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Ralph Parker & Tim Lucas


Ralph Parker/Price & Myers
Geometrics, Slipstream, Terminal 2,
Heathrow Airport, 2013

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TRIPPING THE FLIGHT FANTASTIC

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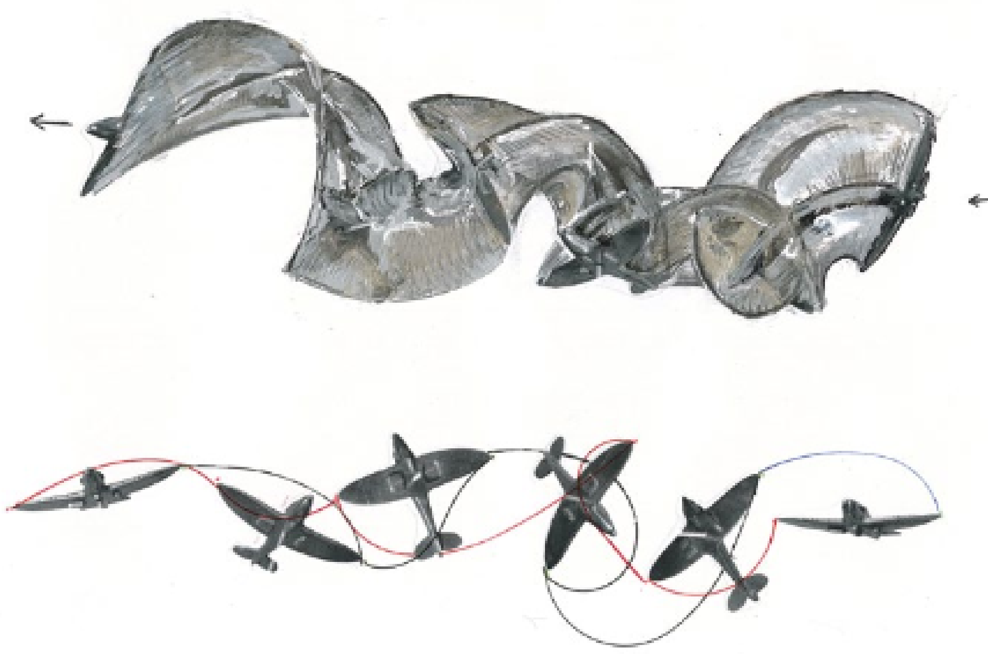
Richard Wilson, *Slipstream*, Terminal 2, Heathrow Airport, 2010
Concept sketch showing the solidification of the motion of a cartwheeling aircraft.

Ralph Parker and Tim Lucas of Price & Myers Geometrics explain the complex architectural and engineering challenges of turning a simple idea – solidifying the motion of a joyfully cartwheeling aircraft – into a vast kit-of-parts jigsaw puzzle for Richard Wilson's new sculpture at Heathrow.

Artists and architects have long concerned themselves with motion. In the early part of the last century, the Futurist Umberto Boccioni's bronze sculpture *Unique Forms of Continuity in Space* (1913) imagined the strange volumes carved in air by the dynamic motion of the body. At a similar time, for quite different reasons, Eadweard Muybridge and Frank Gilbreth corralled photography to expand motion beyond human perception.

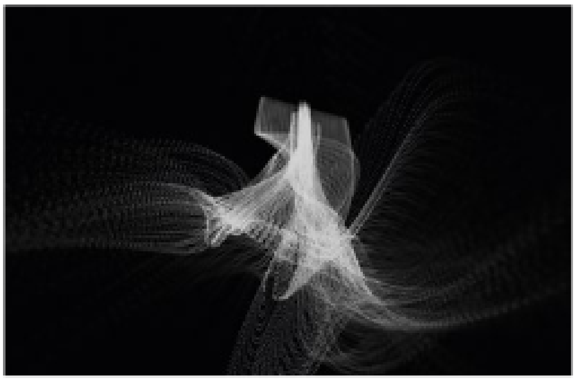
Today, computing power is in some senses catching up with Boccioni's future dream. For *Slipstream* – a Richard Wilson sculpture in the new Terminal 2 at Heathrow – the artist imagined an aircraft on a fantastic acrobatic trajectory through the space, and architect Ralph Parker devised from first principles a method of designing and capturing the motion of the aircraft, before processing the result into a 76-metre (249-foot) jigsaw kit of over 30,000 unique parts. Echoing construction techniques from the aerospace industry, each of the 22 cassettes that comprise the sculpture are built on a production-line assembly from individually CNC-labelled interlocking, self-setting-out pieces. Sophisticated engineering, involving wind tunnel and blast testing, allows the 70-tonne sculpture to span between four pre-existing columns flying 20 metres (66 feet) above the concourse.



