Wagtail payload module joint bending study

Philip Teakle
TEAKLE COMPOSITES
31st January 2010

Aim

The purpose of this brief report is to provide some basic design data for joints and couplings in payloads launched in the Australian Space Research Institute's Small Sounding Rocket Program. This was prompted by several recent bending failures – three in 2009 and several in previous years.

Fig 1.

Model

Geometry: The payload for the purposes of this study was assumed to be 132 mm diameter (the maximum diameter of the Zuni booster) and 1200 mm long including a 3:1 slenderness ratio nose cone. This is close to the largest payload envelope permitted in the ASRI Payload User's Guide.

Boundary layer: A fully turbulent boundary layer and a surface roughness of 0.01 inches (approximately equivalent to the natural surface of cast iron) was assumed.

Flight conditions: The aerodynamic coefficients were estimated for Mach 2.0 close to ground level, which is approximately the maximum dynamic pressure achievable by Zuni launch (maximum speeds with most typical payloads are closer to Mach 1.6). This flight condition corresponds approximately to a dynamic pressure of approximately 284 kPa, a Reynolds number based on the payload diameter of 6.1×10^6 and a speed of 680 m/s (2450 km/h). Base drag was omitted from the analysis because of the presence of the Zuni rocket body. Aerodynamic loads were estimated at various angles of attack in the interval 0° – 10°. The aerodynamic coefficients were estimated using Missile DATCOM Rev 3/99.

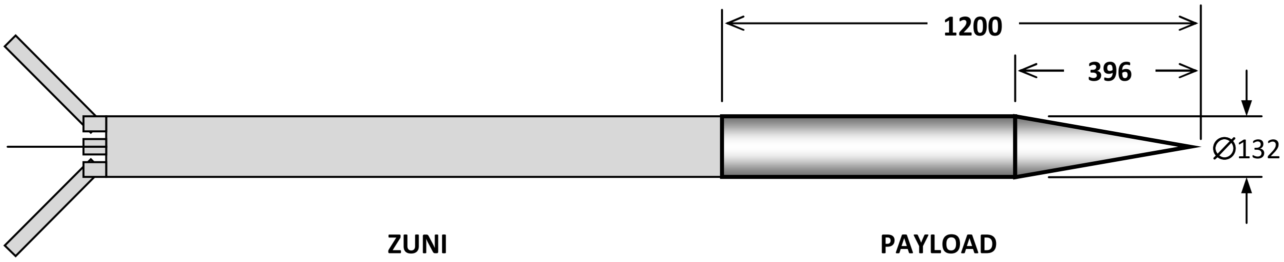


Figure 1: Geometry of simulated payload

Results

The variation of the magnitude of the bending moment at the base of the payload with angle of attack is illustrated in Figure 2. Other aerodynamic forces are tabulated in Table 1.

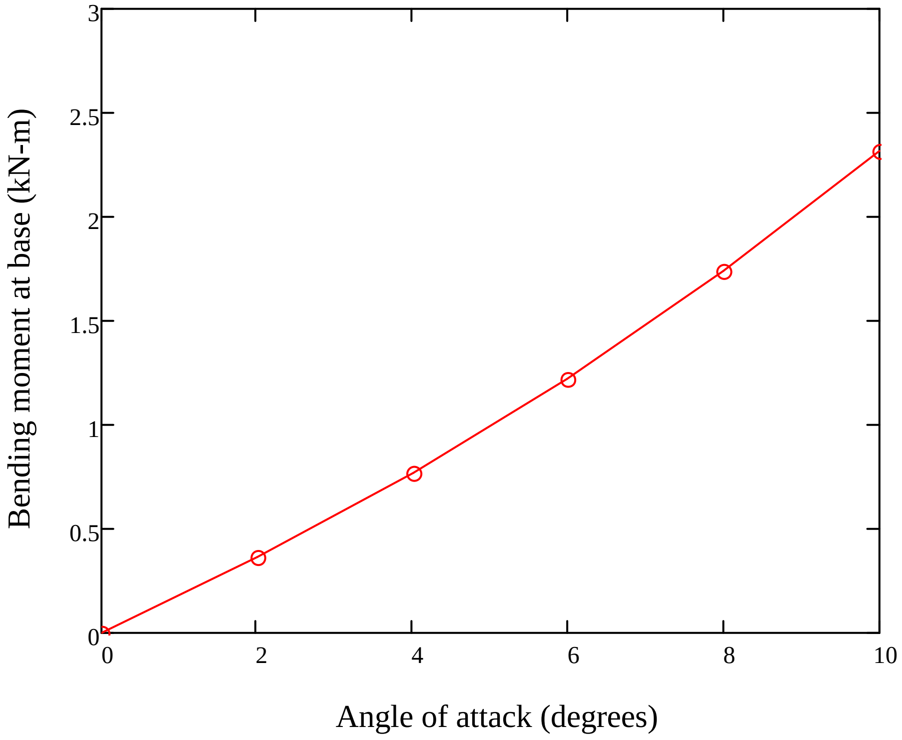


Figure 2: Variation of bending moment at the base of the payload with angle of attack at Mach 2

