Riveted Joint Failure Mode Investigation

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Topics: Riveted Lap Joints · UTM Testing · Failure Mode Analysis · NACA 2613 Rib Design

Theoretical Background — Failure Modes

Riveted lap joint mechanics

Shear of Rivets

$$P = n \cdot (\pi/4) \cdot d^2 \cdot \tau_y$$

Rivet fails across shear plane. Governed by rivet cross-section and shear yield strength.

Tearing of Plate

$$P = (p - d) \cdot t \cdot \sigma_y$$

Net plate section at rivet hole tears. Controlled by pitch, diameter, and plate yield strength.

Bearing Failure

$$P = n \cdot d \cdot t \cdot \sigma_{br}$$

Hole crushes under compressive stress. Dominant in thin plates with large-diameter rivets.

Design rule: the governing failure mode is whichever gives the lowest load (P_shear, P_tear, or P_bearing).

Specimen Testing & Material Properties

1 mm thick metal plates · 2.4 mm and 3.2 mm diameter rivets · 3 rivets per joint

Spec.	Description	d (mm)	Type
a / e	3.2 mm rivet (×2)	3.2	Lap Joint
b / f	2.4 mm rivet (×2)	2.4	Lap Joint
c	Flat (w = 24 mm)	—	Flat Plate
d	Flat (w = 21.6 mm)	—	Flat Plate

Material Properties:

- Plate $\sigma_y \approx 90$ MPa | $\sigma_{UTS} \approx 300$ MPa
- Rivet $\tau_y \approx 53.8$ MPa | $\sigma_{y,rivet} \approx 93$ MPa

Experimental Results & Discussion

All four riveted specimens failed by rivet shear

Spec.	Exp. Peak (kN)	Analytical (kN)	Observed Mode
a (3.2 #1)	~1.10	1.30	Shear
b (2.4 #1)	~1.30	0.73	Shear
c (flat 24)	~7.30	2.16 (yield)	Ductile fracture
d (flat 21.6)	~6.40	1.94 (yield)	Ductile fracture
e (3.2 #2)	~2.10	1.30	Shear
f (2.4 #2)	~1.10	0.73	Shear

Key Takeaways:

- All riveted specimens failed by rivet shear.
- loads exceeded predictions

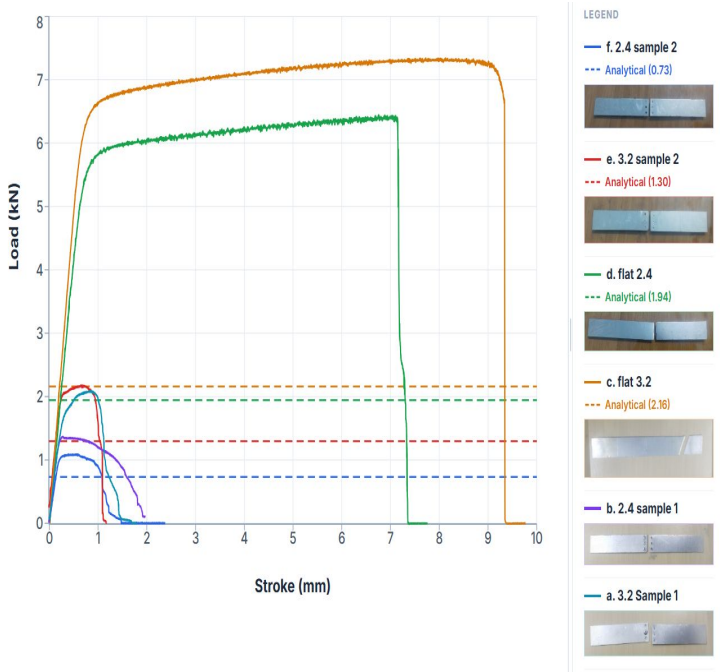


Fig. 3.1 — Load-displacement: flat vs. riveted specimens

Different Thickness Specimens & Failure Mode

Parameter	Specimen A (2 mm)	Specimen B (0.5 mm)
Joint Type	Double riveted lap joint	Single riveted lap joint
No. of Rivets	2	3 in a row
Width	10 mm	24
Observed Failure	Shear of rivets	Bearing failure

