ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 11, May 2014

Study of structural built up & contour deviation of inboard slats assembly

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Abstract— ***This paper mainly focuses on the structural built up and the contour deviations of Inboard Slat assembly of the indigenously developed LCA Tejas aircraft, having multi role combat capabilities. The scope of the project dwells on the manufacturing and integration of the detail parts to form the Slat assembly and thereof assigning a cause for the contour deviation. The slats form the leading edge of the wing, when deployed produces high lift in turn affect the stalling speed of an aircraft. Slats increase the lift generation by changing the AOA. The contour values must maintain a deviation of +-0.5 mm which are in the acceptable range as per the Quality Control (QC). The different types of errors responsible for contour deviation from its aerodynamics are studied in details and the measures in form of pareto analysis is done. The contour deviations were subjected to scrutiny and the findings/recommendations are appended in the project report.***

Index Terms— **LCA Tejas, slat assembly, Quality control, Pareto analysis.**

I. INTRODUCTION

Slats are aerodynamics surfaces on the leading edge of the wings of fixed-wing aircraft which, when deployed, allow the wing to operate at a higher angle of attack. A higher coefficient of lift is produced as a product of angle of attack and speed, so by deploying slats an aircraft can fly slower or take off and land in a shorter distance. They are usually used while landing or performing maneuvers which take the aircraft close to the stall, but are usually retracted in normal flight to minimize drag. Types include:

Automatic - the slat lies flush with the wing leading edge until reduced aerodynamic forces allow it to extend by way of springs when needed. This type is typically used on light aircraft.

Fixed - the slat is permanently extended. This is sometimes used, especially on specialist low-speed aircraft (these are referred to as slots).

Powered - the slat extension can be controlled by the pilot. This is commonly used on airliners.

HIGH-LIFT WING DESIGN

A short take-off and landing (STOL) aircraft must be able to fly at low controlled speeds, yet it must also offer acceptable cross-country (cruise) performance. The challenge is to design a wing with a high lift coefficient so that the wing area is as small as possible, while allowing for take-off and landing speeds that are as low as possible. Short wings make the aircraft easier to taxi, especially when operating in an off-airport environment with obstructions. They also allow for better visibility, and require less space for hangaring, while also being easier to build and stronger (less weight and wing span to support).

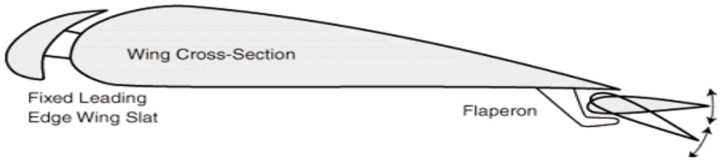

Fig 1: wing cross section

II. LEADING-EDGE WING SLATS

The alula is a high-lift device located at the leading edge of bird wings that allows these animals to fly at large angles of attack and low speeds without wing stalling. The influence of the alula in the wing aerodynamics seems to be similar to that of leading-edge slats in aircraft wings.

It is in the interest of safety to perform takeoff and landing at as low a speed as possible. But also, one does not want the normal flying characteristics to be affected. Consider a near-level flight condition in which the airplane weight is equal to the lift (L = W). For minimum flying speed (takeoff or landing), the wing would be operating at maximum lift or $C_{L,\,max}$. From the equation for total lift on a wing,

$$L = 1/2\ \rho_\infty V^2 S\ C_L$$

Where $1/2\ \rho_\infty V^2$ = the dynamic pressure, S is the surface area of the wing, and C_L = the coefficient of lift, after some manipulation, it is possible to calculate the minimum flight velocity needed for takeoff or landing V_{min},

