West Africa Built Environment Research (WABER) Conference
10th Anniversary Conference, 5-7 August 2019, Accra, Ghana
Proceedings Edited by Laryea, S. and Essah, E.
ISBN: 978 – 9988 – 2– 6010 – 1
DOI: https://doi.org/10.33796/waberconference2019.01

A STRUCTURAL ANALYSIS OF AN ADJUSTABLE DOCKING SYSTEM FOR MULTIPLE AIRCRAFT MODELS: CASE STUDY

Tawanda Mushiri[1], Marvin Maswera[2], Charles Mbohwa[3]
[1,3]University of Johannesburg, Bunting Road Campus, Johannesburg, South Africa.
[2]University of Zimbabwe, Mt Pleasant, Harare, Zimbabwe

A docking system was designed for the company under study. Since all movements in the dock will be achieved by the use of actuators initially probed by a central control unit, precise design was necessary. Distance is a critical issue in the operation of the platform. Two adjacent platforms must not attempt to get in contact with each other while there are people working on the lower platform of the two. The platform must not under any circumstance get in contact with the aircraft to avoid collision and damage of the aircraft. A mechanical Prototype was developed to illustrate the working principal of the dock and is working well to demonstrate this docking system. The implementation of this research paper can result in huge savings to the airline which can be seen in the long run. With further programming, information on several aircraft can be loaded into the docking system and once the aircraft name has been inputted in the appropriate field, the dock can automatically adjust to fit the dimensions of the aircraft under docking. The dock can also be developed to incorporate the lifting of heavy materials which will be loaded on or off the aircraft. 800N weight of human being was considered in this design. von Mises stresses were analysed to determine when failure can occur and some possible areas of concentration were shown to avoid breakdown of structure whilst in use. The stress is useful for one to be careful not to exceed limits.

Keywords: adjustable docking system, aircraft, automated, case study, design

INTRODUCTION AND BACKGROUND

It goes without saying that an aircraft is an asset in the air and a liability on the ground (Simon Finn, 2016). Thus with every minute that passes, an airline is either making profit or it is suffering an economic loss. It is therefore very important to minimise unnecessary ground hours for every aircraft. However, some stoppages cannot be evaded. For example, every machine needs to be rested for at least 10% of its operation time (Sullivan et al., 2010). On the other hand, maintenance is inevitable and the airline industry allows no room for mistakes. This leads to multiple intensive checks having to be carried out consistently. The C-check is one

[1] tawanda.mushiri@gmail.com
[2] marvinmaswera@gmail.com
[3] cmbohwa@uj.ac.za

Tawanda Mushiri, Marvin Maswera, Charles Mbohwa (2019) A structural analysis of an adjustable docking system for multiple aircraft models: case study In: Laryea, S. and Essah, E. (Eds) Procs West Africa Built Environment Research (WABER) Conference, 5-7 August 2019, Accra, Ghana, 21- 40

heavy check conducted on every aircraft after about 18 months of service. During this check, almost every part of the airplane has to be accessed (Cross, 2006).

Airplanes by design are very huge machines and accessing most parts of the aircraft from the outside (like the wings and vertical stabiliser) can only be achieved by using aiding equipment. Docks, scaffold like structures used during major checks, fall under this category of equipment. A good docking system must give the operator the most optimum and least strenuous work position during checks while simultaneously not posing any threat of harm to the aircraft structure. For this reason, some docks are specific only to one aircraft. In some other cases, a cage like structure is attached to rails in the roof of the hangar and then suspended, moving around the hangar. All these systems of course have their own advantages and drawbacks. Figure 1 shows a docking system in practice.

Figure 1: Docking system

The docks at case study are designed specifically for one model of an aircraft. With limited aircraft models in an airline, this might not be seen as a challenge at the moment but this system's limitations are seen once the airline purchases different models of aircrafts. Even aircrafts supplied by the same manufacturer do not share the same dimensions hence there will be need to have multiple sets of docks in and around the available hangars. This becomes ridiculously space consuming and at some point impractical if the airline keeps growing big to such an extent that we have fleets of different models of aircrafts.

The docks also proved to be labour intensive. During setup, most engineers had to be involved in the setup. They assisted in accuracy during setup and also in power, and at one point there was need for a forklift. With automation, all these problems can be addressed.

The docking system fulfilled the following:

- Be manufactured at minimum cost
- Be automated and require less labour for set up as compared to the current one o Have less setup time than the existing one

- Be flexible and sustainable i.e. must be flexible enough to be modified in case a new model with unseen dimensions has been released
- Be cheap to maintain
- To come up with a prototype which illustrates the major principles of operation of the platforms.

Literature survey of docking systems

Commercial airplanes are very large. Most exterior, and many interior parts are well beyond the reach of a maintenance technician standing on a facility's floor. To allow technicians to reach these areas, various work platforms are used in maintenance facilities (Smith, 2003). With the scaffolding system, the strength of the structure is ensured by the combination of different struts and ties, just like in an ordinary scaffold. Joints are usually bolted and whilst the bulk of the structure is made of aluminium, the base which rests on wheels for mobility's sake is made of steel. This is shown in Figure 2.

Scaffolding system

Figure 2: Scaffolding system.

This is a traditional system which has been around for a long time. It is the one currently used at company under study.

