A Study on Frictional Effect at Contact Interfaces of Aero-Engine Bolted Joints

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Abstract: Bolted flange joints are extensively used in the aero-engine assembly, for fastening static components, rotors, external accessories, etc. The core functional requirements of bolted joints are to assemble the different parts, prevent the leakages at the assembly interfaces, maintain proper alignment and fit, and to meet the structural integrity requirements. The critical structural integrity requirements could be a load transfer, provide required stiffness and strength, and meet the design life, etc., depending on location of bolted joint deployment. Bolted joint in aero-engine also need to be custom designed with different design configurations and for optimal number bolts, for an assembly interface for minimal weight and to accommodate within the space constraints of aero-engine design, unlike bolted joint applications in conventional industry. This necessitates the design of different bolted joint configuration like back to back flange, stepped flange joint etc. It is essential to study the behaviour of load transfer, contact pressure distribution, deformation, and slip at the bolted joint interface to make an effective design of a specific configuration. The objective of present study is to study influence of friction on the load transfer behaviour, contact stress distribution, contact openings, and slip at the bolted jointed interfaces. Finite element study is carried out at on back to back and stepped flange configurations using ANSYS contact modelling.

Keyword: **Bolted Flange, Stepped Flange, Back to Back Flange, Frictional Analysis, Contact Analysis**

I. INTRODUCTION

Bolted joints are widely used in the aerospace industry especially in the aero engine assembly. This paper intends to examine and find out the different result variations of both friction and contact analysis for stepped flange and conventional back to back flange. The intention was also to find out the contact parameters and friction parameters using the various tools available in Ansys and Autodesk Fusion 360. FEA model has been created to assess the strength of the flange, Finite Element Method being one of the most powerful tools is used for the same.
The objective of this paper is to assess the flange separation, contact pressure distribution between flanges, deformation or the overall displacement, stress on the flange as well as the bolt for conventional back-to-back and stepped flange bolted joints. The structural analysis was carried out for external axial pressure and the required constraints were provided.

II. REVIEW OF LITERATURE

There are many researches going on in the field of aero-engine to provide better results in terms of flange strength, contact pressure between flange and bolt strength. We came across few already published papers that gave us better insight in flange design and helped us in providing different parameters for our paper. Before the availability of Computer Aided Design (CAD) and the advancement of technology, there were only approaches, theories, and experimental studies that were conducted in order to analyse the behaviour of bolted flange joints with metal to-metal contact beyond the bolt circle.

Schneider [1] used a beam theory model to solve flanges with metal-to-metal contact. His method was quickly adopted by the American Society of Mechanical Engineers (ASME) Code.

Jianbin Cao and Zhousuo Zhang [2] provided Quantitative characterization of contact pressure distribution in bolted joints by using a three-dimensional finite element model of the bolted joints using the software ANSYS, and pretension force and contact between the joint components that were accommodated in the model. According to the finite element analysis results, a polynomial equation system was derived for mathematical representation of contact pressure distribution in bolted joints. An experimental platform was constructed for the measurement of contact pressure distribution.

Montgomery [3] explained different methods of simulating bolted joints using ANSYS, FEA commercial software. He reviewed six different methods for simulating bolted joints, no bolt, coupled bolt, rigid body element (RBE) bolt, spider bolt, hybrid bolt and solid bolt. He has used half bolt sector to review all different simulation methods. He discussed merits and demerits of each type of simulation and left it to the designer to decide the options based on task specific requirements.

Many authors covered the difficulties associated with the conventional back-to-back flange bolted joints. There are hardly any literature papers available on stepped flange bolted joints which are also used in gas turbine aero engine. Present work is focused to carry comparative studies on behaviour of conventional back-to-back and stepped flange bolted joints.