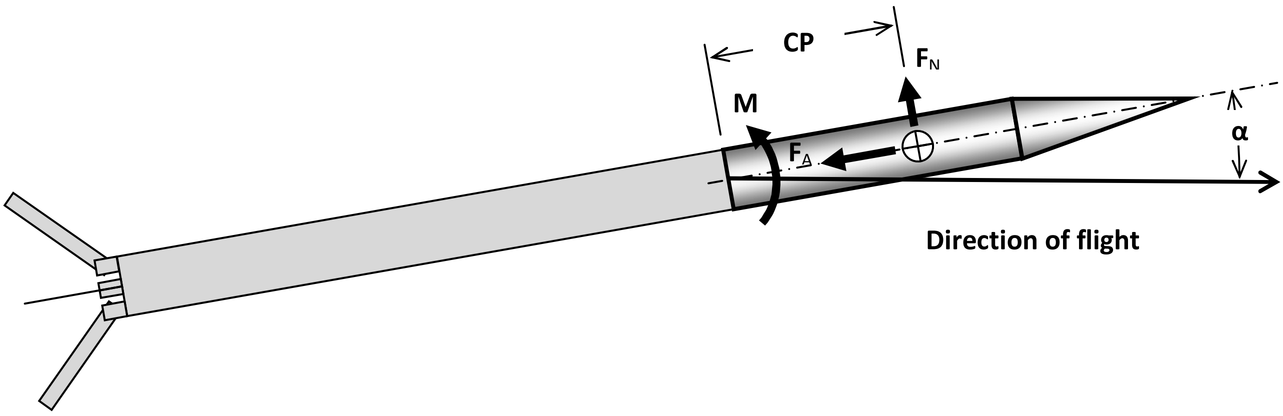


Figure 3: Definition of symbols in Table 1

Table 1: Aerodynamic payload forces at various angles of attack

α (deg)	M (kN·m)	F_N (kN)	F_A (kN)	CP (m)
0	0	0	0.90	0.81
2	0.37	0.47	0.89	0.79
4	0.77	1.01	0.89	0.76
6	1.22	1.65	0.88	0.74
8	1.74	2.41	0.87	0.72
10	2.32	3.32	0.86	0.70

Discussion

The angle of attack of a Zuni sounding rocket is unlikely to exceed 4° during a normal flight. This was the angle-of-attack limit suggested to us during the University of Queensland HyCAUSE mission nosecone design. At this small angle the side loads exceed the axial loads. It is therefore recommended that all payload joints or couplings be acceptance tested before flight to a bending load of 0.77 kN·m unless it can be demonstrated to the ASRI Trials Manager's satisfaction that the joints do not require this test or can be tested to a different load, for example by virtue of their location. The joint should be designed to withstand the acceptance test load with a suggested design margin of at least 2.

No allowance has been made for bending due to dynamic loads due to pitch oscillations, rotation, displacement of the centre of mass from the sounding rocket centre line or payload asymmetry. In most cases these are expected to be minor relative to the static aerodynamic loads.

Payloads of designs different to the assumed geometry above may have significantly higher bending loads, such as those with non-circular cross sections and greater lengths. In these cases separate analyses and acceptance tests should be performed to the ASRI Trials Manager's satisfaction.

Previously successful and unsuccessful joint designs are included below for guidance.