With the scaffolding system, the strength of the structure is ensured by the combination of different struts and ties, just like in an ordinary scaffold. Joints are usually bolted and whilst the bulk of the structure is made of aluminium, the base which rests on wheels for mobility's sake is made of steel.

Fitting in a scaffold dock is more of manual work requiring group effort. This owes to its weight and archaic design. At some point, forklifts can even be used to aid.

Modular system

Figure 3: Modular system

Little differences can be cited between modular and scaffold systems. The major difference is that modular systems, since they are smaller in size, can be combined with other platforms to suit specific jobs. This makes them suitable for different models of aircrafts if they get the perfect and most appropriate combinations. Modular systems is shown in figure 3.

Teleplatform

Figure 4: Teleplatform

Teleplatform is a fairly modern system as far as aircraft maintenance is concerned. It involves structures attached to the roof of the hangar which operate from an aerial point. Mechanics will be standing in a cage like structure at the bottom end of a vertical member whose height can be varied to the desired level depending on the point of work (Sauvage, 1989). This system is usually integrated to the hangar and it therefore turns out to be space saving compared to other systems. In most cases it is not fully automated, requiring operators to sometimes climb up to the cages and lower or lift the cage to the desired height by use of electronic controls. However, its design has to be integrated into the hangar design and therefore it is usually not applicable to already existing hangars (Rodgers, 2010). Another setback in teleplatforms is their inability to access relatively low sections like the underwing which would still be too high for regular stepladders.

Summary

Maintenance and Repair Organisations (MROs) have become the most common form of docking in the industry. Detail on this has been outlined in the following subsections. Gulf Aircraft Maintenance Company (GAMCO), also known as Abu Dhabi Aircraft Technologies (ADAT) is a very reputable Maintenance and Repair Organisation (MRO) in the Middle East. Apart from giving full line maintenance support to Etihad Airways among others, GAMCO is also responsible for base maintenance of some fleets of major airlines. With different customers having different models of aircrafts, GAMCO's support equipment has to be flexible.

Figure 5: A typical Fly Emirates hangar, yellow teleplatforms attached to the roof

Figure 6: An aircraft under maintenance at a Fly Emirates hangar (Emirates, 2017).

Challenges faced by existing platforms

Current designs have different challenges. Most of them are of fixed heights. For big airlines with many hangars this is not a very big challenge as they can afford to group aircrafts and maintain them systematically in appropriate hangars but for smaller airlines with limited hangars, buying multiple sets of platforms seems to be the best solution currently (Reynolds, 2004). On the face of it this might seem normal and procedural but on the other hand, it has its own shortfalls. Firstly, it is uneconomic in terms of space since all these platforms have to be stored somewhere. This might even transform to storage rentals and this is a non- value adding activity all in all (Redford, 2005). Secondly, the idea of buying platforms for every aircraft bought is a direct expense. Whilst some people may think that this is part of aircraft manufacturers' courtesy, it is not as these are usually bought from individual companies which specialise in manufacturing aircraft maintenance support equipment. Also, once the aircraft has reached the end of design life, the platforms will be disposed. Usually they cannot be resold since the aircraft that uses such platforms would be considered to be outdated, making those platforms outdated too. Fitting of platforms is a very critical process in which not only the aircraft is at risk to damage but where also the safety of operators is a very sensitive issue. Maximum concentration and high coordination are therefore the two most essential attributes required for this activity. For any system, the aircraft is first pulled into the hangar and positioned for the scheduled maintenance. The platforms are then fit into their appropriate position.

Aim of the study
To design a docking system which is adjustable to meet the specifications of different models of airplanes. This is to do a structural analysis of an adjustable docking system for multiple aircraft models: case study.

Objectives of the study
The docking system designed must

- Be manufactured at minimum cost
- Require less labour for set up as compared to the current one
- Have less setup time than the existing one
- Be flexible and sustainable i.e. must be flexible enough to be modified in case a new model with unseen dimensions has been released
- Be cheap to maintain
- To come up with a prototype which illustrates the major principles of operation of the platforms.

DESIGN FORMULAE

The basic formula for designing scaffolding is as follows which is used to determine the weight of the aeroplane under design.

Equation 1: Scaffold equation design.

$$W = W_T(N_L + N_D)\left[1.5H + nH + \frac{2}{3}D + B\right] + 3W_C(N_L + N_D) + 0.75w_D BDN_D + nN_L W_C$$

Where W_T = unit weight of each tube;
W_C =average weight per coupler;
N_L =number of lifts;
N_D =number of loaded lifts;
n =number of standards per standard group;
H =lift height;
D =c/c of standard transversely;
B =c/c of standard longitudinally;
w_D =uniformly distributed deck load (Brown, 2013)

For structural engineering we use the following;

Equation 2: Simple bending equation $\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$

Where;
M-applied bending moment
E- Young's modulus of elasticity
σ- Stress at distance y from the neutral axis
I- second moment of area of the beam cross-section about the neutral axis
R-radius of curvature of the neutral axis at the section
y- distance from the neutral axis of the beam cross-section (Hearn 1978)
Equation 3: Moment of simple beam

$$M = EI\frac{d^2y}{dx^2}$$

where M, I and E have their usual meanings as given in the previous equation and $\frac{d^2y}{dx^2}$ mathematically equals $\frac{1}{R}$, the inverse of the radius of curvature of the neutral axis at the section