III. MATERIALS & METHODS

3.1 Modelling

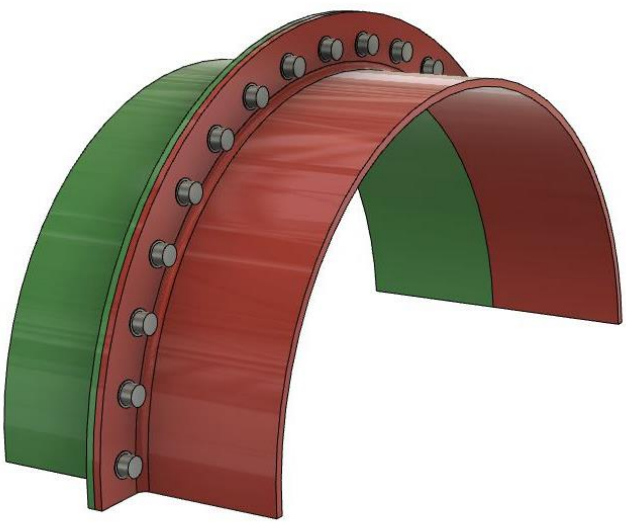

Figure I. Conventional Back to Back Joint

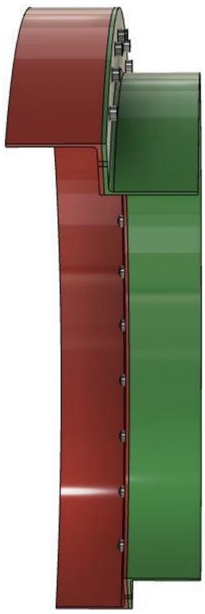

Figure II. Stepped Flange Bolted Joint

The design was considered to be for conventional back-to-back flanges and stepped flanges. They were modelled as steel bolt-nut set connecting the two flanges together in a circular pattern. M8 bolt and nut are used to connect the two flanges each 5 mm thick made of structural steel. A total of 36 bolts are used to clamp the two shell structures together. The thickness of the flanges is the same throughout with R5 mm fillets at the bends. The full sector models are shown in *Fig. I & II*.

3.2 Meshing

A half pitch sector was modelled for the FE analysis since the analysis of the entire joint wouldn't be practical and neither provide any more insights. Boundary conditions were chosen successfully to replicate the existing forces of the actual joint so that the results weren't skewed. The assembly of the half pitch model comprises of total three bodies, the two flanges and nut and bolt. For a more real-world oriented analysis, washers were also placed in contact between the nut, bolt and flanges. The softwares used for modelling and analysis are Autodesk Fusion 360 and ANSYS respectively.

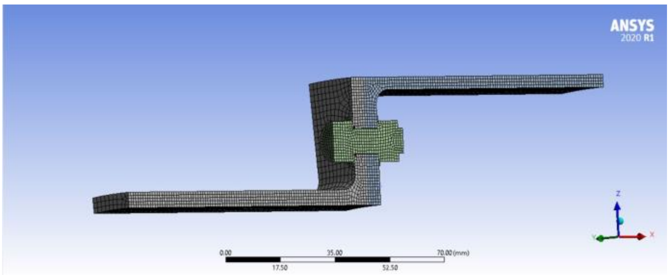

Figure III. FE Model of Stepped Flange Joint

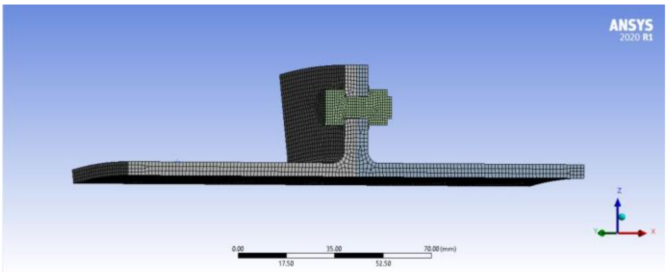

Figure IV. FE Model of Conventional Joint

The contact faces were between the nut and flange, bolt and flange, between the shank of the bolt and the flange and between the flanges themselves. These faces were all given frictional contact between them. These contacts were all studied for different frictional coefficients ranging from 0.1 to 0.6 for both the types of flanges.