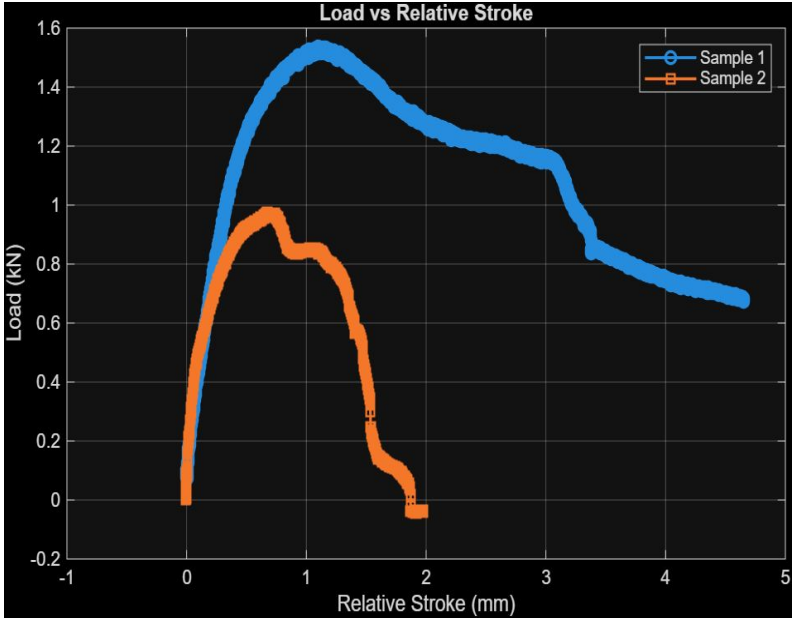


Fig. 5.1 — Shear (A) vs. Bearing (B) failure response

Bearing hole elongation — 0.5 mm plate

Achieving Targeted Failure Modes

Parameter	Specimen C	Specimen D
Joint Type	Double riveted	Single riveted
Rivets	2 in a row	3 in a row
Pitch (p)	12 mm	8 mm
Edge Distance (e)	7 mm	6 mm
Thickness (t)	0.5 mm	0.5 mm
Observed Failure	Tearing	Bearing → Tearing

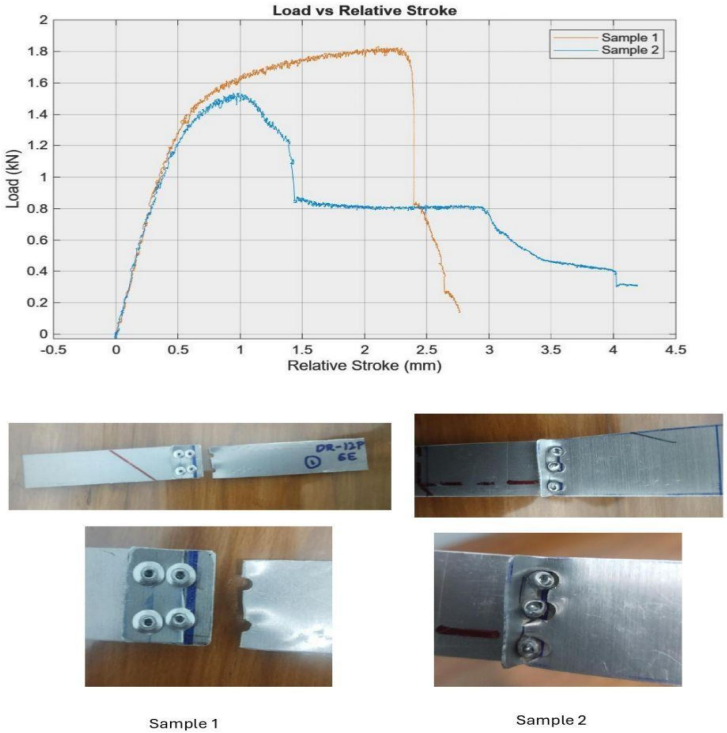
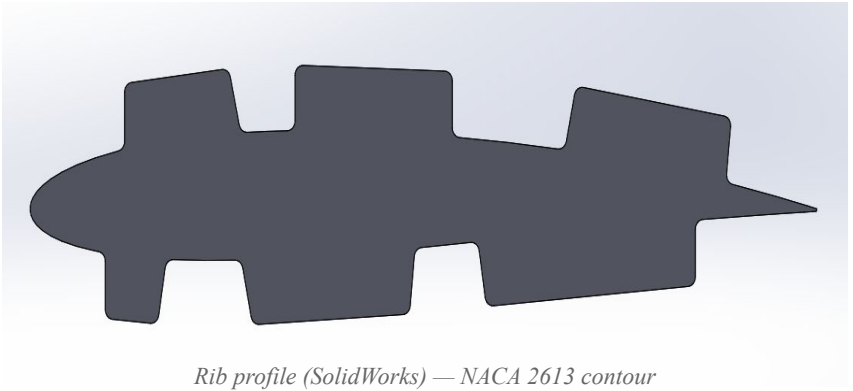