Equation 4: The maximum allowable stress of a member

$$P_e = \frac{\pi^2 EI}{L^2}$$

Where P_e = maximum allowable stress,
L= length
E and I have the same values as mentioned before

MATERIALS AND METHODS

Table 1. Designed docking system

PARAMETER	MINIMUM	MAXIMUM
Height (m)	3 (lowest deck)	20 (highest deck)
Live weight carrying capacity (per platform) (kg)	300	1400
Length(m) (along the aircraft body)	3	15
Breadth(m) (from the aircraft going outwards)	3	6
Number of bays	2	4
Live weight carrying capacity (per bay) (N)	1000	7200
Number of people accommodated per bay	1	8

The docking system was made up of individual platforms which can be put together to ensure continuity during working. The parameters given in this section will be the extremes. Aluminium was selected for bay and rail design to avoid any damage on the aircraft should the two come in contact. High carbon steel was selected for the base and hardened chrome was used for hydraulic cylinder design. The docking flexible was made as a prototype for testing purposes.

The docking system was made up of individual platforms which can be put together to ensure continuity during working. The parameters given in this section will be the extremes. Sample size under study is 104 people who interacted with researchers and giving some ideas.

Solid Works software was used in the design and simulations.

RESULTS AND DISCUSSION

The designed concept has a fixed minimum distance between to adjustable decks. It can be completely folded as shown in Figure 7. When fully opened, all three decks will be available for use. Figure 7 shows an intermediate stage of the system where only 2 platforms are in use. The red hydraulic actuators will allow for height adjustment for the decks involved. Please note that in the following calculations, the average weight of a grown up human being will be assumed to be 800N and this will be the design weight. Appendices are further expanded to show exactly what was under study.

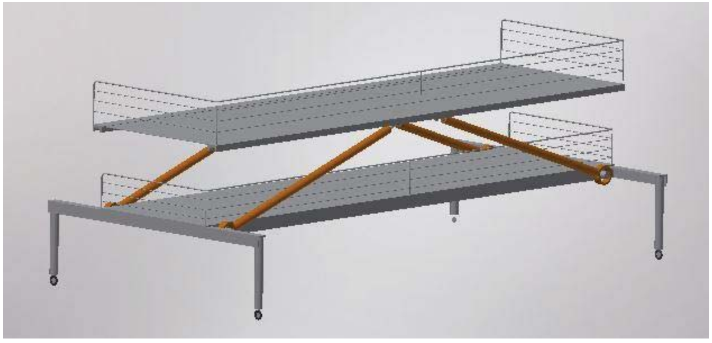


Figure 7: Collapsed Dock

SELECTED DESIGN

Calculations and design

Each will be made of an aluminium alloy. One bay will be designed for 7200N. However, since this is equal to the weight of 9 grown-ups, the weight will be assumed to be uniformly distributed at 800N/m. Designing for a maximum length of 15m, the calculation is as follows. Assuming the uniformly loaded structure with fixed ends,

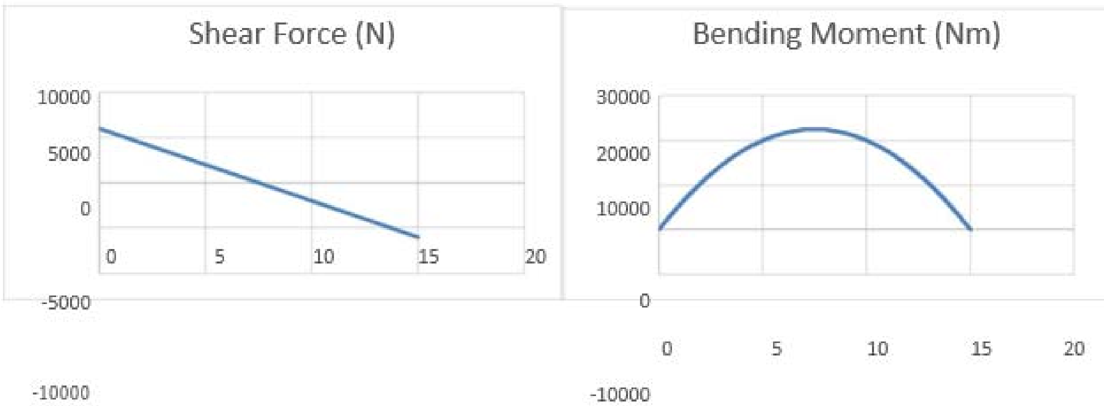


Figure 8:a.) Shear Force diagram with Shear Force/N (y-axis) plotted against distance/m (x-axis) b.) Bending Moment Diagram showing Bending Moment/Nm (y-axis) vs Distance/m (x-axis)

Assuming the uniformly loaded structure with fixed ends,

$$B.M = 6000x - 400x^2$$

where B.M is the Bending Moment and x is the distance from one end of the platform taken to be the reference i.e. the left end.

Integrating once $\frac{\partial B.M}{\partial x} = 6000 - 400x$. By equating this to zero to find the value of x at the turning point, x=7.5m. By substituting this value into equation 6.1, B.M=22500Nm. This is used as M in $\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$.

The shear force and bending moment diagrams are shown in figures 6.1 and 6.2 respectively.