$$V_{min} = \sqrt{\frac{2W}{\rho_\infty C_{L,max} S}}$$

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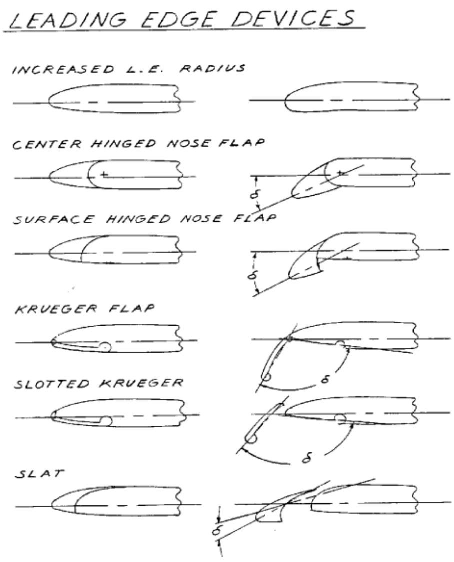

Fig 2: leading edge slats

III. ASSEMBLY PARTS

Leading-edge wing slats assembly parts list and assembly instructions

	Fabricated parts	Material used
1.	RIB #1	AL ALLOY BAR 25*70 SL-200
2.	RIB #2	AL ALLOY BAR 25*70 SL-245
3.	RIB #3	AL ALLOY BAR 25*70 SL-270
3.	RIB #4	AL ALLOY BAR 25*70 SL-270
4.	RIB #5	AL ALLOY BAR 25*70 SL-260
5.	RIB #6	AL ALLOY BAR 25*70 SL-240
6.	RIB #7	AL ALLOY BAR 25*70 SL-250
7.	TRACK RIB #1	AL ALLOY BAR 80*100 SL-260
8.	JACK RIB #1	AL ALLOY BAR 80*100 SL-260
9.	TRACK RIB #2	AL ALLOY BAR 75*90 SL-255
10.	T.E. BLOCK	AL ALLOY BAR 65*170 SL-1750
11.	TOP SKIN	CLAD AL-ALLOY SHEET 2*420*2100
12.	BOTTOM SKIN	CLAD AL-ALLOY SHEET 2*250*2020
13.	SPACER TRACK #1	CLAD AL-ALLOY SHEET 1*80*85
14.	SPACER TRACK #2	CLAD AL-ALLOY SHEET 1*75*90
15.	SPACER JACK #1	CLAD AL-ALLOY SHEET 1*75*90
16.	TRACK #1	MARRAGING STEEL 70*150 SL 450
17.	TRACK #2	MARRAGING STEEL 70*140 SL 415
18.	COVER TRACK#1	CLAD AL-ALLOY SHEET 1.5*60*75
19.	COVER TRACK#2	CLAD AL-ALLOY SHEET 1.5*60*75

Table 1: slats Assembly

A. PART LIST

	FASTNERS AND SEALANTS	
1.	BOLT	
2.	ANCHOR NUT	
3.	WASHER	
4.	CASK SCREW	
5.	SELF LOCKING NUT	
6.	RIVETS	
7.	RIVETS(CHERRY)	
8.	SEALANT	PR-1422 A2
9.	SEALANT	PR-1431 G

Table 2: Parts List

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INTERNAL WRENCHING BOLTS (NAS144 THROUGH NAS158 AND NAS172 THROUGH NAS176)

These are high-strength bolts used primarily in tension applications. Use a special heat-treated washer (NAS143C) under the head to prevent the large radius of the shank from contacting only the sharp edge of the hole. Use a special heat-treated washer (NAS143) under the nut.

INTERNAL WRENCHING BOLTS (MS20004 THROUGH MS20024) AND SIXHOLE, DRILLED SOCKET HEAD BOLTS (AN148551 THROUGH AN149350)

The NAS144 through NAS158 and NAS172 through NAS176 are interchangeable with MS20004 through MS20024 in the same thread configuration and grip lengths. The AN148551 through AN149350 have been superseded by MS9088 through MS9094 with the exception of AN149251 through 149350, which has no superseding MS standard.

TWELVE POINT, EXTERNAL WRENCHING BOLTS, (NAS624 THROUGH NAS644)

These bolts are used primarily in high-tensile, high-fatigue strength applications. The twelve point head, heat-resistant machine bolts (MS9033 throughMS9039), and drilled twelve point head machine bolts (MS9088 through MS9094), are similar to the (NAS624 through NAS644); but are made from different steel alloys, and their shanks have larger tolerances.

