Deflection of utility modules on 5B's mounting system under static wind conditions

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Introduction

By 2033, almost 90% of power plant modules are expected to be over 2.5m^2 [ITRPV 2023]. These larger surface area modules can experience greater deflection and stresses under the same wind pressure. The MAVERICK(MAV) system by 5B is a photovoltaic (PV) array prefabricated in a factory for rapid field installation [Evans 2019]. The system is not impacted by dynamic wind loads due to a resonant frequency >1Hz, and experiences relatively low static wind loads due to its aerodynamic design (see Fig 1). However, the system uses a hinged corner mounting system for the modules which results in vastly different deflection and mechanical stresses on the modules.

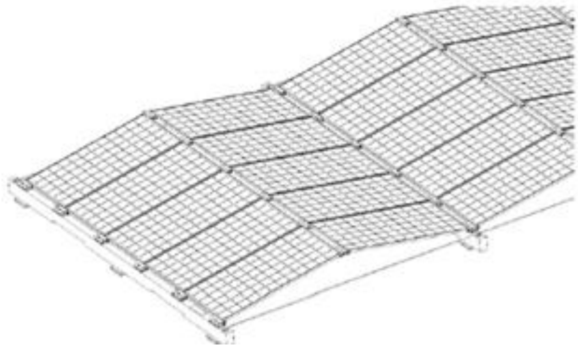

Fig 1: 5B's MAVERICK system with corner hinge mounted modules.

Previously, it was found that the module frame plastically deforms before any damage occurs to the cells within, including microcrack propagation [Ciesla 2021]. There was also no impact on module performance under pressures relevant to Wind Regions A and B according to (AS/NZS 1170). However, module designs have become less standardised. For 5B, it is extremely laborious to physically test in detail every different module, new mounting hinge iteration and wind scenario [Johns 2023]; the configurations are endless.

In this study, we evaluate different methods of collecting and analysing deflection data of loaded modules on 5B corner mounts in terms of simplicity and accuracy. We also present some early results using detailed deflection data to calibrate a Finite Element Model (FEM). Optimised FEM can accurately predict module deflection and stress under loading conditions [Hartley 2020], thereby providing some answers prior to conducting any physical tests at all.

Experimental methodology

Four sister modules were used in this work: utility size JA Solar JAM72S30-540MR, glass-backsheet, 22780mm long, 1134mm wide, 35mm frame height, 35mm frame flange on all edges.

The modules were mounted to a specially designed solid steel test jig using 5B's corner hinge mounts. An automated x-y scanning deflection measurement system, affectionately called 5BB, was built to scan the relative height of the underside of the deflected module with a touch probe (Fig. 2). Rubber mats cut to size were used for uniform loading and applied in ~40kg increments.

Each of the modules were mounted in a different configuration of:

- face down or face up, to simulate uplift and down force respectively
- both ends fixed, or one end sliding, to simulate movement that may or may not occur depending on the hinged mounts and wind conditions

The frame deflection was captured using a tripod-mounted camera; green circles and lines were added to the frame as reference markers (Figure 3).