Integrating $EI\frac{d^2y}{dx^2} = \frac{wlx}{2} - \frac{wx^2}{2}$ twice we get $EI\frac{dy}{dx} = \frac{wlx^2}{4} - \frac{wx^3}{6} + c_1$ and $EIy = \frac{wlx^3}{12} - \frac{wx^4}{24} + c_1x + c_2$ where c_1 and c_2 are constants. Applying boundary conditions i.e. when x=0 y=0 and when x=l y=0. Also, when x $= \frac{l}{2}, \frac{dy}{dx} = 0$. Solving using these boundary conditions, it can be established that c_1=-112500Nm and c_2=0. Therefore $EI\frac{dy}{dx} = \frac{wlx^2}{4} - \frac{wx^3}{6} + c_1$ becomes$EIy = \frac{wlx^3}{6} - \frac{wx^4}{24} - 112500x$. To have a maximum deflection of 100mm, we solve for y. Given that E for alumina is$3.7\text{x}10^{11} N/m^2$ and with the knowledge that the maximum bending occurs at the centre i.e. at x=L/2, I was calculated and from equation 2.5, d was found to be 22.507mm, therefore the thickness of the bay will be at least 13mm. The mass of this bay was calculated to be about 2320kg, which would result in at least 10 tonnes of the complete design of the platform. Therefore, for weight considerations, a 0,005m sheet has been used instead while supported by 7a rigid frame of aluminium solid round bars of 0.02m diameter each as shown in figure 6.4. This gave a mass of approximately 1430kg which is at least a 38% weight reduction per bay.

For the hydraulic actuator, the total weight shared among the four actuators will be 21500N. Sizing an actuator is basically determining 3 things; the bore size, the rod size and the stroke. In this section, the design load was calculated.

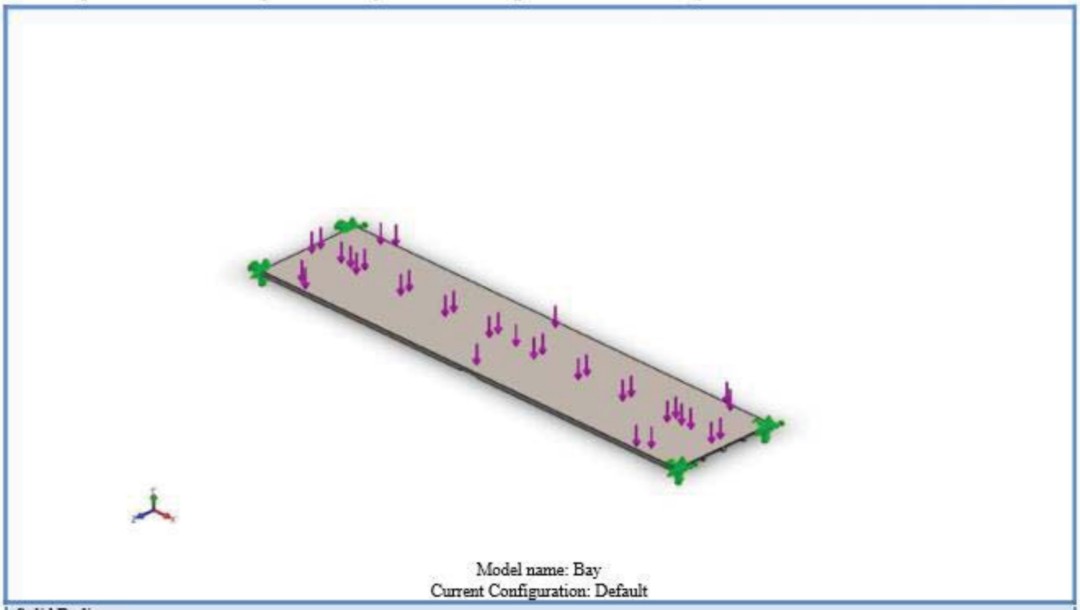
Of the many types of hydraulic rams available, the single acting cylinder has been chosen and it will use weight on the return stroke. All the four cylinders are supposed to take up a combined load of 21500N. This leaves an average of 5375N per cylinder. To determine the minimum bore diameter, P=F/A, hence A=F/P, with a maximum working pressure of 150bars. After using a safety factor of 4, this gives a safe working area of 0.0229m^2, hence the diameter is 0.1708m which is 170.8mm. The design bore diameter was taken to be 175mm.

To determine the rod diameter, equation 4 was used to determine I then find the diameter. Alumina was used once again because of its high elastic modulus. After using a safety of 4, D was found to be 129.2mm which was rounded up to 140mm for standard shaft sizing.

Electric motor and hoist were also designed and selected in this paper.

Simulations and analysis

Simulations were carried out to determine the maximum stress, strain and displacement associated with the bays. The results are given in this section. Strain, displacement and strain were analysed on the platform bays. The assumption was that the bay is uniformly distributed. Figure 10 shows the bay.