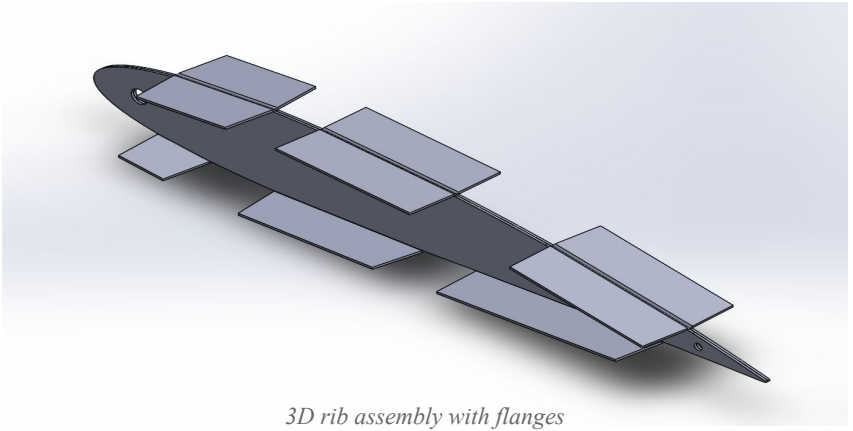
Fig. 6.1 — Tearing failure curves & specimen photos (Week 3)

NACA 2613 Wing Rib Design

- NACA 2613: max camber 2% at 60% chord, max thickness 13% of chord.
- Rib formed as a Double C-Section I-Beam (two C-channels back-to-back), 0.5 mm sheet metal.
- Rivet diameter: 2.4 mm | Pitch: 4D = 9.6 mm (prevents tearing) | Edge distance: 2D = 4.8 mm.

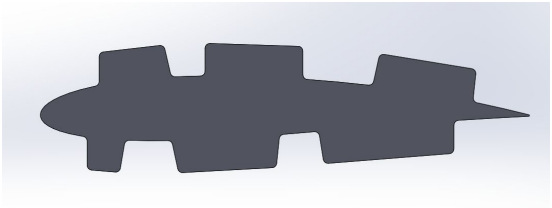


Rib profile (SolidWorks) — NACA 2613 contour



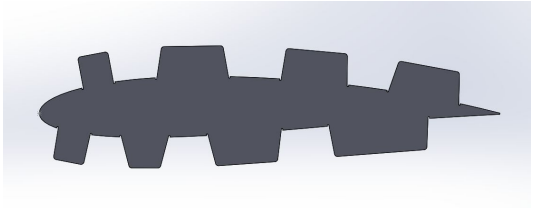
3D rib assembly with flanges

Rib Section Geometry & Dimensions



Design -1

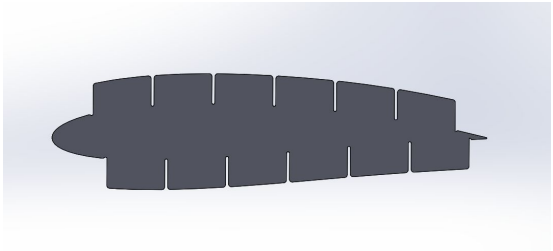
- Without bending notches
- Number of rivets per rib = 16*2 = 32