3.3 Material Properties

The materials used in this model were all assumed to be made of structural steel with a yield strength of 250 MPa and ultimate strength is 460 MPa.

Table I. Material Properties

Density	Young's Modulus	Poisson Ratio	Bulk Modulus	Yield Strength
7850 kgm^-3	200 GPa	0.3	167 GPa	250 MPa

3.4 Boundary Conditions

Since only the half pitch model was being analysed, the boundary conditions needed to be accurate for the results to be valid. One end of the shell was constrained in all directions. The other end had a load of 20 MPa applied to it. The ends of the sector model were constrained in the tangential direction to imitate the real-world conditions.

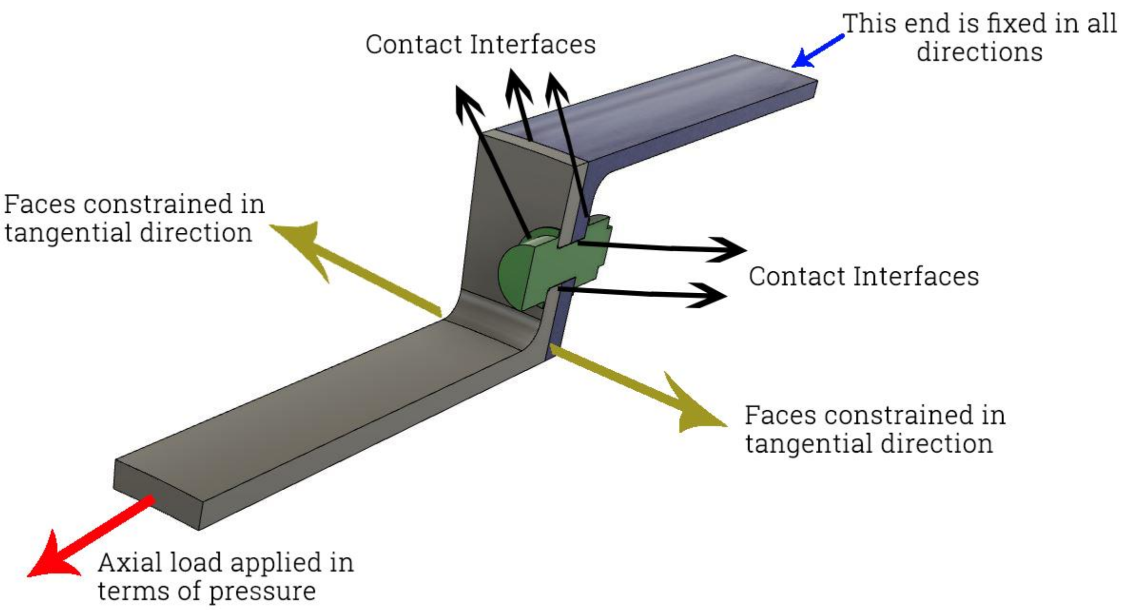

Figure V. Boundary Conditions on the Half Pitch Model

IV. RESULT & DISCUSSION

Table II. Result of Stepped Joint

Frictional Coefficient		0	0.1	0.2	0.3	0.4	0.5	0.6
Total Deformation (mm)	Lower Flange	39.521	39.479	39.456	39.436	39.419	39.403	39.389
	Upper Flange	15.925	15.921	15.919	15.916	15.914	15.913	15.911
	Bolt & Nut	16.996	17.099	17.092	17.087	17.083	17.079	17.076
Equivalent Stress (MPa)	Lower Flange	647.25	638.23	630.11	622.98	616.61	610.9	605.69
	Upper Flange	1380.5	1380.5	1380.5	1380.5	1380.5	1380.5	1380.5
	Bolt & Nut	802.65	811.68	818.5	819.2	816.44	811.31	804.52
Normal Stress (MPa)	Lower Flange	45.529	45.872	46.181	46.415	46.598	46.738	46.486
	Upper Flange	1494.8	1494.8	1494.8	1494.8	1494.8	1494.8	1494.8
	Bolt & Nut	505.66	533.81	595.02	625.92	650.2	669.37	684.8