Solid Bodies

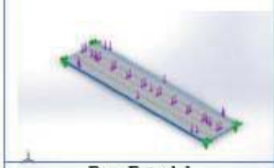
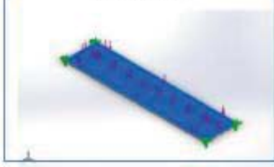
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude7 	Solid Body	Mass:27772.4 kg Volume:3.47155 m^3 Density:8000 kg/m^3 Weight:272170 N	C:\Users\DELL\Documents\Engi n eering Platform\Bay frame.SLDPRT May 18 14:45:50 2017
Boss-Extrude1 	Solid Body	Mass:1074.15 kg Volume:0.27125 m^3 Density:3960 kg/m^3 Weight:10526.7 N	C:\Users\DELL\Documents\Engi n eering\HENMECH\Level 4\ME460\Final Platform\Bay\Bay.SLDPRT May 18 02:52:51 2017

Fig. 10. Solidworks analysis

Table 2. Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off

Table 3. Units

Unit system:	SI (MKS)
Length/Displacement	Mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Table 4. Material Properties

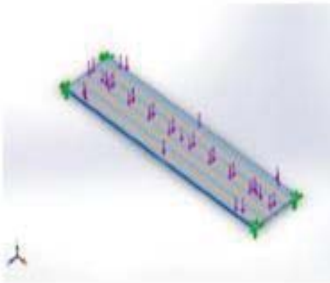
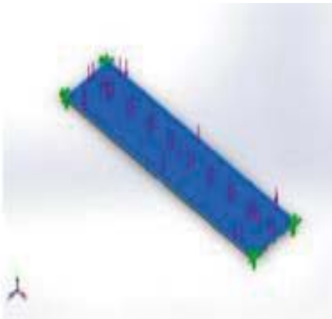
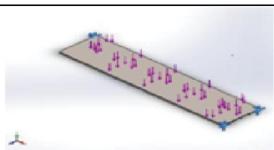
Model Reference	Properties		Components
	Name:	AISI 321 Annealed Stainless Steel (SS)	SolidBody 1(Cut-Extrude7)(Bay frame-1)
	Model type:	Linear Elastic Isotropic	
	Default failure criterion	Max von Mises Stress	
	Yield strength:	2.34422e+008 N/m^2	
	Tensile strength:	6.2e+008 N/m^2	
	Elastic modulus:	1.93e+011 N/m^2	
	Poisson's ratio:	0.27	
	Mass density:	8000 kg/m^3	
	Thermal expansion coefficient:	1.7e-005 /Kelvin	
Curve Data: N/A			
	Name:	Alumina	
	Model type:	Linear Elastic Isotropic	
	Default failure criterion	Unknown	
	Tensile strength:	3e+008 N/m^2	
	Compressive strength:	3e+009 N/m^2	
	Elastic modulus:	3.7e+011 N/m^2	
	Poisson's ratio:	0.22	
	Mass density:	3960 kg/m^3	
	Shear modulus:	1.5e+011 N/m^2	
	Thermal expansion coefficient:	7e-006 /Kelvin	

Table 5. Loads and Fixtures

Fixed-1		Entities: 4 edge(s) Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-0.643555	7200.73	-0.108887	7200.73
Reaction Moment (N.m)	0	0	0	0

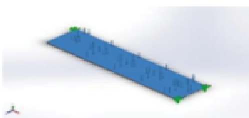
Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Type: Apply normal force Value: 7200 N

Table 6. Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.643555	7200.73	-0.108887	7200.73
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Table 7. Stress analysis

Name	Type	Min	Max
Stress1	VON: von Mises Stress	5729.76 N/m^2 Node: 1775	3.31493e+007 N/m^2 Node: 4448