Design – 2

- With bending notches
- Number of rivets per rib = 14*2 = 28

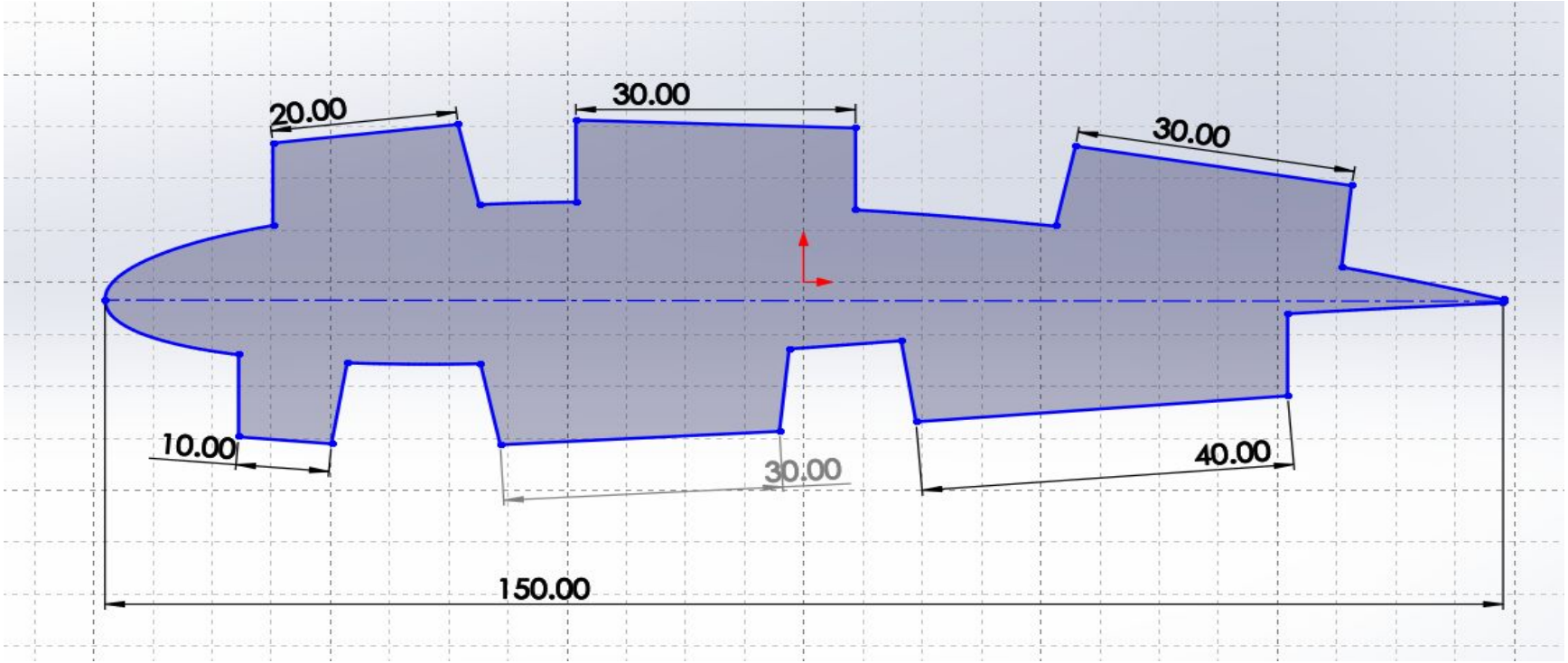
Bending notches



Design – 3

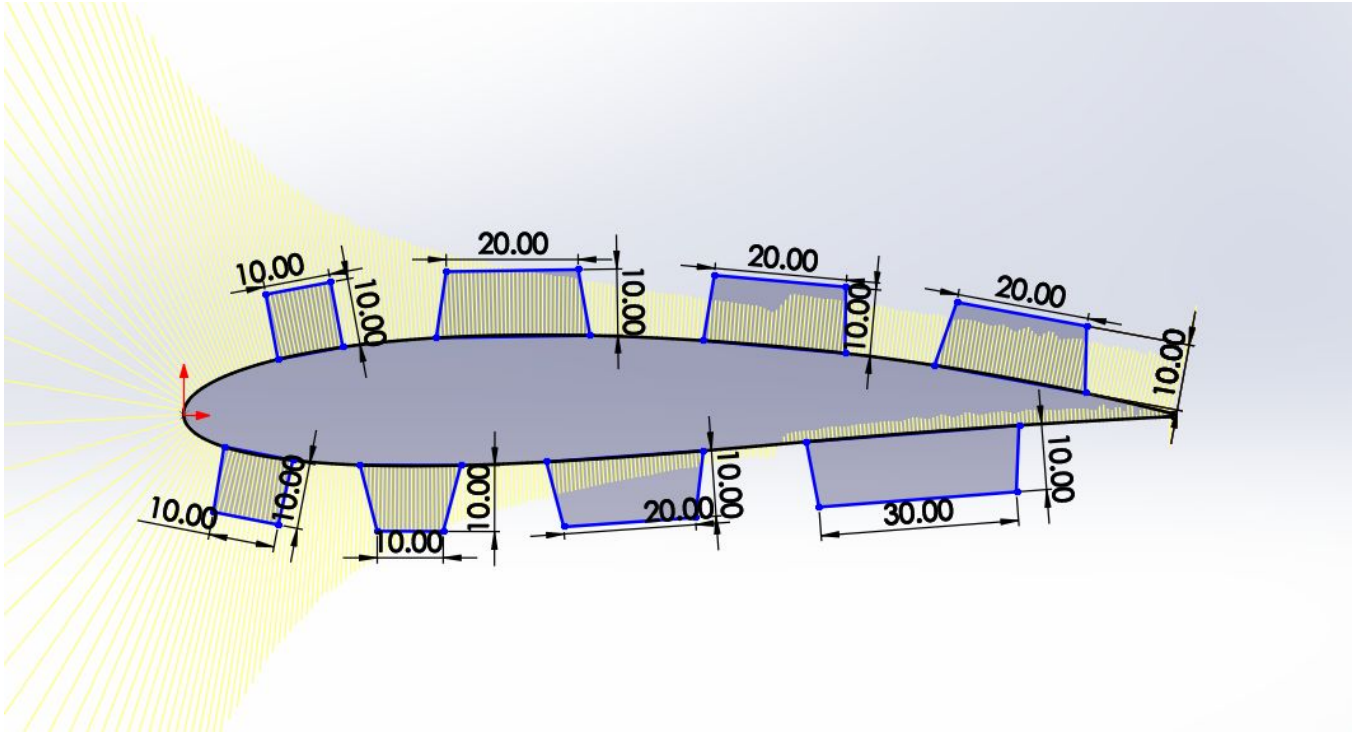
- Less gap between flanges