CLOSE-TOLERANCE SHEAR BOLTS (NAS464)

These bolts are designed for use where stresses normally are in shear only. These bolts have a shorter thread than bolts designed for torquing.

NAS6200 SERIES BOLTS

These are close tolerance bolts and are available in two oversized diameters to fit slightly elongated holes. These bolts can be ordered with an “X” or “Y” after the length, to designate the oversized grip portion of the bolt (i.e., NAS6204-6X for a 1/4 inch bolt with a 1/64 inch larger diameter). The elongated hole may have to be reamed to insure a good fit.

CLEVIS BOLTS (AN21 THROUGH AN36)

These bolts are only used in applications subject to shear stress, and are often used as mechanical pins in control systems.

EYEBOLTS (AN42 THROUGH AN49)

These bolts are used in applications where external tension loads are to be applied. The head of this bolt is specially designed for the attachment of a turnbuckle, a clevis, or a cable shackle. The threaded shank may or may not be drilled for safe tying.

B. COTTER PINS AND SAFETY WIRE

The cotter pins mostly used on custom aircraft are an380 and an381. Cadmium plated cotter pins are an380 and stainless are an381. Cotter pins are used for safe tying bolts, screws, nuts and other pins. You will normally use them with castle nuts. The ms number you may see is ms24665. The dash numbers indicate diameter and length of the pin. As an example, an380-2-2 would be a cadmium plated pin 1/16" in diameter and 1/2" long. All supply companies will have charts showing the various sizes versus the reference number.

FIG 3: WIRE PLIERS

INSTALLATION

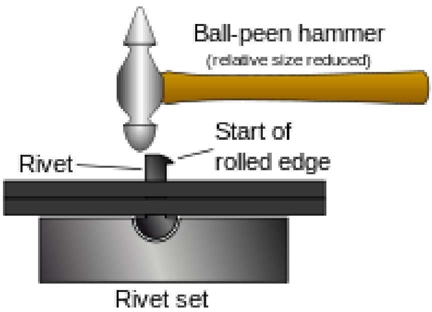

FIG 4: MANUAL INSTALLATION OF A SOLID RIVET

FIG 5: IMPACT METHOD FOR SOLID RIVET AND SEMI-TUBULAR RIVETS

C. SEALANT

PRODUCT SPECIFICATIONS FOR CS3204 FUEL TANK SEALANT

FIG 6. CHEM SEALENT FUEL

IV. STRUCTURAL ASSEMBLY

A. RIBS

Ribs are the formers used to retain the shape of the slat contour in the chord direction without any distortion of the skin. The ribs are fabricated from solid block which are routed to the NMG contour of the slat. They are made light weight by pocket milling at the centre. The rib design ensures sufficient strength to the trailing and the leading edge of the slat, so has to avoid buckling/ failure due to the heavy loads acting on the slat.

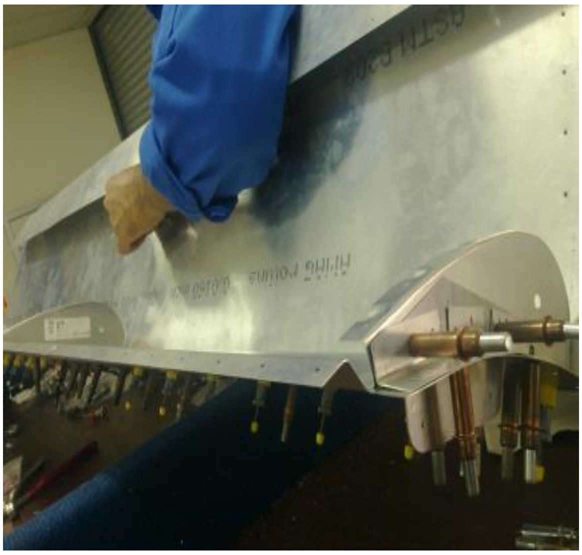

FIG 7: RIBS / FORMERS

B. T.E. BLOCK

The trailing edge block is a monolithic machined member connecting the skin to the rib at the trailing edge.