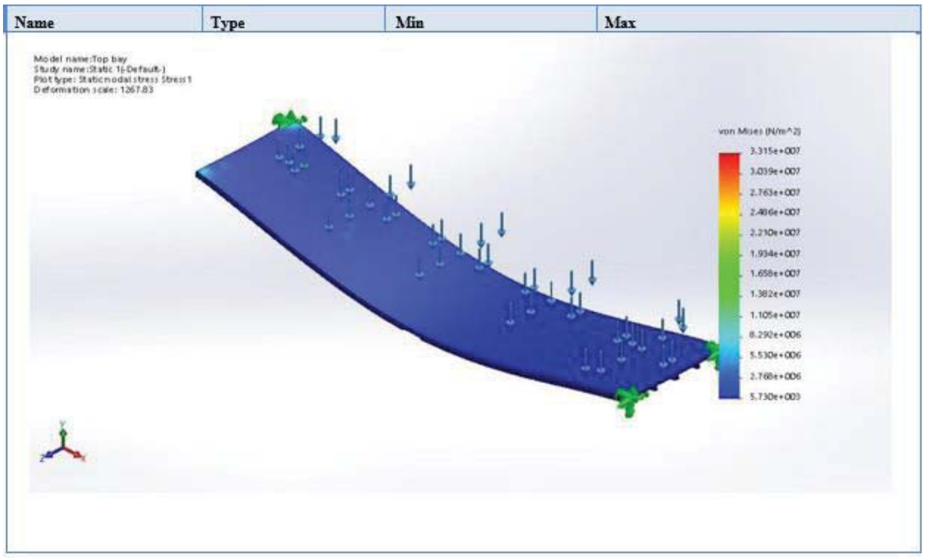


Fig. 11. Stress analysis results

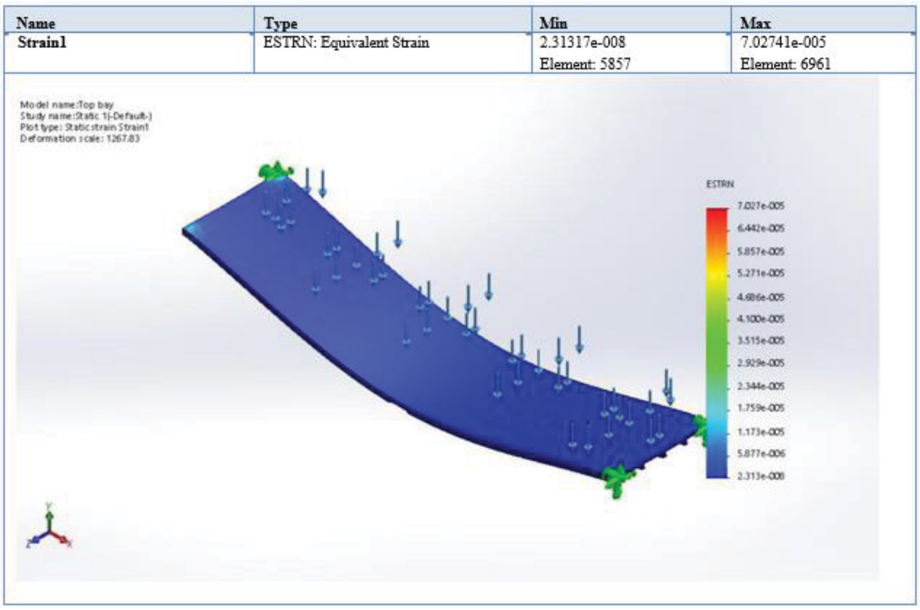


Fig. 12. Maximum Strain

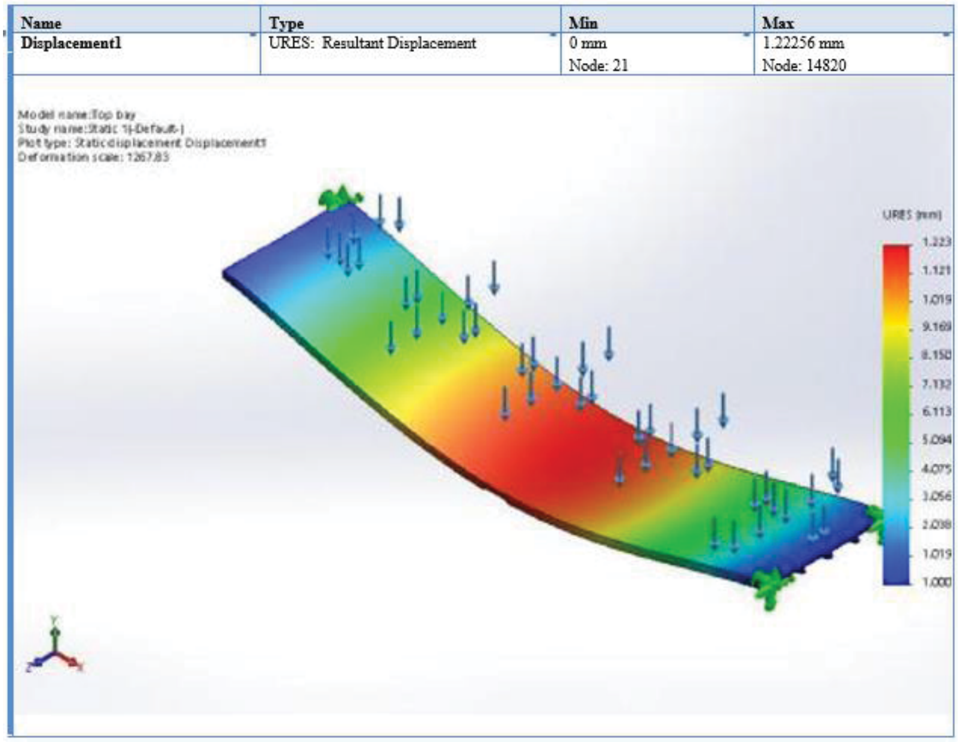


Fig. 13. Maximum Displacement

Illustrations

Docked Plane

In this section, views of a docked plane will be illustrated.

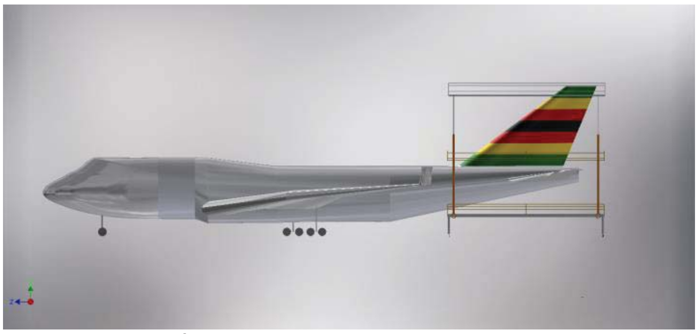


Figure 14: Platforms in place at maximum working height


Figure 15: Platforms in place (a) Front perspective; (b) Rear perspective

It should be noted that whilst only one platform was used in this illustration, several platforms might be used to service many parts of the aircraft at once. The major advantage of this system is that only the necessary platforms are used at a time.