- Number of rivets per rib = 24 or 24*2 = 48

Rib Section Geometry & Dimensions



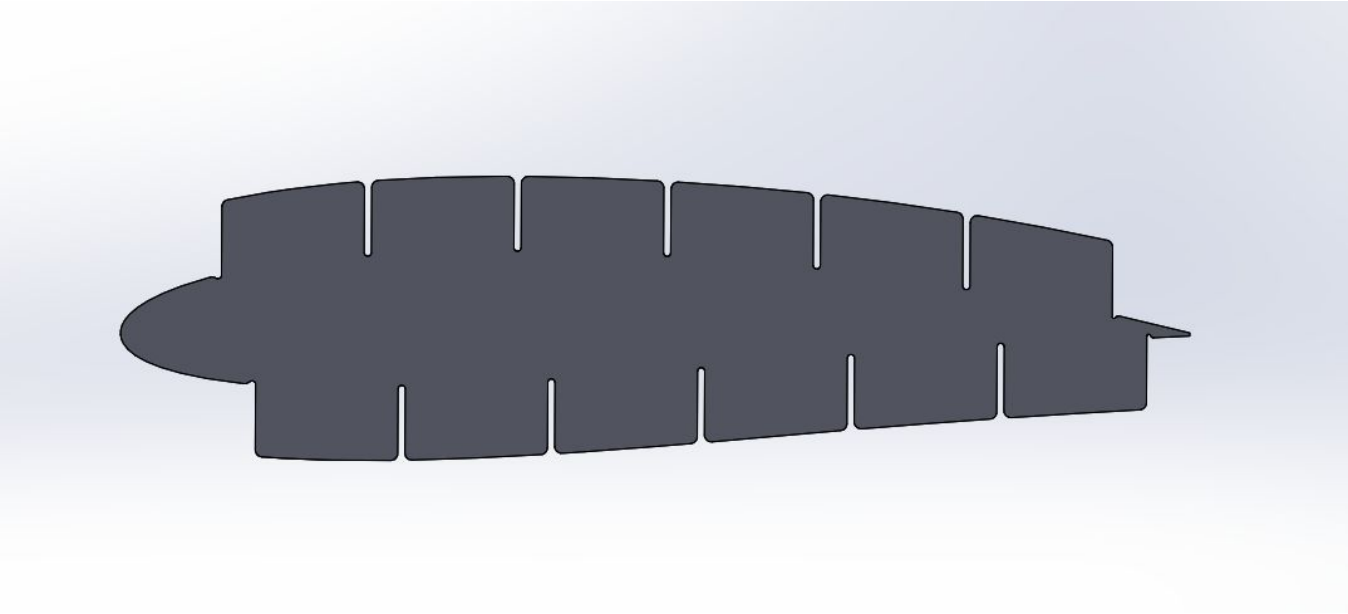
Key dimensions: Total chord 150 mm · Flange cutouts 20–30 mm · Lower flanges 10 & 40 mm ·