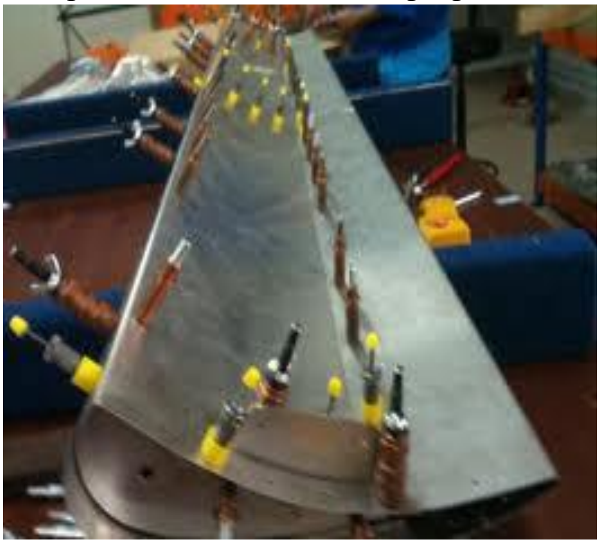

FIG 8: T.E BLOCK

C. ACTUATOR

The actuators have a hydraulic working fluid energized electrically by Digital Flight Control Computer (DFCC) which is fitted to the slat that which brings about the relative movement of the slat with the wings.

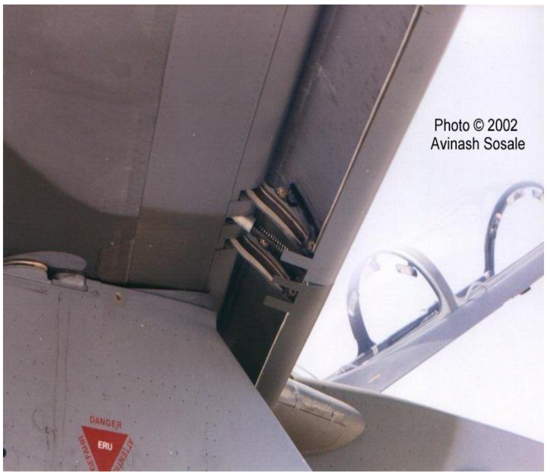

FIG 9: ACTUATOR

D. BOTTOM SKIN AND TOP SKIN

This is a stretch form member formed to slat contour. The two ends of the skin are held on to the machine against a form block. The form block is made to the slat contour. The contour values are generated by numerical master geometry (NMG) which is transformed to a CAD model. Form blocks are made from the CAD model. Bottom skin and Top skin are in two pieces which are riveted to the rib and the trailing edge block.

FIG 10: AIRCRAFT STRETCHED FORMED SKIN

V. ASSEMBLY PROCEDURE OF SLATS

Integration of the detail Parts are done on the assembly jig. The ribs are loaded to the assembly jig in the respective stations namely Station 1 to station 8. Layout for the rivet holes is done on the skin.

The form skin along with the ribs is clamped with C-clamp to the jig at the butting face of the trailing edge. The rivet hole drilling is done as per the layout. A suit on assembly of the skin is done on jig and the extra material is trimmed off. After debarring the skin is re assembled with PR-1430 interfere sealant applied between the skin and the ribs. Solid rivets are put on the top skin. A similar procedure is followed for the

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
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bottom skin and is riveted with blind rivet. The skin and the ribs are riveted at the trailing edge with trailing edge block. Tracks and actuator bracket are also riveted to the slat assembly

A. INSPECTION

The contour readings are taken at station 1 to station 8 at an interval of 25mm using a roller gauge. The clearance provided between the component and the contour plate is 5mm and the tolerance is fixed as +/- 0.5mm. The contour values at different stations are recorded and tabulated for top and bottom skin.