The Prototype

A mechanical Prototype was developed to illustrate the working principal of the dock. The two extreme stages of the Prototype will be illustrated in this section

Figure 16: Prototype manufactured

Figure 17: With the highest deck at the highest position

CONCLUSION AND RECOMMENDATIONS

The aim and objectives have been achieved. The implementation of this project can result in huge savings to the airline which can be seen in the long run. A model was manufactured even though due to financial lack, only the mechanical aspect of it was tackled. This means that a docking system is designed for safety of human beings to be able to do maintenance in a better environment. It is portable and can be used from one aeroplane to another and is very easy to maintain. The designed docks were linked to the already existing designs in this research as shown in appendices. The docking system designed is only one of its kind which is flexible and foldable.

With further programming, information on several aircraft can be loaded into the docking system and once the aircraft name has been inputted in the appropriate field, the dock can automatically adjust to fit the dimensions of the aircraft under docking. The dock can also be developed to incorporate the lifting of heavy materials which will be loaded on or off the aircraft. The limitations are obviously inevitable as new technologies are ongoing, this may fit for a while and then go out of fashion.

ACKNOWLEDGEMENTS

Would like to thank University of Johannesburg for funding this paper to be registered in this conference.

REFERENCES

Brown, R. 2013. *Code Of Practice For Metal Scaffolding Safety*, Occupational Safety and Health Branch Of The Labour Department.

Cooper, J. 2008. Aviation Maintenance Technician Handbook.

Cross, S. 2006. Aircraft Maintenance Platfrorms. *In:* Engineering, S. C. (Ed.). Christchurch, New Zealand Southern Cross Engineering.

Emirates, E. 2017. Aircraft Maintenance [Online]. Available: http://www.emiratesengineering.com/en/010100.aspx?menu=1 [accessed 4 February 2017].

Hills, D. 2011. The Aircraft Advisor.

Lemberg, C. C. A. D. S. 2010. Major Airlines Of Europe [Online]. Facts On File. Available: http://www.nationsonline.org/oneworld/airlines/airlines_europe.htm [accessed 14 February 2017].

Lufthansa. 2016. Lufthansa Technik Ag [Online]. Available: Https://Www.Lufthansa-Technik.Com/A380-Maintenance-New-Dimensions [Accessed February 2 2017].

Milwaukee 2014. Milwaukee Cylinder Series Lh. Lh.

Parsons, J. 2010. Guide To Airline Maintenance. 2**,** 10.

Redford, G. 2005. Philosophy Of Airline Management. Australia Patent Application. 12 August 2005.

Reynolds, J. L. 2004. 1992). Aircraft Maintenance And Production Planning. Elsevier**,** 10.

Rodgers, C. P. 2010. Aircraft Ground Support & Maintenance Equipment. In: Industrial, L. (Ed.) Ground Support For Flying. Seville, Spain.

Sauvage, A. J. 1989. Air Force One Complex-Bigger Than Big - Modern Steel Construction. Elsevier**,** 38-43.

Simon Finn, S. G. 2016. An Overview Of The Commercial Aircraft *Elsevier***,** 128.

Smith, J. H. 2003. *Maintaining The Fleet*. Germany Patent Application.

Stanford, D. 2010. Support Equipment. 3.

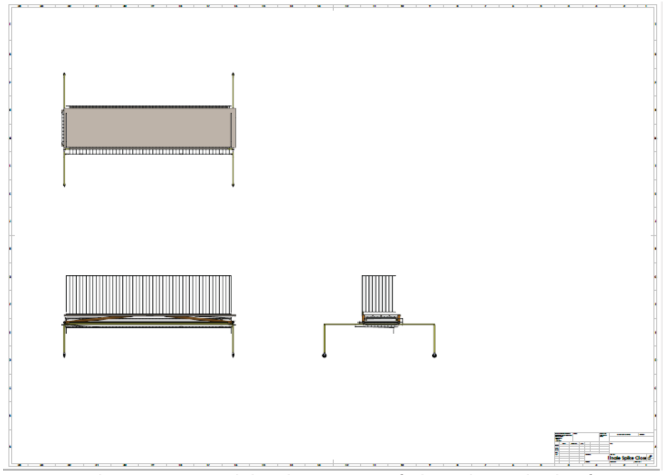
Sullivan, G. P., Pugh, R., Melendez, A. P. & Hunt, W. D. 2010. *Operations & Maintenance Best Practices,* Atlanta, Efficiency Solutions, Llc.

Upright, I. 2010. Aviation Maintenance Platforms And Docking Systems

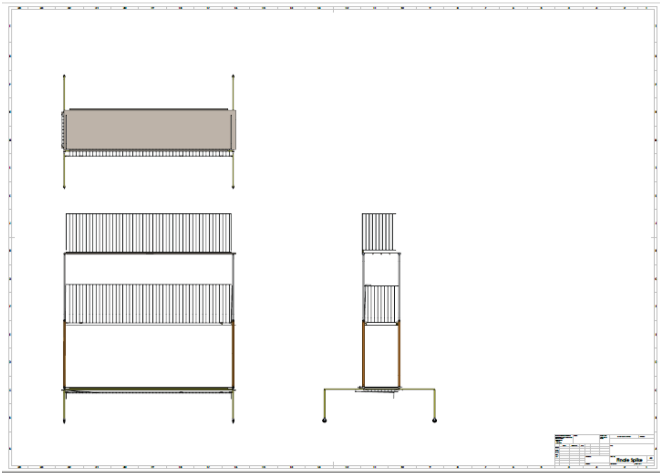
Wordpress. 2011. *Maintenance, Repair & Overhaul (MRO) Companies In The Middle East Countries* [Online]. Wordpress

Available: https://aircraftengineering.wordpress.com/tag/gamco/ [Accessed 30 January 2017].