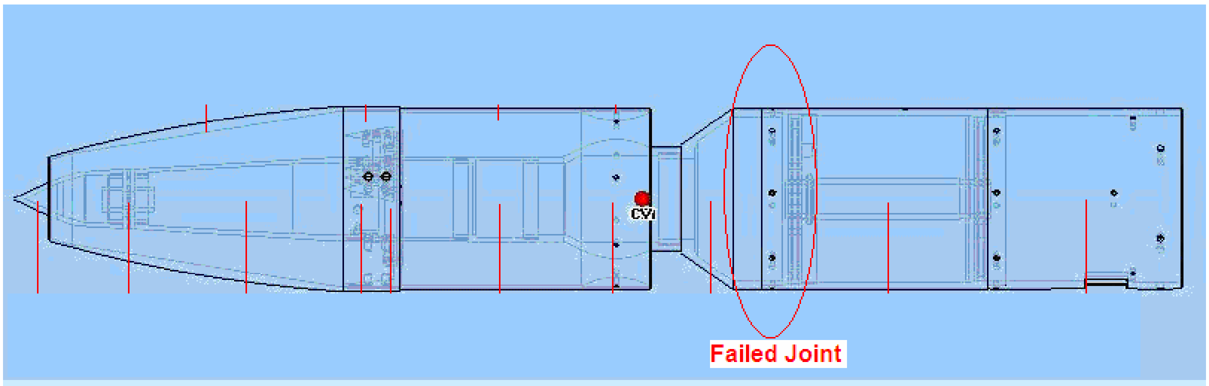


Fig.2

Fig 2. Payload joint had reduced length, wall thickness and screw size. Joint