FIG 11: SLAT ASSEMBLY JIG

FIG 12: GUAGE PINS

B. INSTALLATION PROCEDURE

The slats are attached to the leading edge of the wing close to the fuselage. The tracks provided in the slat assembly are matched to the track way on the wing and are locked. There is a relative motion between the slat and the wing, which is brought about by the radial bearing having an elliptical hole with an adjustable pin provided inside the track assembly.

One end of the actuator is attached to fixed bracket located in the wing and the other end is connected to the bracket on the slat assembly.

This adjustable pin helps in setting of the slat assembly to a maximum angle of 17.30 ‘. This adjustment is done by

1. Using a Slat-o-meter, or
2. Actuator Testing Set-Up (ATS).

Maximum Relative Movement of the Slat into the Wing Assembly

1. In-board Slat 17.30’
2. Mid-board 27.30’
3. Out-board 30.30’

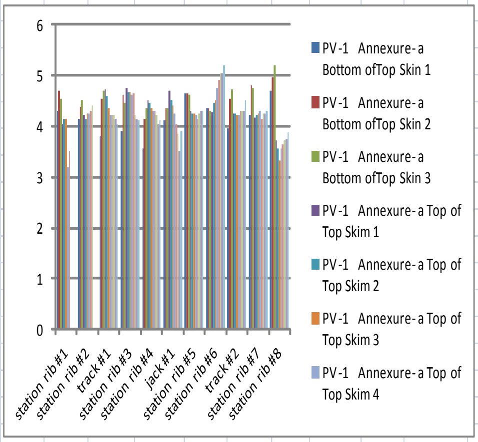
VI. COLLECTION OF DATA

(I.e. snag sheets of in-board slat L.H & R.H pertaining to PV1, PV2, and PV3)

A. SNAG SHEET PV-1

Table 4: Snag sheets of PV1

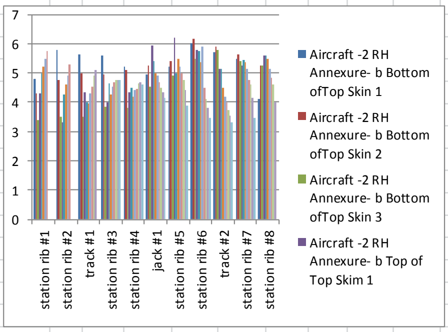
	PV -1 Annexure- a										
	Bottom ofTop Skin			Top of Top Skim							
	1	2	3	1	2	3	4	5	6	7	8
station rib #1	4.31	4.69	4.55	4.05	4.15	4.15	3.18	3.52			
station rib #2	4.15	4.37	4.51	4.21	4.15	4.25	4.25	4.31	4.41		
track #1	3.81	4.55	4.71	4.72	4.58	4.35	4.23	4.21	4.21	4.15	4.05
station rib #3	3.91	4.61	4.45	4.76	4.66	4.66	4.61	4.65	4.21	4.15	4.11
station rib #4	3.55	4.13	4.35	4.51	4.45	4.35	4.31	4.31	4.21	4.05	4.11
jack #1	4.12	4.35	4.35	4.71	4.51	4.41	4.25	4.05	3.85	3.52	3.91
station rib #5	4.65	4.65	4.61	4.31	4.25	4.25	4.21	4.15	4.25	4.31	4.31
station rib #6	4.35	4.35	4.31	4.28	4.45	4.51	4.75	4.91	5.05	5.05	5.21
track #2	3.95	4.53	4.72	4.25	4.25	4.21	4.21	4.31	4.31	4.31	4.51
station rib #7	4.21	4.81	4.75	4.17	4.21	4.25	4.31	4.15	4.25	4.25	4.31
station rib #8	4.71	4.95	5.21	3.71	3.55	3.33	3.55	3.65	3.71	3.75	3.88