Rib Section Geometry & Dimensions



Total chord - 150 mm

Rib Section Geometry & Dimensions



Total chord - 150 mm Flange width – 20mm each·

Wire EDM cutting of sheet metal

Physical Ribs with flanges

Design 1 - Fabricated Rib Before Bending

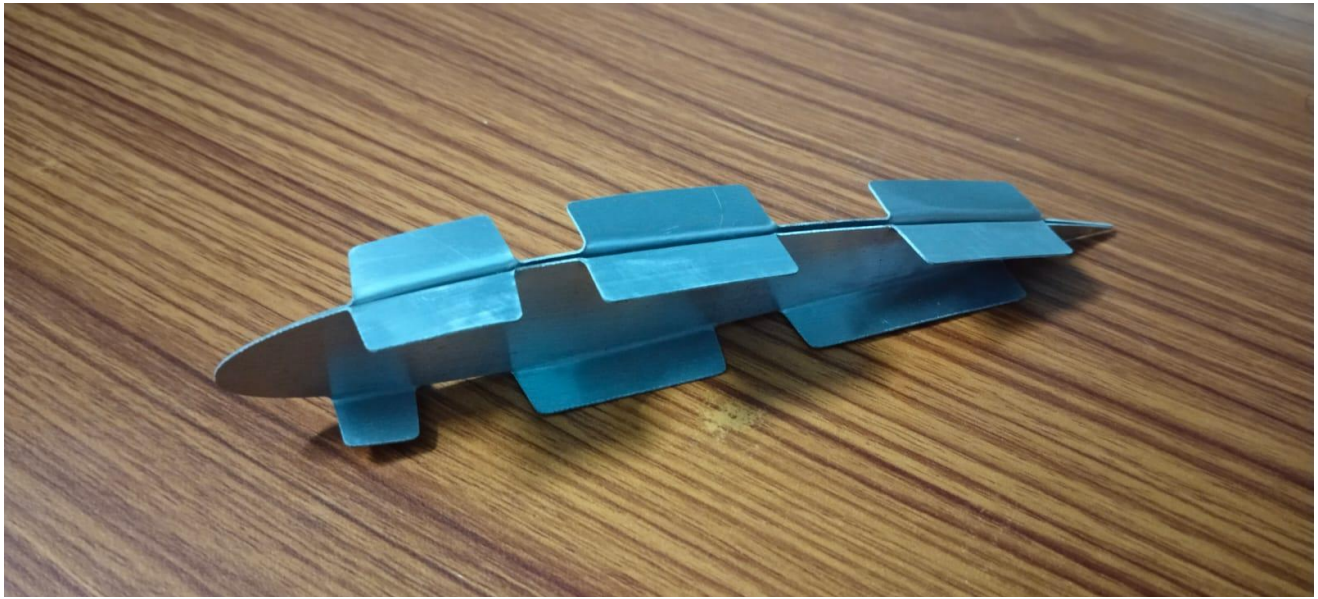
Physical Ribs with flanges

Design 2 - Fabricated Rib Before Bending

Physical Ribs with flanges

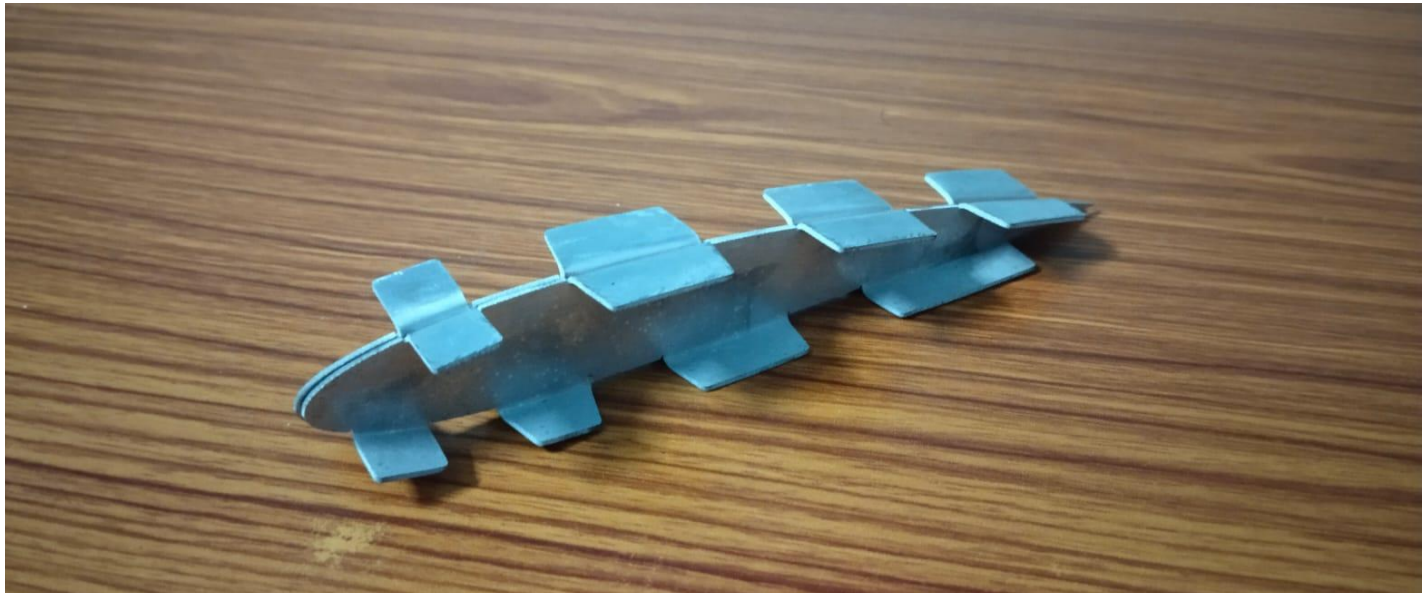
Design 3 - Fabricated Rib Before Bending