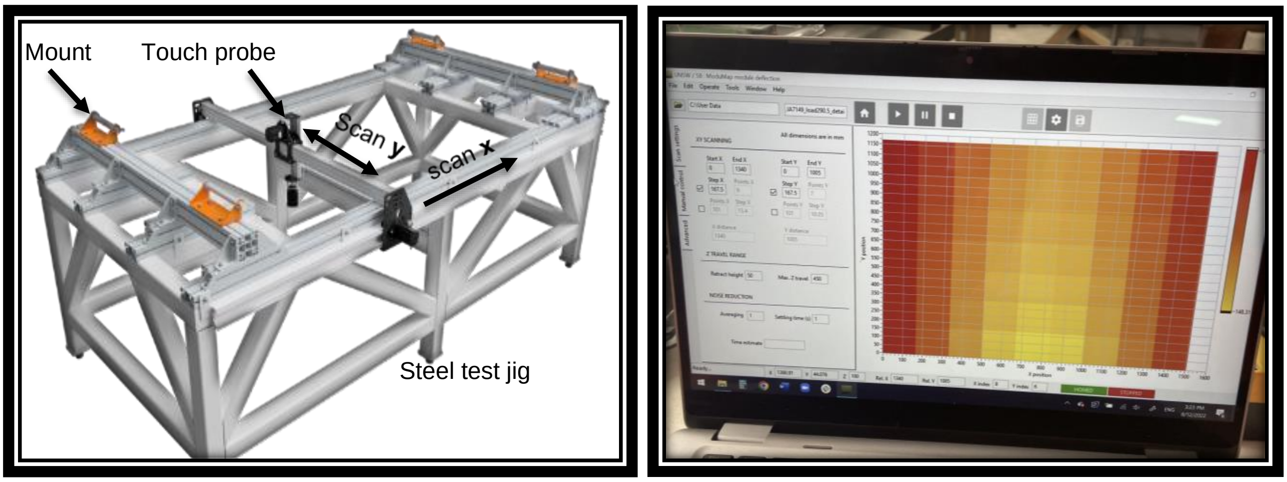

Figure 2: (a) Steel test jig with automated touch probe scanner 5BB, (b) 5BB ModuMap software interface with defection map[1].

Figure 3: (a) The tripod mounted camera (b) an example image from the camera showing the setup and frame deflected under load.

Experimental deflection analysis

Table 1 describes and evaluates the tripod and 5BB methods used to monitor the module deflection under load; it is assumed that maximum deflection is at the midpoint along the length of the module. The deflection results are shown later in Figure 5.

Table 1: Methods of analysing experimental deflection

Source	Method description	Pros	Cons
Tripod camera and ImageJ (Fig 3)	• Align tripod camera • Stick green circles to module centre and ends • Take photo at each stage ImageJ: • Draw line from centre of each end green dot to middle green dot • The line lengths, and angle at the intersection can be used to calculate the deflection distance	• Frame is critical factor in failures [Ciesla 2021 and Johns 2023] • Fast to setup and take images • Can accommodate slight frame bumps or camera/module tilt	• Cannot measure face of module including centre, or far side if uneven • Resolution of image means limited to pixel size (±2mm precision here) • Time to setup and analyse in Image J

5BB (Fig 2)	• Automated x-y scanner with touch probe sensor • Locate module centre, set scan grid, wait • Midpoint, side: extract z height values at the midpoint on the side closest to the tripod (~6.5cm from edge) • Centre, centre: extract z height values at the centre of the module	• Sub-mm accuracy • Can scan module face including centre, choice of data resolution. • Can visualise instantly the 2D deflection map, and identify uneven deflection (eg. Fig 2b)[1] • very simple analysis for single points	• limit ~6cm from edge and ~40cm from ends (can't measure frame) • Effort to align first scan • ~20min for 20 point grid. • detailed scans need detailed analysis • junction box is an obstacle when face-up • Probe accident needs recalibration or entire restart if broken.

Finite Element Modelling (FEM)

A quarter module (assuming symmetry) was modelled in Ansys and calibrated using the face-down fixed-end configuration. The simulated deflection with increasing load for each configuration is plotted later in Fig 5. The model assumes no separation between the module and the mounts, resulting in overestimated module deflection and stresses due to the increase in effective stiffness of the frame; this will be further optimised in future. Despite this overestimation, it can be seen in Fig 4(a), that the stresses on the cells in worst case uplift scenarios [Ciesla 2021] are minimal. Fig 4(b) shows the cell stresses are much higher on the same FEM module mounted by standard quarter point fixing under a standard 1200Pa load. In both cases cell stresses are well below the 120 MPa required to form cracks in Cz cells [Demant 2014].

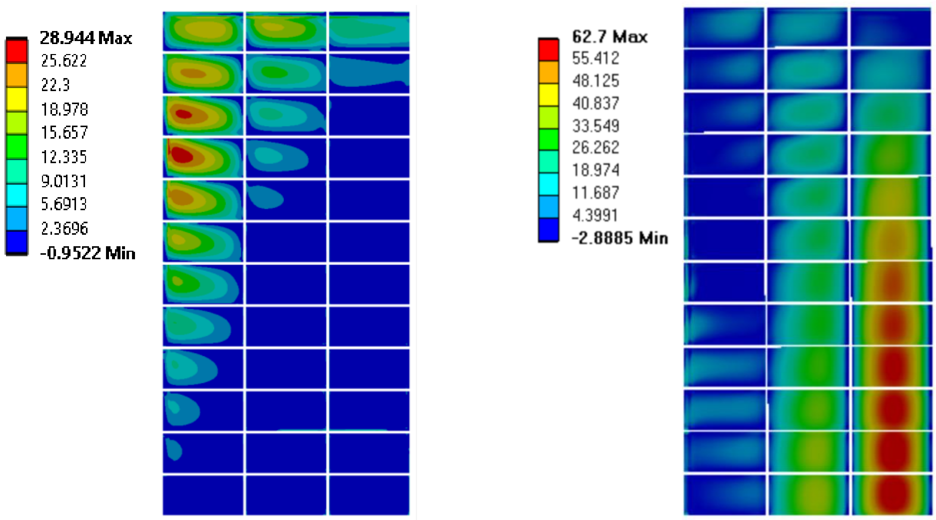

Figure 4: FEM tensile stress in the cells for the module on: (a) 5B's Maverick worst case uplift with safety factor Wind Region A (1053 Pa) [Ciesla 2021] (b) a standard quarter point mount under 1200 Pa