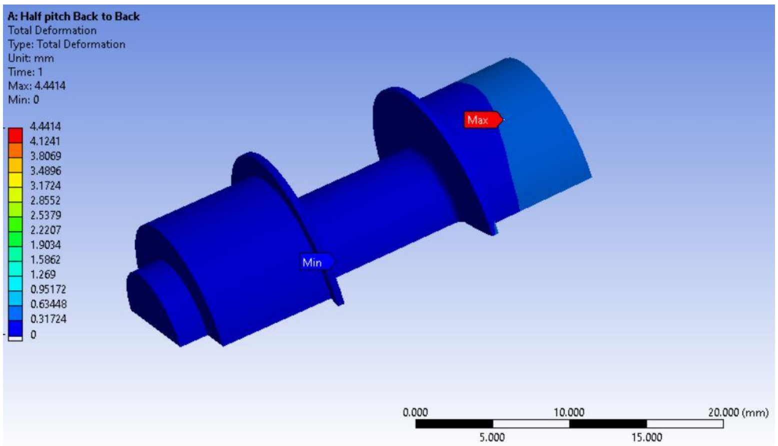

Figure VI. Max Deformation in the Bolt

The analysis showed that as the coefficient of friction increased, the total deformation in the flanges also decreased given in *Fig. VII*. Another interesting result is that the deformation was much larger in the flanges in the stepped flange. *Fig. VIII* shows that the bolt also experienced maximum stress in the back-to-back joints while the stress being lesser in the stepped flange. A contact tool also revealed that area near the bolt hole is either sticking or is near for the stepped flange.

Table III. Results of Back-to-Back Joint

Frictional Coefficient		0	0.1	0.2	0.3	0.4	0.5	0.6
Total Deformation (mm)	Left Flange	4.4233	4.6733	4.4078	4.4093	4.3893	4.3706	4.353
	Constrained Flange	0.3677	0.3527	0.3664	0.3663	0.3655	0.3646	0.3636
	Bolt & Nut	0.4542	0.4582	0.456	0.4563	0.4555	0.4538	0.4525
Equivalent Stress (MPa)	Left Flange	1127.9	1124.6	1113.8	1113.2	1106.4	1100.2	1094.3
	Constrained Flange	1309.9	1322	1321.9	1321.7	1315.8	1310	1304
	Bolt & Nut	1949.6	1783.7	1721.3	1727	1693.2	1663	1635.8
Normal Stress (MPa)	Left Flange	164.96	163.42	162.52	162.45	161.89	161.37	160.88
	Constrained Flange	168.55	163.42	167.28	167.21	166.87	166.54	166.22
	Bolt & Nut	1810.2	1730.6	1697.3	1699.3	1681.1	1664.9	1650.2

