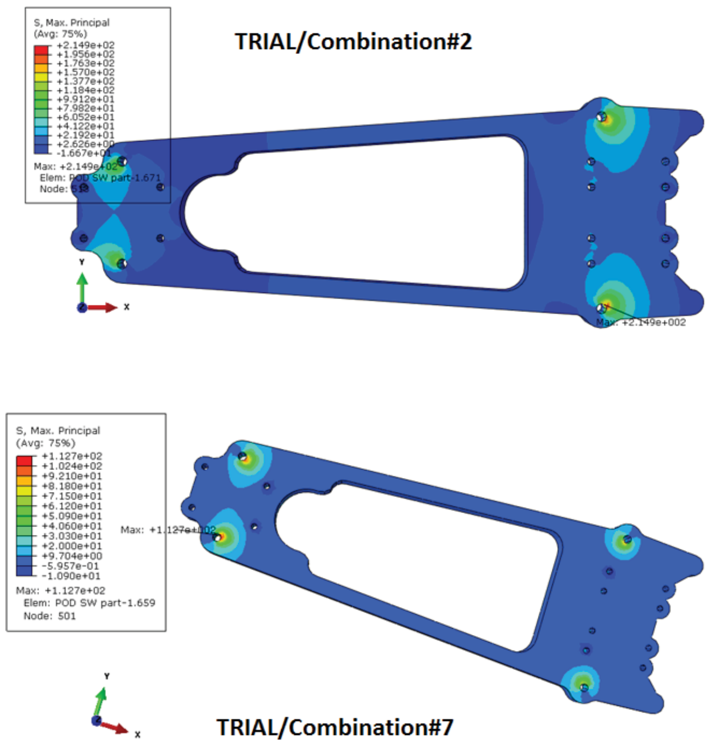

FIGURE 5. Stress distribution Trial#2 vs #7**.**

To assure stress value that we gain as output FEM process does not have influenced or been less affected by the number of mesh be used. Convergency check should be done by drawing the graphic of max. principal stress versus the number of mesh elements. The number of mesh elements varied from less number element with easily drawn meshing stage to the high number of mesh element and high time demand processing, then tried for 3D model stress analysis. Each number of mesh elements graphed for each maximum principal reaction stress as the process output.

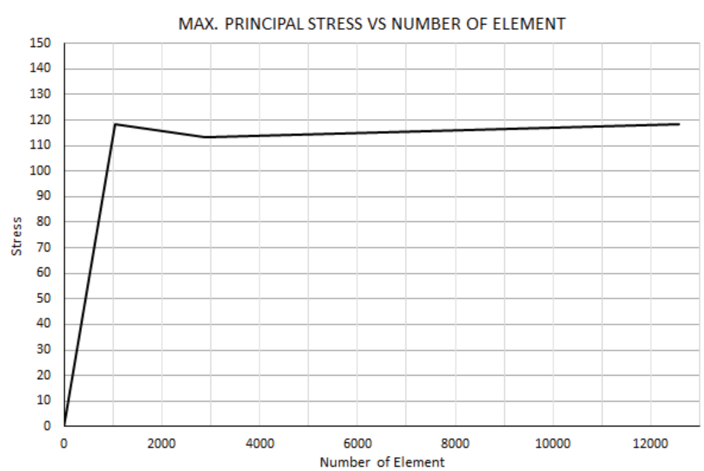

FIGURE 6. Maximum principal stress vs. mesh element number for Trial#7.

Figure 6 shows that there was no difference significantly from a smaller number of elements such as 4000 number of elements than 12 000 number of elements. This means that using a 4000 number of elements would be giving around the same stress value instead of 12 000 number of elements while less time-consuming processing.

EXAMINATION: POD PART LOAD & STRESS ANALYSIS

Stress analysis on the POD part at a taxi or non-air mission condition was done simultaneously while examining the tightening strategy. While analyzing the tightening strategy, concluded that the tightening combination that gives Trial# 7, hole combination H3, H4 | H5, H8, which stress reaction at minimum. Then, stress analysis on the POD part at air-mission refers to combination H3, H4 | H5, H8 as reference load location while changing the POD part position both for pitch and roll stress analysis.