Deflection results and discussion

Figure 5 shows the deflection calculated by each experimental method described above and the FEM. The frame deflection measured from the tripod images is within ±2mm of the deflection measured on the face of the module ~6cm from the edge using 5BB, demonstrating good accuracy of the tripod method. The centre of the module is up to ~6mm more deflected than the side according

[1] Uneven deflection with one side significantly lower can result from misaligned mats

to 5BB. The fixed and sliding end scenarios show similar deflection until larger loads where the sliding end shows significantly more deflection.

The FEM shows good agreement for the centre of the module in the fixed end scenario but requires further optimisation of boundary conditions with a moving end, currently slightly overestimated. Deflection and stress are lowest in the fixed end scenarios. Fixing the front facing/corner modules in the 5B array that experience the highest wind pressures can minimise deflection and stress.

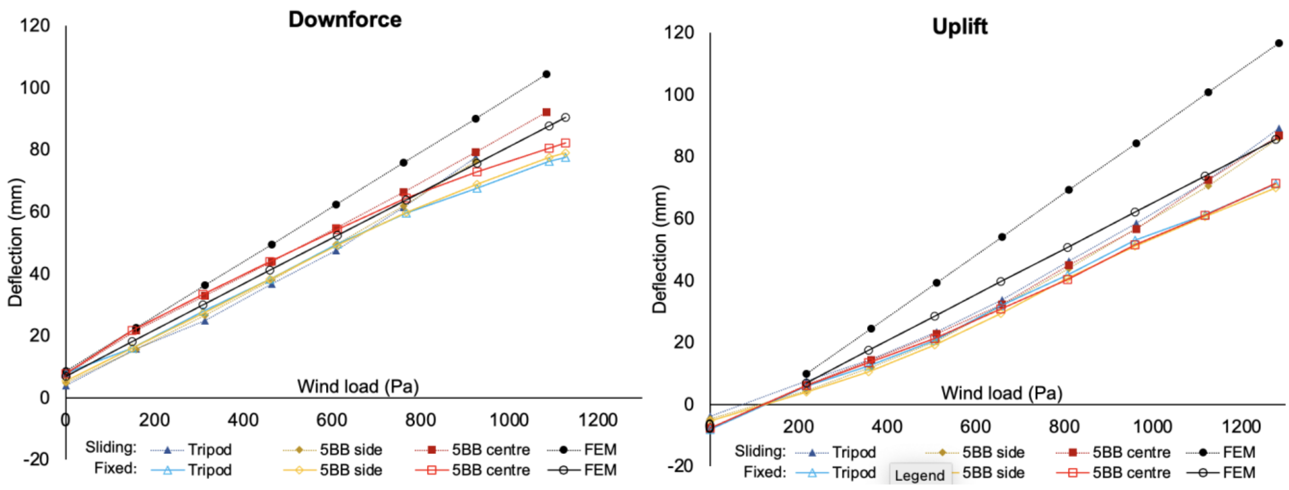

Figure 5: Deflection respective to wind load in 40kg/160Pa increments at the midpoint of the module length, from FEM (centre) and experimentally by the Tripod (frame), 5BB (centre and side adjacent to tripod), for both sliding and fixed end scenarios for (a) downforce (b) uplift[2]

Summary/Conclusions

- Deflection of utlity size modules mounted with 5B corner hinges was measured in different configurations and by different methods
- Tripod camera images with ImageJ analysis was able to monitor frame deflection to ±2mm.
- An automated touch probe (5BB) scanned the module underside to map the height within 1mm
- 5BB can monitor the module centre, the area where cells are, and identify uneven loading
- Tripod images are faster and monitor the frame which is the critical point of failure.
- FEM shows that stress on the cells is low under relevant wind pressures, and lower than stress on cells in a standard mount under 1200Pa
- Fixing the more exposed modules (preventing movement) can minimise deflection and stress

References

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[2] Uplift has negative deflection in 0Pa wind, 0kg added is equivalent to 217Pa wind to account for inverted module weight