

Vertical Picture-Frame Wing Jig Structure Design with an Eye to Foundation Loading

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ABSTRACT

The foundation of many production aircraft assembly facilities is a more dynamic and unpredictable quantity than we would sometimes care to admit. Any tooling structures constructed on these floors, no matter how thoroughly analyzed or well understood, are at the mercy of settling and shifting concrete, which can cause very lengthy and costly periodic recertification and adjustment procedures.

It is with this in mind, then, that we explore the design possibilities for one such structure to be built in Belfast, North Ireland for the assembly of the Shorts C-Series aircraft wings. We evaluate the peak floor pressure, weight, gravity deflection, drilling deflection, and thermal deflection of four promising structures and discover that carefully designed pivot points and tension members can offer significant benefits in some areas. However, when taken as a whole, a structure with moment-supporting corners and thermally independent upper and lower beams outperforms the other designs considered.

INTRODUCTION

Electroimpact has a history of delivering innovative, first-class automation and manufacturing solutions in the aerospace industry. Each project is an opportunity to execute, learn from, and advance the state of the art. So, when called on to design and build a new set of picture-frame jigs for the Shorts C-Series wings in Belfast, North Ireland, the first step was to reflect on past projects and identify the challenges we would be facing in the development of the major structure.

The list was not short. This structure would form the frame that all other tooling would depend on for accuracy and rigidity. The requirements were daunting, and there would be

no tolerance for failure. But one challenge stood out above the rest: foundation movement.

We know from past experience that foundations do move and that this can be a serious problem for the precision structures that rely on them. Concrete has a tendency to shift and settle, seemingly of its own volition. It can move a great deal as it cures in the months (and years) after it is first poured, it can creep under load, and it can swell with changes in temperature. Understanding fully the mechanics of what is happening beneath our jig is far beyond the scope of this paper, but we must acknowledge that the beast is there, and do what we can to mitigate its causes and minimize its effects.

There are a multitude of other challenges in the design of a precision jig structure for the exacting environment of aircraft manufacture, but the foundation is singled out because we are utterly dependant on it to be successful, yet it is all too easy to overlook during our analysis of structural steel. As we carefully balance deflection, weight, and resonance against cost and manufacturability, we cannot ignore the floor that will support our steel. That one factor can easily render even the most elegant design miserably unfit for use unless it is given the consideration it deserves. In the following text, we will look beyond typical structural steel analysis and explore several possible causes of foundation movement and what can be done to mitigate them. Only then do we have any hope of seeing our steel jig behave in the real world as it does on our computer screens.

BACKGROUND

In the year before work began on this project, a team of Electroimpact engineers completed the installation and handover of a very similar structure to the same customer. This was a vertical picture-frame jig for the C-Series

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demonstrator wing box (figure 1) in a factory just down the street from the new building site. Though there are some critical differences, the data collected during the establishment of this demonstrator wing box jig highlighted the problem quite clearly.



Figure 1. C-Series Demonstrator Wing Box Jig, Belfast

Hundreds of data points collected over three months illuminated three key contributors to foundation movement. First, we observed a change over time, with the largest movement occurring during the first month after jig construction, and leveling out as the concrete cured. Second, there was a noticeable shifting of the floor due to uneven heating of the jig upper beam. Finally, and most significantly, we saw a very large movement immediately under the outboard corner of the inboard tower, as well as a smaller movement under the inboard corner of the outboard tower.

The first issue can only be properly mitigated through improved foundation design, and even still can probably never be truly eliminated. The foundation settling trend was measured fairly uniformly across the length of the jig, meaning that the forces from the jig itself were not a significant factor. Fortunately, the foundation for the new factory will be more robust than the one on which the demonstrator wing box jig was built.

The second point must also be addressed in the factory layout rather than jig design. By controlling the ambient temperature more closely and doing so in such a way as to heat the jig structure evenly, we should be able to greatly reduce or eliminate this factor. Rather than radiant heaters mounted to the walls, the new factory is to be equipped with forced-air heating systems, which will be a substantial improvement.

The third point, however, is both the most severe and also the most dependant on jig design. This is an opportunity for significant improvement, and is the driving problem explored

in this paper. Figure 2, below, plots six sets of data collected across two weeks and illustrates this point. Inboard and outboard tower footprints are outlined in yellow, while piling locations are shown in red.

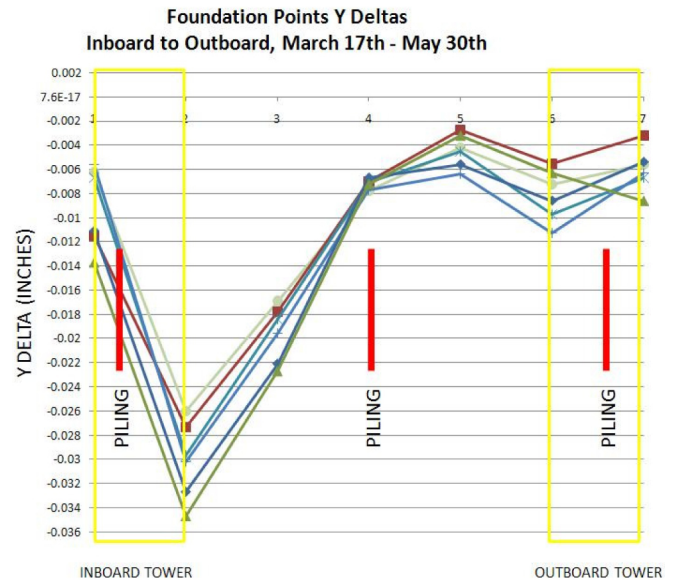


Figure 2. Foundation Settling, Inboard to Outboard

The large sag at the outboard corner of the inboard tower is obvious. Examination of the overall jig design on this project shows that this is the area of the highest foundation loading. The inboard tower is taller and heavier than the outboard tower, and moment loads from the upper beam are resolved here as well. This drives the pressure concentration to the outboard edge of the footprint, essentially tipping the tower about its pilings. Additionally, we observed a dependency between the foundation displacement and the moment loads. That is to say, due to the height of the tower and the geometry of the upper beam, as the foundation settles under the tower the upper beam moves outboard, which in turn actually causes an even more severe moment, feeding the problem.

The way-forward comes in several pieces. First of all, the foundation design was substantially improved, incorporating a thicker pad, more reinforcement, and more pilings. This will not only mitigate the settling issues we saw on the demonstrator wing box jig, but should also serve to greatly reduce the tipping effect caused by sparse pilings. Also, the heating system in the new factory will create a much more hospitable environment for large, precision jig structures.

The final point, though, is the key lesson we are focusing on for this discussion. We will be looking extensively at what can be done with the jig design to reduce the foundation-resolved moment loads. The theoretical benefits of this are two-fold. First, eliminating pressure concentrations like those found on the demonstrator wing box jig should directly reduce the amount of movement seen in the foundation.