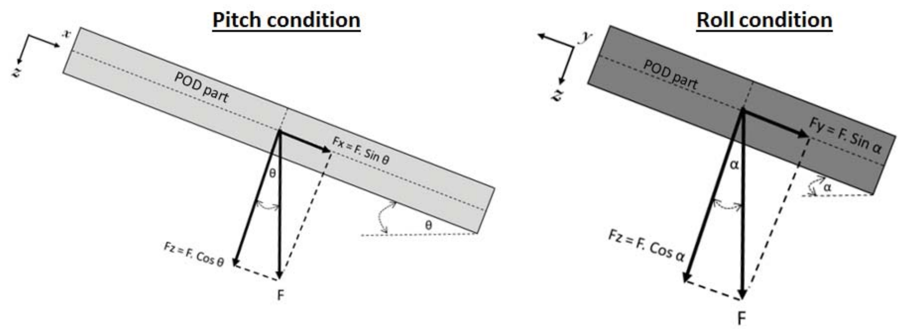

FIGURE 7. Free body diagram (FBD) pitch and roll on POD part.

Figure 7 shows the FBD (free body diagram) for each air mission position both for pitch and roll. Degree of pitch stated as θ degree and on roll stated as α degree. F as a force load (N) comes from the load weight of the payload. cause by pitch θ degree and α degree then come to Fx, Fy, and Fz as projection force from F as payload load.

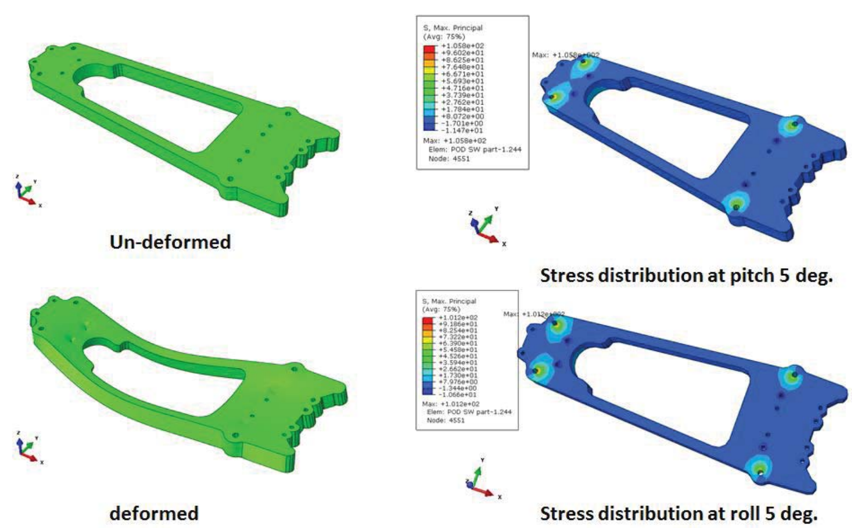

FIGURE 8. Pitch and roll stress distribution**.**

As shown by Fig. 8, the un-deformed and deformed form changing on the part, before and after load applied illustrated clearly. Blue area of stress distribution on part defined as low-stress reaction then followed by green area, yellow area, orange area and red area as maximum stress occurred while applied load. At Pitch position, stress max. principal gained at 105.8 MPa while at roll position stress max. principal gained at 101.2 MPa. Detail explained in Table 2 on the result and discussion chapter.

EXAMINATION: THREADED BAR LOAD & STRESS ANALYSIS

Examination threaded bar load and stress analysis done for analysis single-threaded bar from four in total about its reaction by applied load 75 kg in payload weight, boundary condition, and varied in off and on a mission such taxi, pitch and roll. Figure 9 shows the free body diagram for each taxi, pitch, and roll condition. On taxi condition, just applied Fz force as working load as consequence from payload weight. Fz acting at the end tip of the threaded bar so the bar just gained axial stress in area A. In pitch condition, bar occupied by Fx and Fz force where Fx acting as the bending force that caused bending stress and Fz caused axial load and axial stress. Fx and Fz are projection force of F, payload weight. In roll condition, bar occupied by Fy in y-minus direction and Fz force where Fy acting as bending force caused bending stress and Fz caused axial load and axial stress.