failed at Max-Q, 1 second into flight.

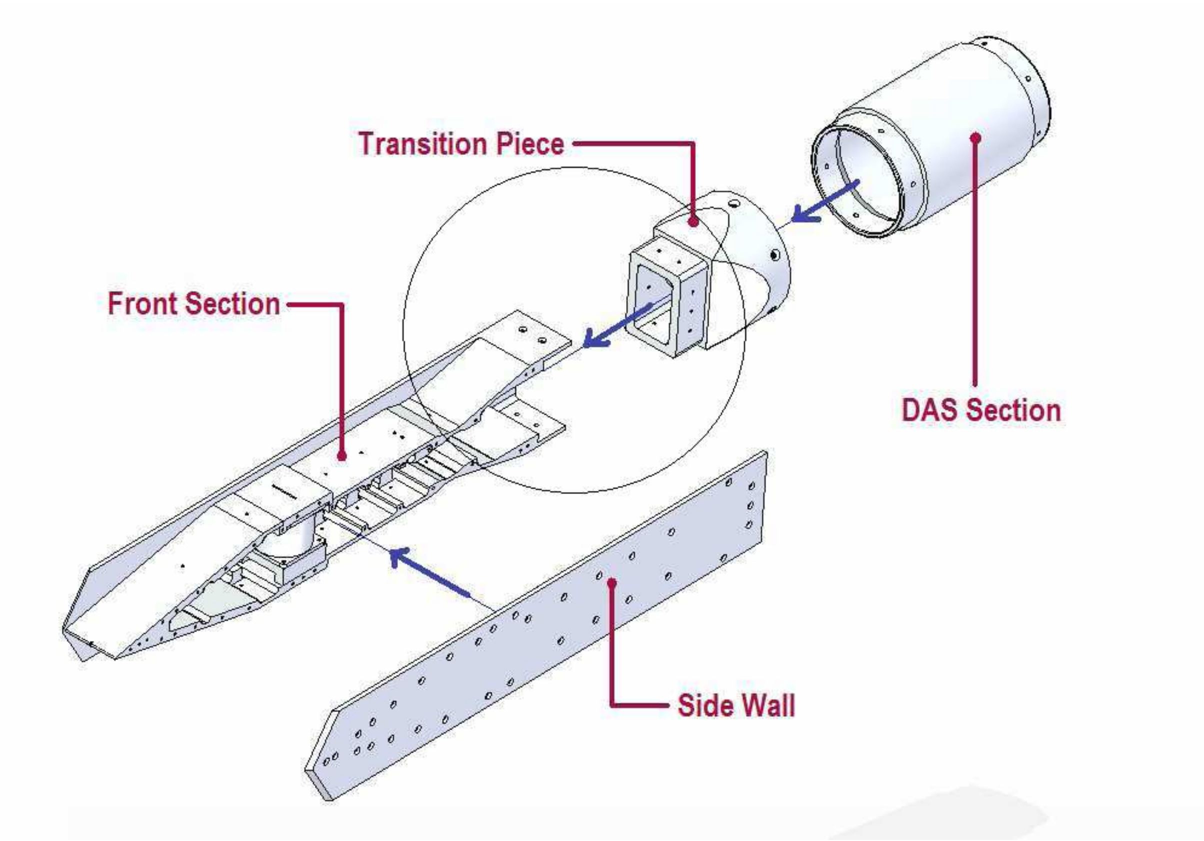
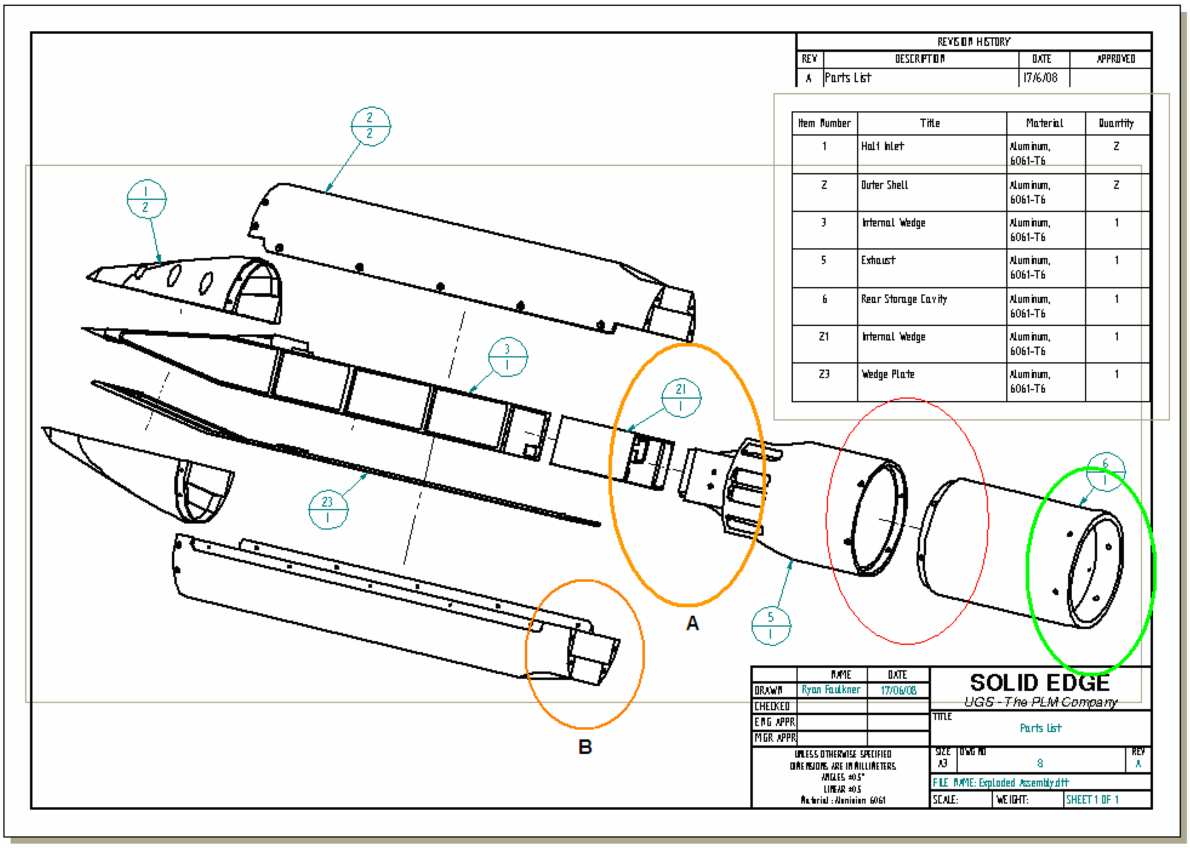