B. SNAG SHEET OF PV-2

Table 5: Snag sheets of PV2

	PV -2 Annexure- b										
	Bottom ofTop Skin			Top of Top Skim							
	1	2	3	1	2	3	4	5	6	7	8
station rib #1	4.8	4.3	3.4	4.3	5	5.2	5.5	5.75			
station rib #2	5.8	4.8	3.5	3.3	4.25	4.6	4.9	5.3			
track #1	5.65	5	3.5	4.35	4	3.95	4.3	4.55	4.9	5.1	
station rib #3	5.6	5	3.85	4	4.65	4.25	4.55	4.7	4.75	4.75	4.75
station rib #4	5.2	5.1	3.8	4.35	4.5	4.2	4.4	4.45	4.65	4.7	4.6
jack #1	4.95	5.3	4.55	5.95	5.4	5	4.9	4.7	4.5	4.35	4.15
station rib #5	5.2	5.4	4.9	6.2	5	5.5	5.2	5	4.75	4.4	3.9
station rib #6	6	6.2	5.5	5.8	5.75	5.35	5.9	4.5	4.1	3.8	3.45
track #2	5.7	5.9	5.8	5.15	5.15	4.5	4.2	4	3.75	3.55	3.3
station rib #7	5.5	5.7	5.4	5.25	5.45	5.35	5.15	4.75	4.6	4.15	3.45
station rib #8	4.1	5.3	5.25	5.6	5.6	5.5	5.15	4.85	4.6	4	



ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
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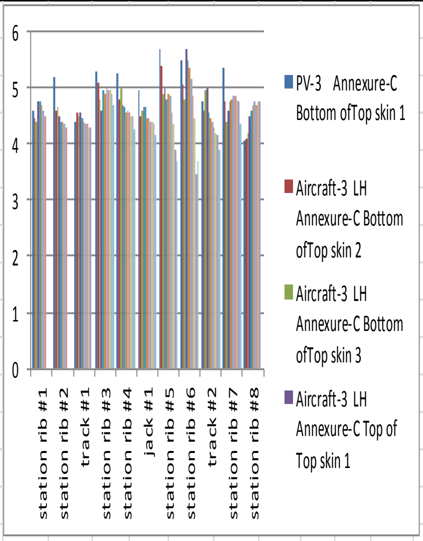
C. SNAG SHEET OF PV-3

Table 6: Snag sheets of PV3

	PV-3 Annexure-C										
	Bottom of Top skin			Top of Top skin							
	1	2	3	1	2	3	4	5	6	7	8
station rib #1	4.6	4.45	4.4	4.75	4.75	4.7	4.6	4.5			
station rib #2	5.2	4.6	4.65	4.5	4.4	4.4	4.35	4.3			
track #1	4.4	4.55	4.5	4.55	4.45	4.4	4.35	4.35	4.3	4.3	
station rib #3	5.3	5.1	4.8	4.6	4.95	4.9	5	4.95	4.95	4.9	4.7
station rib #4	5.25	4.8	5	4.7	4.65	4.55	4.6	4.55	4.5	4.5	4.26
jack #1	4.95	4.5	4.6	4.65	4.65	4.45	4.45	4.4	4.4	4.35	4.15
station rib #5	5.7	5.4	4.9	5	4.8	4.9	4.85	4.55	4.35	3.9	3.7
station rib #6	5.5	5.05	4.8	5.7	5.5	5.35	5.15	4.85	4.45	3.45	3.7
track #2	4.75	4.6	4.95	5	4.55	4.45	4.4	4.3	4.2	4.15	3.9
station rib #7	5.35	4.75	4.4	4.6	4.75	4.8	4.85	4.85	4.8	4.75	4.35
station rib #8	4.05	4.1	4.2	4.5	4.6	4.7	4.75	4.7	4.75	4.75	



VII. ISHIKAWA DIAGRAMS

The categories typically include:

- People: Anyone involved with the process
- Methods: How the process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations and laws
- Machines: Any equipment, computers, tools etc. required to accomplish the job
- Materials: Raw materials, parts, pens, paper, etc. used to produce the final product
- Measurements: Data generated from the process that are used to evaluate its quality
- Environment: The conditions, such as location, time, temperature, and culture in which the process operates.