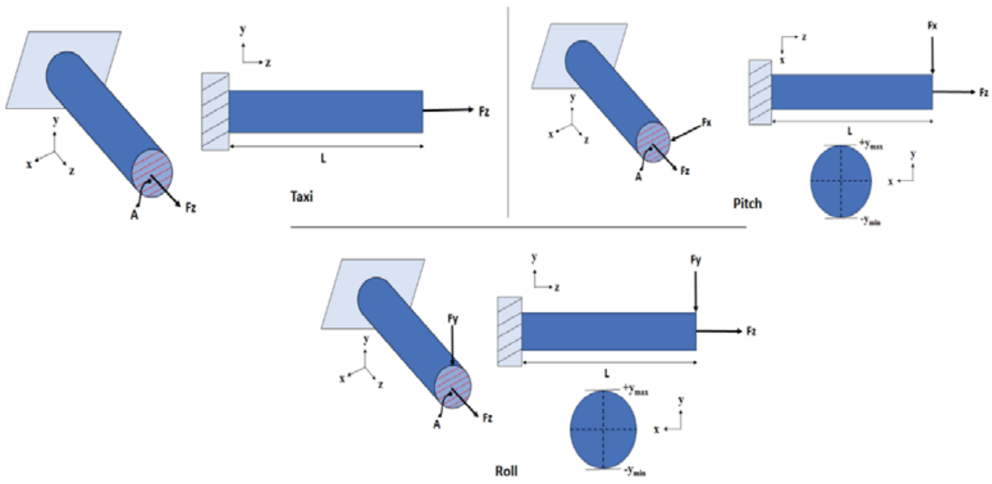

FIGURE 9. Scheme taxi axial load and combined load on bar both at pitch and roll condition.

Threaded bar model simplified with a smooth surface and un-headed bar instead of threaded and head bar. With un-headed and un-threaded morphology, stress concentration factor assumed not affected in this model and pure stress resulted caused only by force applied. Boundary condition (BC) applied at the end of bar and force, F acting on another side of the yz area of bar as shown in Fig. 10.

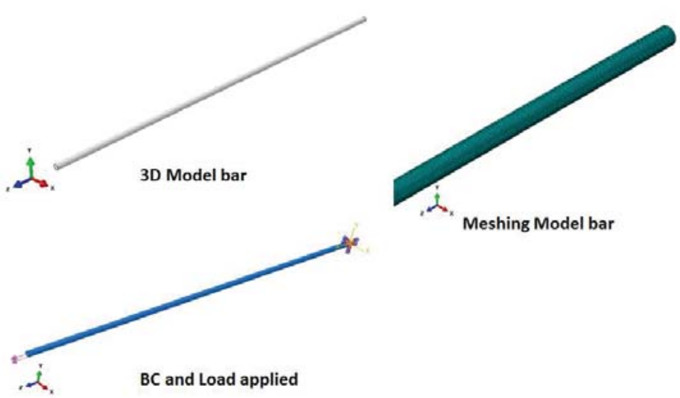

FIGURE 10. The 3-D model of threaded bar.

Stress distribution at bar caused by axial load Fz in the taxi position illustrated in detail in Fig. 11. Stress distribution as the reaction of applied force maximum happened at the end of the bar at boundary condition applied. The lower tension stress area is indicated by the blue area, followed by the green area, yellow, orange area, and red are at maximum tension stress in a circular pattern. The maximum stress value is stated at 7.39 MPa.

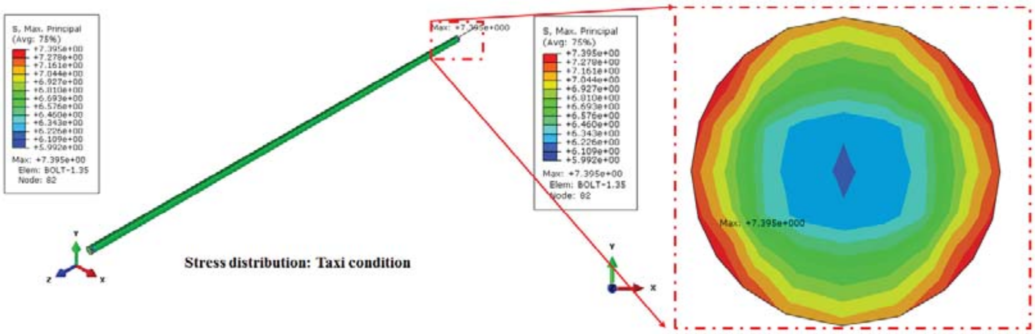

FIGURE 11. Stress distribution axial load on the bar.