Fig 3.

Fig 3. Failed joint attributed to extra lift due to large flat sides of payload. Photo of failed joint can be seen at start of report (Fig 1). Joint failed at Max-Q 1 second into flight.



REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
A	Parts List	17/6/08	

Item Number	Title	Material	Quantity
1	Half Inlet	Aluminum, 6061-T6	2
2	Outer Shell	Aluminum, 6061-T6	2
3	Internal Wedge	Aluminum, 6061-T6	1
5	Exhaust	Aluminum, 6061-T6	1
6	Rear Storage Cavity	Aluminum, 6061-T6	1
21	Internal Wedge	Aluminum, 6061-T6	1
23	Wedge Plate	Aluminum, 6061-T6	1

	NAME	DATE
DRAWN	Ryan Faulkner	17/06/08
CHECKED		
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±0.5°
LINEAR ±0.5
Material : Aluminium 6061

SOLID EDGE
UGS - The PLM Company

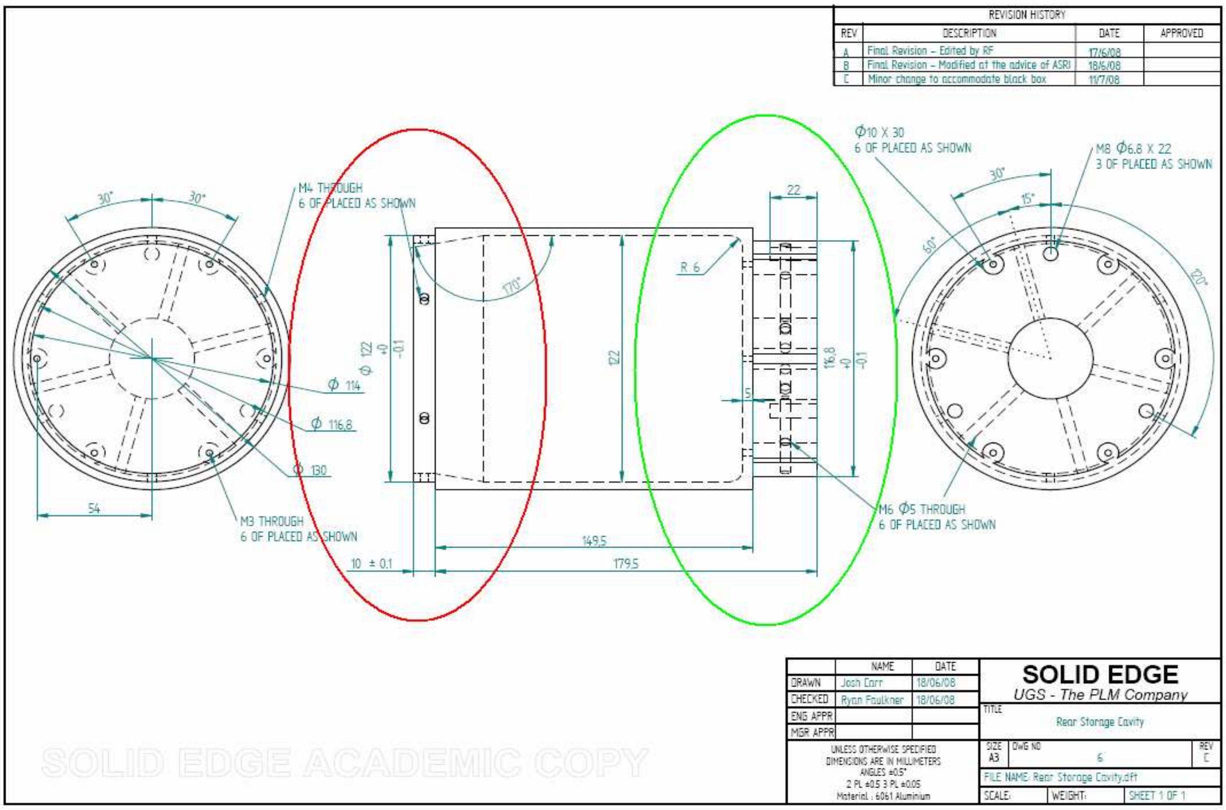
TITLE
Parts List

SIZE	DWG NO	REV
A3	8	A

FILE NAME: Exploded Assembly.dft

SCALE:	WEIGHT:	SHEET 1 OF 1

Fig 4.



REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
A	Final Revision – Edited by RF	17/6/08	
B	Final Revision – Modified at the advice of ASRI	18/6/08	
C	Minor change to accommodate black box	11/7/08	

	NAME	DATE
DRAWN	Josh Carr	18/06/08
CHECKED	Ryan Faulkner	18/06/08
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±0.5°
2 PL ±0.5 3 PL ±0.05
Material : 6061 Aluminium

SOLID EDGE
UGS - The PLM Company

TITLE
Rear Storage Cavity

SIZE	DWG NO	REV
A3	6	C

FILE NAME: Rear Storage Cavity.dft

SCALE:	WEIGHT:	SHEET 1 OF 1

Fig 5.

Figs 4&5. Joint circled red failed while joint circled green which is made to standard ASRI module joint dimensions in ASRI PUG held. Failed joint can be seen to have reduced length and wall width. It also had smaller retainer screws the heads of which pulled through the wall during joint failure. Note joint circled orange (Fig 4) is same joint as previous failed joint (Fig 3) but payload has rounded walls and joint walls reinforced by design (circled orange B).

It is suggested at the very least to use the dimensions and tolerances of the ASRI payload and recovery module for tube joints. Complete assessment of all other joints should be made to the stresses described in this report.