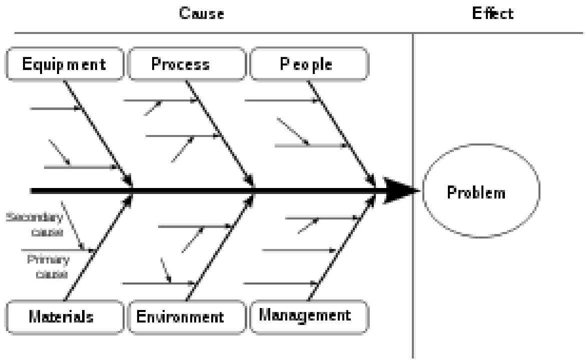


FIG 13. CAUSE AND EFFECT DIAGRAM (GENERAL)

CRITICISM

In a discussion of the nature of a cause it is customary to distinguish between necessary and sufficient conditions for the occurrence of an event. A necessary condition for the occurrence of a specified event is a circumstance in whose absence the event cannot occur. A sufficient condition is a circumstance in whose presence the event must occur. Ishikawa diagrams are meant to use the necessary conditions and split the "sufficient" ones into the "necessary" parts. Some critics failing this simple logic have asked which conditions (necessary or sufficient) are addressed by the diagram in case.

SCRUTINIZING THE DATA TO ASSIGN A CAUSE FOR THE CONTOUR DEVIATION USING CAUSE & EFFECT DIAGRAM

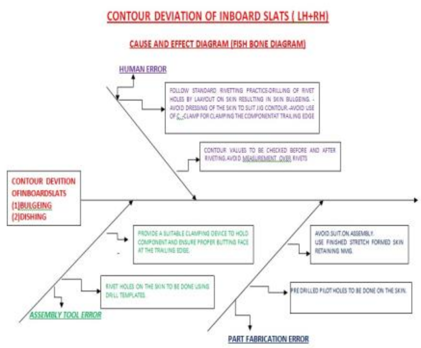


FIG 14: CAUSE AND EFFECT DAIGRAM FOR CONTOUR DEVIATION OF SLATS

VIII. INFERENCE

INFERENCES DRAWN FROM CAUSE AND EFFECT DIAGRAM

A. HUMAN ERROR

- Follow standard riveting practice.
- Selection of correct shank length for solid rivet and grip length for blind rivet.
- Rivet holes done by lay-out method results in bulging.
- Avoid dressing of the skin to suit the jig contour.
- Avoid use of C-clamps for rigid clamping at butting face of trailing edge.
- Contour values to be checked before and after riveting.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 11, May 2014

- Avoid contour measurement on rivet head.

B. PART ERROR

- Obtain finished stretched form part to NMG contour.
- Pre drilled pilot holes to be done on skin.

C. TOOL ERROR

- Provide a suitable clamping device to hold component and ensure proper butting face at the trailing edge.
- Rivet holes on the skin to be done using drill templates.
- Use correct feelers at ICY attachment points

IX. RECOMMENDATIONS

- Avoid suite on assembly which is causing waviness in the skin.
- It is suggested to provide proper clamping devices so that trailing edge sits flush with the contour plates during the assembly.
- Its suggested to have drill templates, thus maintaining the correct pitch to avoid bulging
- Use the feelers in locating brackets
- Avoid job methods for marking and layout on skin for rivet holes.
- Inspection is to be done before and after riveting.
- Avoid measurements of contour values over the rivets.
- Use the grip length gauge to assure the correct grip length, thus avoiding ditching and bulging.

X. CONCLUSION

The slat assembly built has a contour variation namely ditching and bulging. Three set of in-board slat assemblies pertaining to PV1, PV2, PV3 were compared. It is evident from the tabulation the readings were falling out of the tolerance limit. This structural variation in the contour from the drawing dimension is commented as deviation but aerodynamically acceptable.

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