Same as POD part analysis, convergency check should be done by drawing the graphic of max. principal stress versus the number of mesh elements. The number of mesh elements varied from less number element with easily drawn meshing stage to the high number of mesh element and high time demand processing, then tried for 3D model stress analysis. Each number of mesh elements graphed for each max. principal reaction stress as the process output.

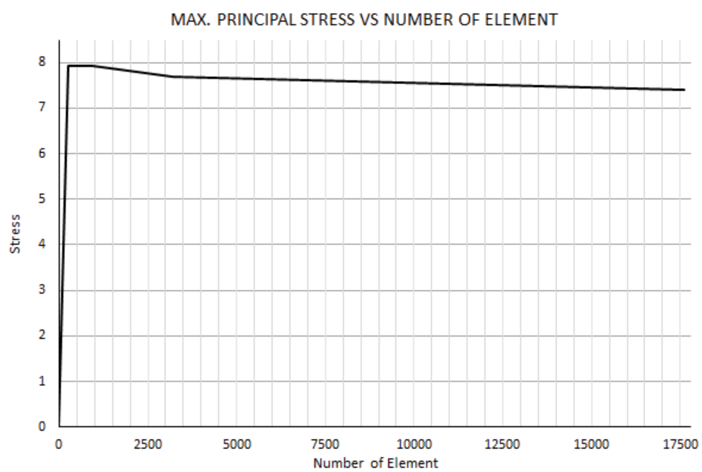

FIGURE 12. The maximum principal stress vs**.** mesh element number for the axial load on the bar.

Figure 12 shows that there was no difference significantly from a smaller number of elements such as 5000 number of elements than 17 000 number of elements. This means that using a 5000 number of elements would be giving around the same stress value instead of 17 000 number of elements while less time-consuming processing.

Stress distribution at bar caused by axial load Fz and bending load Fx in pitch position illustrated in detail in Fig. 13. Stress distribution as the reaction of applied force maximum happened at the end of the bar at boundary condition applied. Compressive stress area indicated by blue area and followed tension stress area indicated by sea blue area, green area, yellow area, orange area, and red are at maximum stress tension. The maximum stress value is stated at 288.4 MPa.

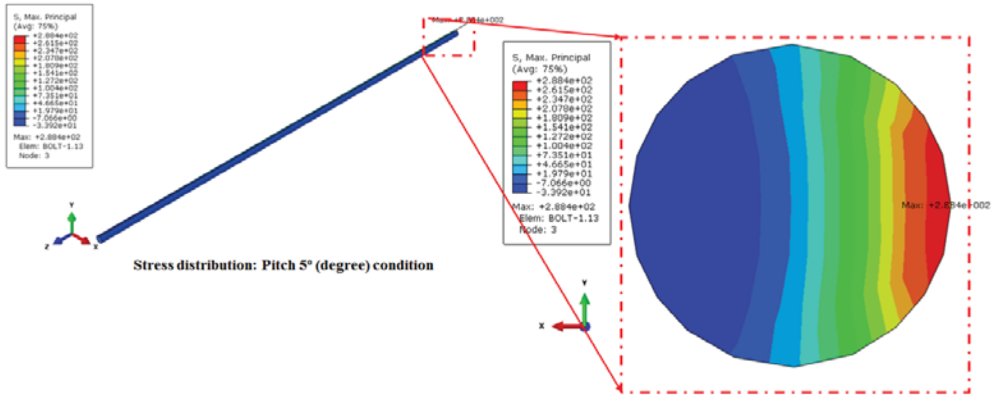

FIGURE 13. Stress distribution combined load on the bar at pitch condition.