Physical Ribs with Bent Flanges



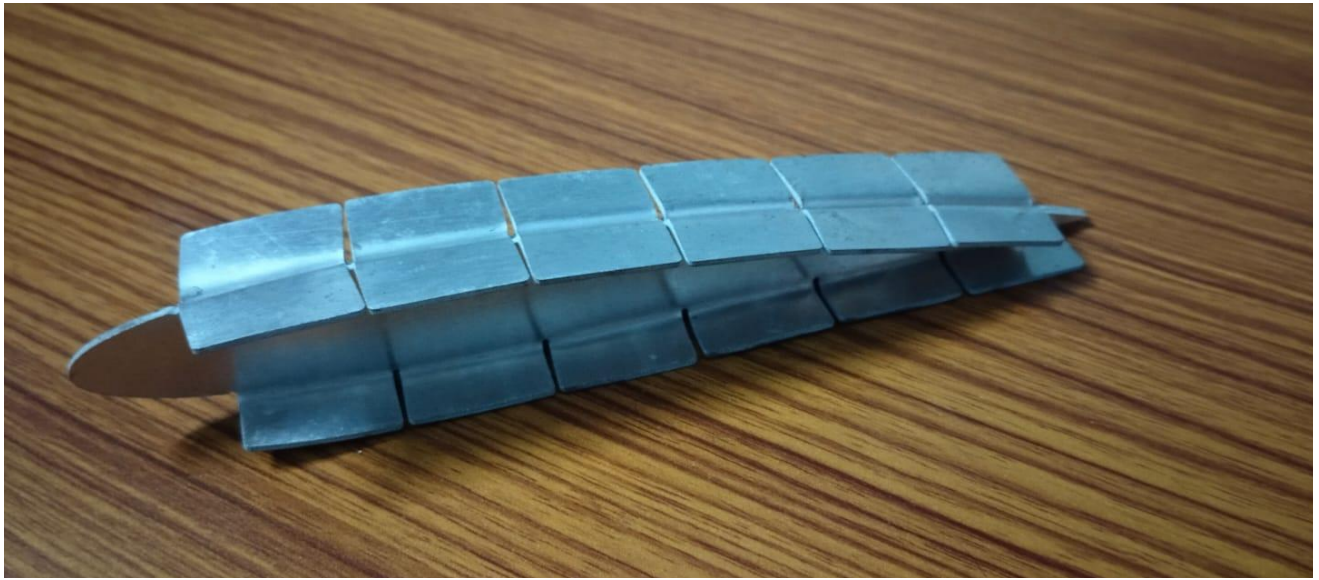
Design 1 - Fabricated Rib After Bending

Physical Ribs with Bent Flanges



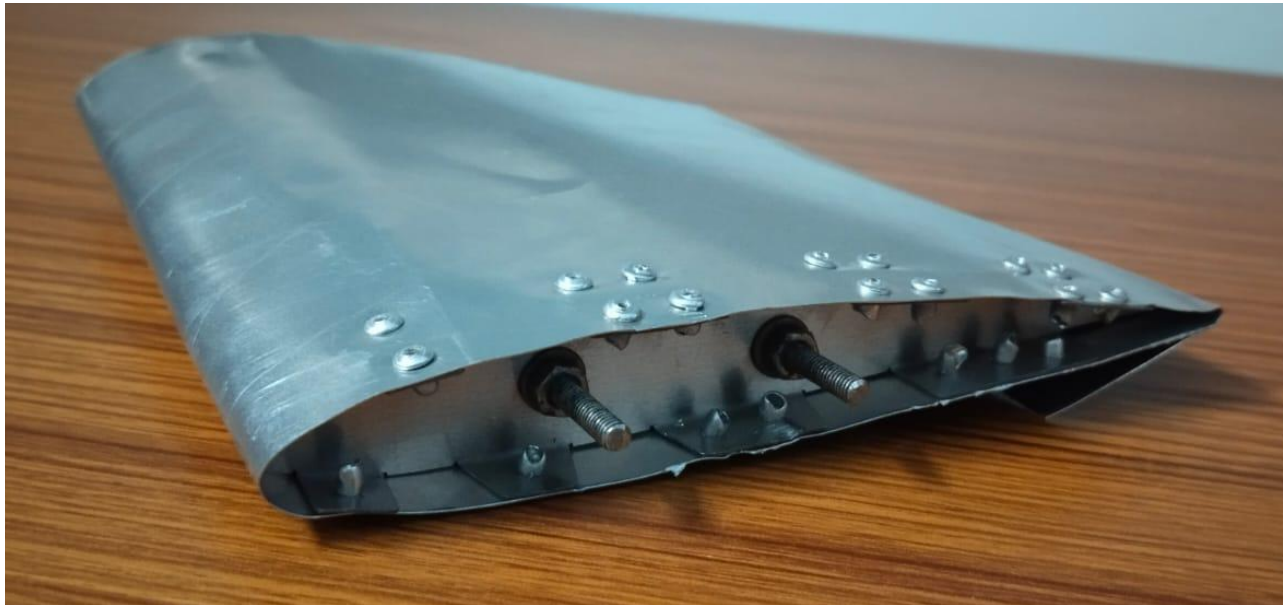
Design 2 - Fabricated Rib After Bending

Physical Ribs with Bent Flanges



Design 3 - Fabricated Rib After Bending

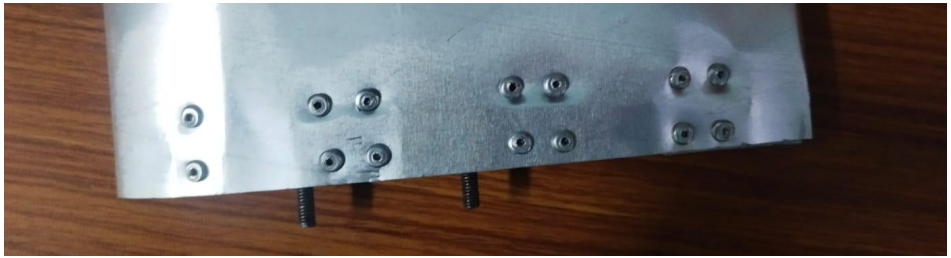
Ribs with Flanges – Riveted to Wing Skin



Design 2 – Bolted together and riveted to 0.3mm wing skin

Ribs with Flanges – Riveted to Wing Skin

Side View



Top View