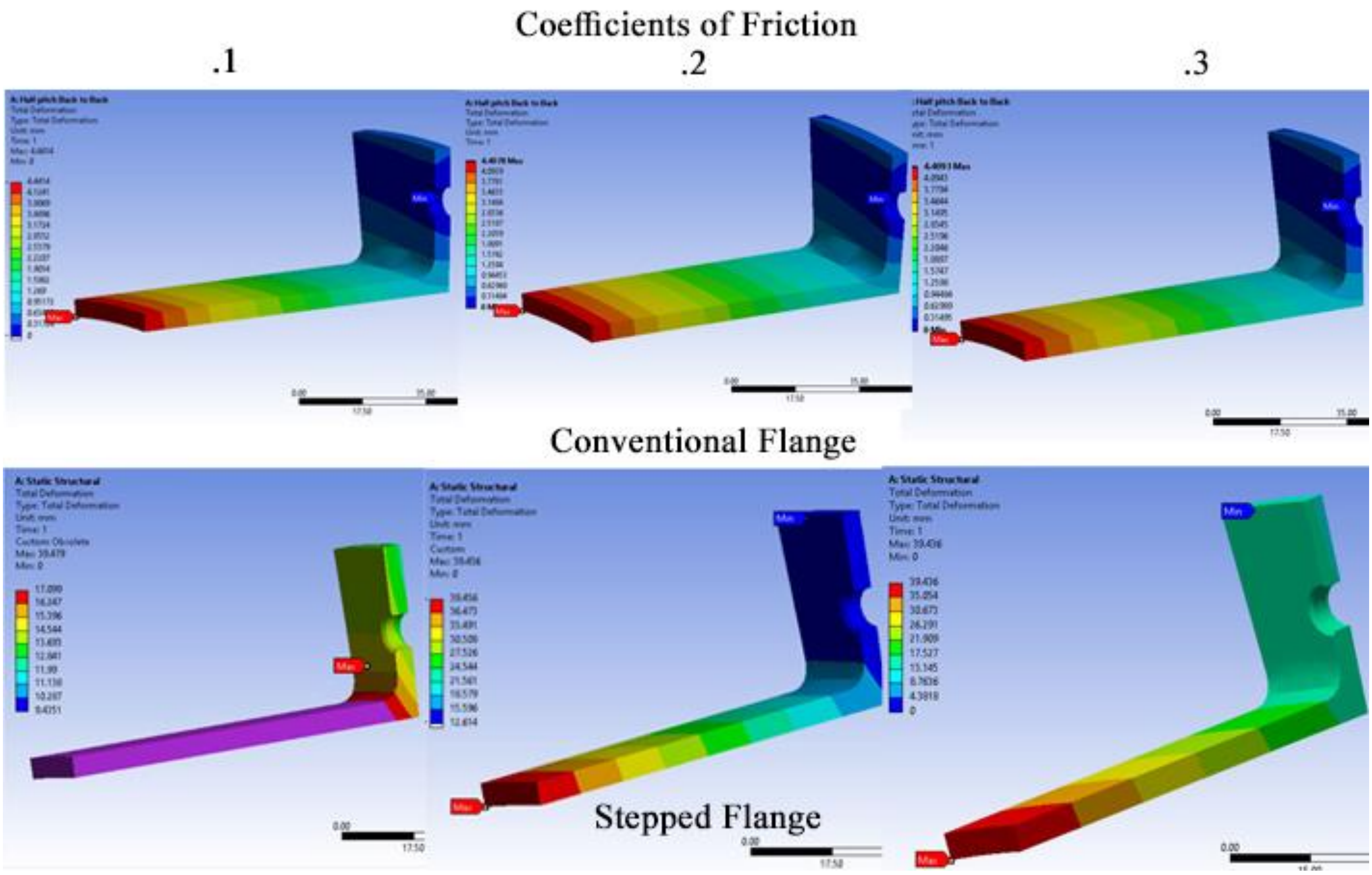

Figure VII. Deformation of the Flanges

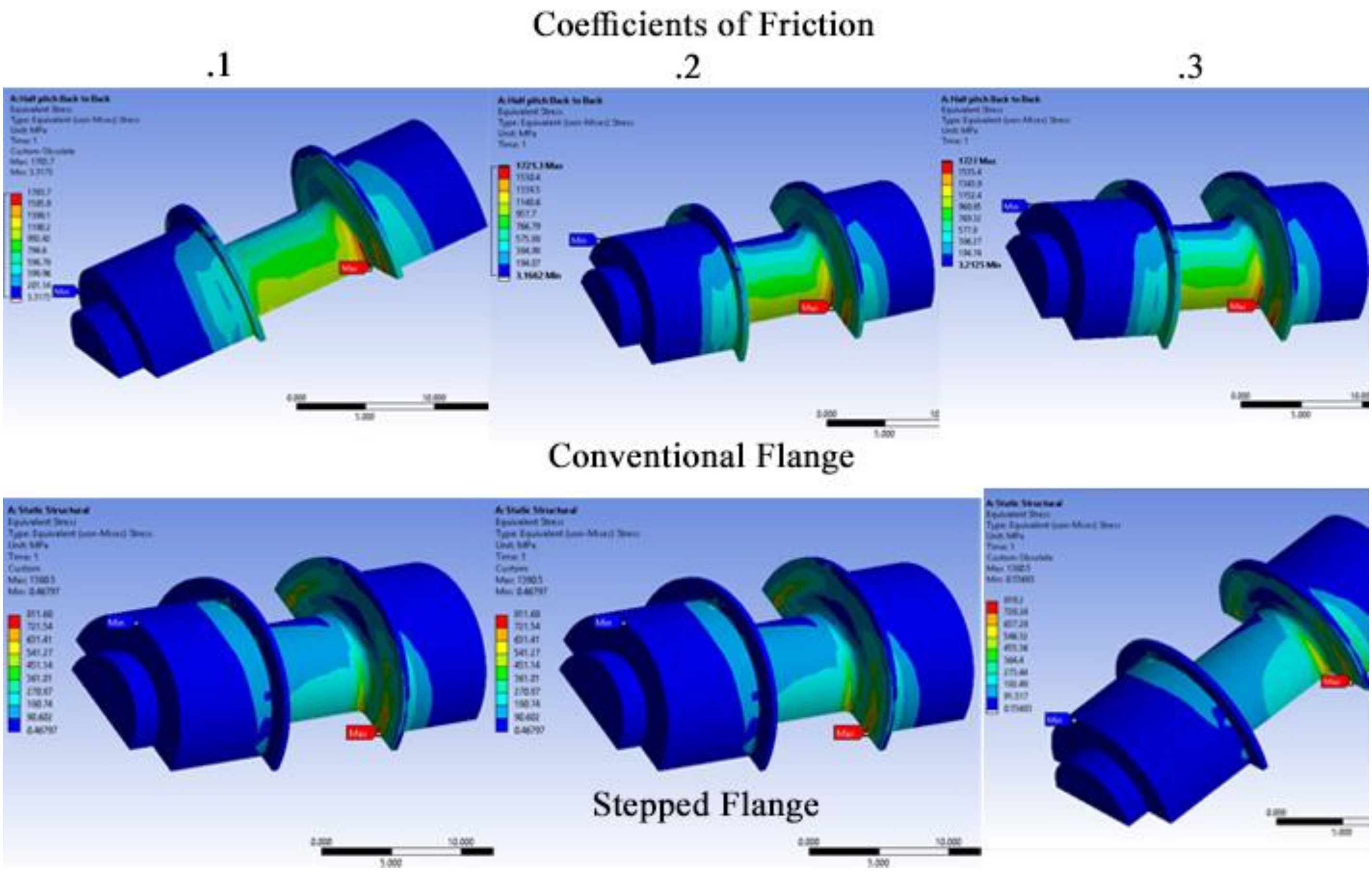

Figure VIII. Stress in the Bolt

V. CONCLUSION

The insights gathered regarding the behaviour of conventional back to back and stepped flange bolted joints for external pressure and different values of coefficient of friction have been very significant. These findings help various engineers and designers in achieving the necessary capability within the space, weight constraints and structural integrity of the aircraft engine application.

The flange separation decreases as the value of coefficient of friction increases. This is observed for the conventional back-to-back bolted flange joint. In similar case the flange separation is not significant for the stepped bolted flange joint.

On inducing contact tool in our analysis, we came across that for both the types of joints, the flanges are always in contact with each other and hence there was no leakage issue.

It was also noted that the maximum stress in the flange in stepped bolted joint was greater than its conventional counterpart. It also reinforced the stress observed on the bolt is higher in conventional bolted joint compared to stepped joint.

VI. ACKNOWLEDGEMENT

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