Stress distribution at bar caused by axial load Fz and bending load Fy in roll position illustrated in detail in Fig. 14. Stress distribution as the reaction of applied force maximum happened at the end of the bar at boundary condition applied. Compressive stress area indicated by blue area and followed tension stress area indicated by sea blue area, green area, yellow area, orange area, and red are at maximum stress tension. The maximum stress value is stated at 270.7 MPa.

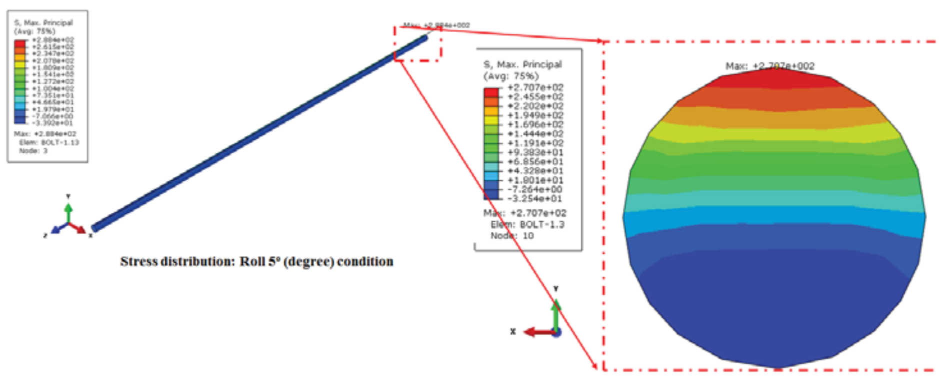

FIGURE 14. Stress distribution combined load on the bar at roll condition.

RESULT AND DISCUSSION

In Table 2, both taxi, pitch, and roll conditions have the same tightening position, H3, H4 | H5, H8, and boundary conditions. Stress distribution both for pitch and roll max. pointed at HA (boundary condition) in such value as 105.8 MPa and 101.2 MPa while taxi or off-mission position gained as 112.7 MPa. it can be concluded that there were no several differences between on and off the mission in the POD part. Detailed information is tabulated in Table 2.

TABLE 2. The results of the POD part stress analysis at 5 deg. both pitch and roll condition.

No.	Aircraft Position	Tightening	Fx, N	Fy, N	Fz, N	Max. Principal Stress FEM (MPa)
1.	Taxi (Block on/ on land)	H3, H4 | H5, H8	184	-	-	112.7
2.	Pitch 5 deg., Air-Mission	H3, H4 | H5, H8	16	-	183	105.8
3.	Roll 5 deg., Air-Mission	H3, H4 | H5, H8	-	-16	183	101.2

In Table 3 both taxi, pitch, and roll conditions have the same tightening position, H3, H4 | H5, H8, and boundary condition. Stress distribution both for pitch and roll max. value as 288.4 MPa and 270.7 MPa while taxiing or off-mission position gained as 7.39 MPa. it can be concluded that there was such amount of difference significantly between on and off the mission in the threaded bar part. Detailed information is tabulated in Table 3.

TABLE 3. Threaded bar stress analysis.

No.	Aircraft Position	θ^{O}	α^{O}	Fx, N	Fy, N	Fz, N	Max. Principal Stress FEM (MPa)
1.	Taxi (Block on/ on land)	-	-	184	-	-	7.39
2.	Pitch, Air-Mission	5 deg.	-	16	-	183	288.4
3.	Roll, Air-Mission	-	5 deg.	-	-16	183	270.7

The manual calculation for load and stress analysis for the threaded bar can be approximated with bar fixed at the end and occupied with combined load, axial load combined with bending load. Formula to approximate the maximum stress while combined load happened can be stated with Eq. (4) which is constructed by Eqs. (1) and (2), and additional input information at maximum stress condition by Eq. (3).

$$\sigma_{z,1} = \frac{F_z}{A} \tag{1}$$

$$\sigma_{z,2} = -\frac{F_y(z-L)}{I_x}.y' \tag{2}$$

$$\sigma_{z,Max} = \frac{F_z}{A} - \frac{F_y(z-L)}{I_x}.y' \tag{3}$$

$$\sigma_{z,Max\ Principal} = \frac{F_z}{A} + \frac{F_y(L)}{I_x}.y'_{max} \tag{4}$$