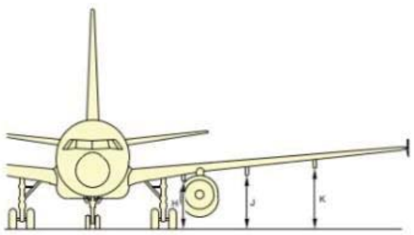
LIST OF APPENDICES



Appendix 1: Assembly drawing of the closed platform



Appendix 2: Assembly Drawings of the fully opened platform

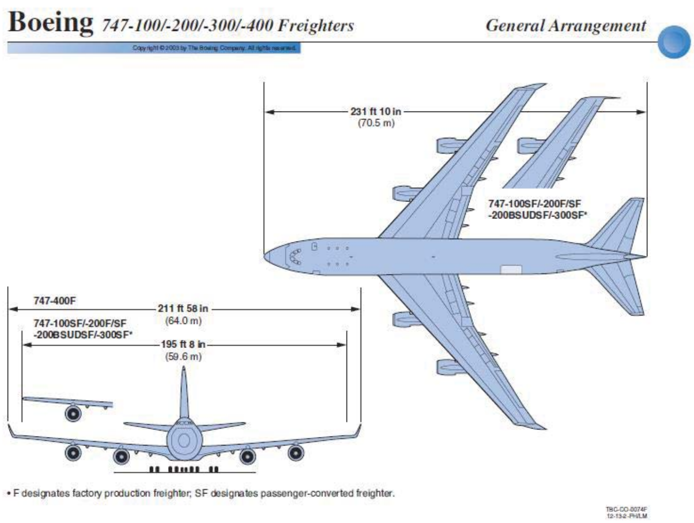


HEIGHT FROM GROUND						
	A/C IN MAINTENANCE CONFIGURATION MID CG		MAXIMUM RAMP WEIGHT FWD CG		MAXIMUM RAMP WEIGHT AFT CG	
	m	ft	m	ft	m	ft
H	2.68	8.79	2.58	8.46	2.56	8.40
J	3.08	10.11	2.98	9.78	2.95	9.68
K	3.48	11.42	3.37	11.06	3.34	10.96

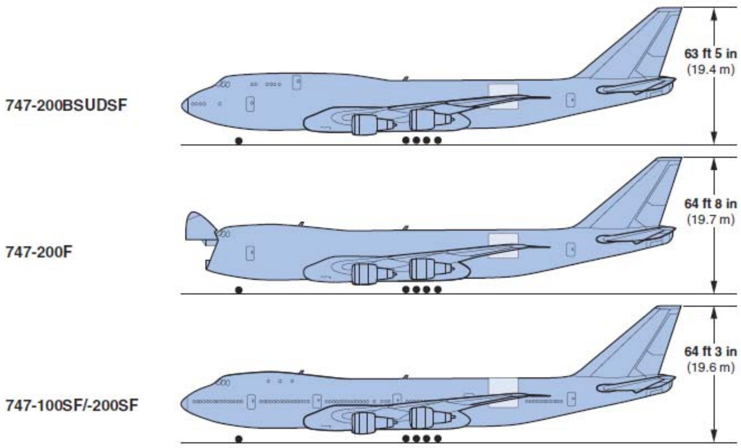
N_AC_020300_1_0180101_01_00

Ground Clearances
Flap Track Fairings Up
FIGURE-2-3-0-991-018-A01

Appendix 3: Airbus A320 Dimensions

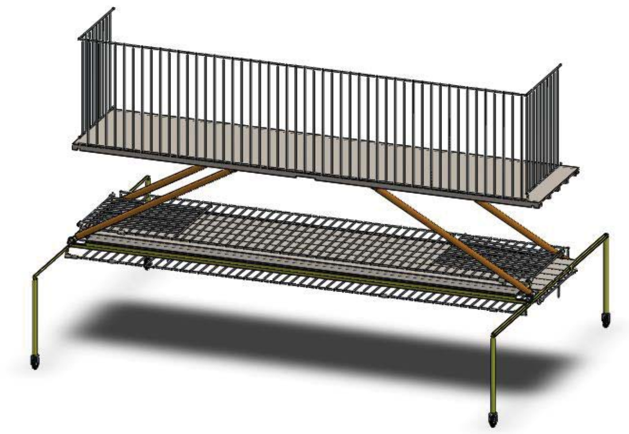


Appendix 4: Boeing 747 dimensions



Appendix 5: Boeing 747 variants and dimensions

Appendix 6: Fully Closed Platform



Appendix 7: As the hydraulic rams are being erected into position

Appendix 8: With the rams in their vertical working position

Appendix 9: Safety rails in the bottom corner deployed while simultaneously holding the rams in an upright position

Appendix 10: The highest platform elevated to maximum height

Appendix 11: The middle platform with the safety rails in place

Appendix 12: Maximum possible working heights