(Occurred at the fixed end: y'=y'max and z= 0)

where

Fz	:	Load force acting at z-axis (N)
Fx	:	Load force acting at x-axis (N)
z	:	Refer to distance value from end-bar fixed (mm)
L	:	Refer to the total length of the bar (mm)
y'	:	y-axis distance from neutral axis (mm)
I_x	:	Moment area about the x-axis (mm4)
A	:	Cross-sectional area (mm2)
$\sigma_{z,1}$	:	Refer to axial stress caused by axial load, Fz (MPa)
$\sigma_{z,2}$	:	Refer to bending stress caused by bending load, Fy (MPa)
$\sigma_{z,Max}$	:	Refer to maximum principal stress caused by combined load axial, Fz and bending load, Fy at y' point (MPa)
$\sigma_{z,Max\ Principal}$	:	Refer to maximum principal stress caused by combined load axial, Fz and bending load, Fy at y'max (MPa)

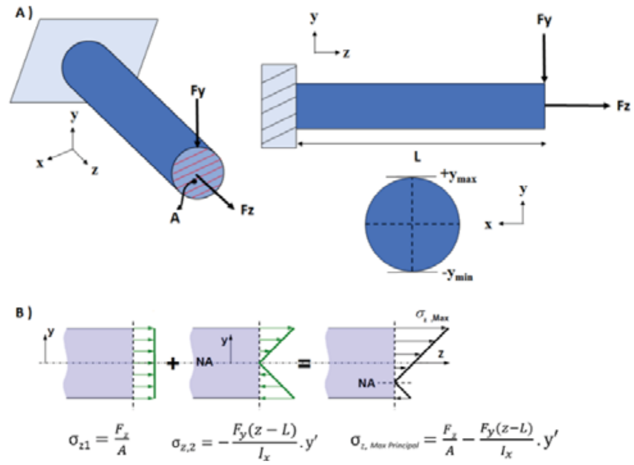

FIGURE 15. illustrated combined load and stress of a bar.

TABLE 4. Mechanics formula approximated for maximum stress, the principal of bar, both at pitch and roll.

θ^{O}	F_y (N)	F_z (N)	σ_y (MPa)	σ_z (MPa)	$\sigma_{Max\ Bending\ Stress}$ (MPa)
0	0	183,94	0,00	6,51	6,51
0,5	1,61	183,93	30,28	6,51	36,78
1	3,21	183,91	60,55	6,50	67,06
1,5	4,81	183,87	90,82	6,50	97,33
2	6,42	183,83	121,09	6,50	127,59
2,5	8,02	183,76	151,34	6,50	157,84
3	9,63	183,69	181,58	6,50	188,08
3,5	11,23	183,59	211,81	6,49	218,31
4	12,83	183,49	242,03	6,49	248,52
4,5	14,43	183,37	272,22	6,49	278,71
5	16,03	183,24	302,39	6,48	308,87

CONCLUSION

Tightening analysis was done by evaluating one single combination from eight tightening possible combinations which one that contributes at minimum stress distribution on the POD part while off or on the mission. A combination with tag number#7 was found to fulfill this requirement. Combination #7 that threaded bar occupied on H3, H4 & H5, H8. Stress maximum principal value that happened at 112.7 MPa while the others varied from 214 MPa to 117.9 MPa.

The result of POD part Analysis. shows that there was no such significant difference between stress distribution while taxiing (off-mission) with Max. Principal Stress value at 112.7 MPa, pitch 5 deg. with Max. Principal Stress value at 105. 8 MPa, and roll 5 deg. (on the mission) with Max. Principal Stress value at 101.2 MPa on POD part. But different facts reveal on the threaded bar by stress distribution analysis.

Threaded bar part analysis on this examination shows that taxi or off-mission position maximum principal stress value at 7.39 MPa while in pitch maximum principal stress value at 288.4 MPa and roll maximum principal stress value at 270.7 MPa. There was such amount difference stress value caused in pitch and roll condition bending load and stress happened then superposition tension stress about axial stress and bending stress while in taxi condition there was such axial load and stress happened only. because of this, need more consideration and more attention to mechanical properties such as tensile strength for the threaded bar while required for on mission with 5 degrees or over.

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