Ralph Parker/Price & Myers Geometrics, *Slipstream*, Terminal 2, Heathrow Airport, 2013
Computer-generated image of the half a million programmatically generated rivet positions on the sculpture.

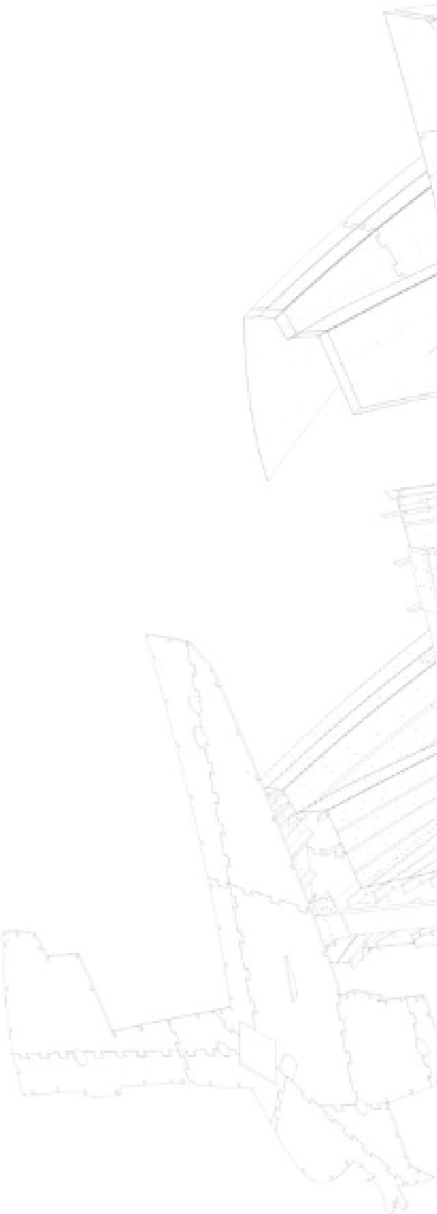
In mathematical terms, to calculate precisely the 'shape in space' described by a complex volume (a hand, or an aircraft) as it moves on a non-linear path is extremely challenging, indeed arguably impossible without some level of discretisation; for example, simplification of the source object, or its trajectory. Swept volume algorithms (for piston heads, undercarriages etc) tend to use a level of discretisation of the trajectory, usually to create a 'mesh' representing the swept envelope. They, like Muybridge's picture series, capture discrete moments in time: a subtle distinction, but a greatly simpler prospect than representing the entirety of the motion. Gilbreth's long-exposure photographs manage to capture this entirety, albeit projected onto the effectively two-dimensional plane of a photographic plate. What was required for *Slipstream* was an approach that worked as Gilbreth's plates had, but in three dimensions.

Besides these esoteric differences, other important considerations included design, structural action and buildability. The motion had to be authored by the artist and the architect, while fitting within the envelope of what was structurally viable as calculated by the Price & Myers' team of engineers. Time and procurement dictated that the form be constructed using only panel-based, CNC-cut parts – a 'flatpack' sculpture, simple and quick to assemble. A mesh-based approach would not be sufficient here, thus calling for a particular type of surface construction: ruled and developable. The architectural challenge of creating this unique form, and translating it into a buildable kit-of-parts for rapid assembly, required a novel combination of film animation software, aerospace design tools and scripting to accomplish.



Beginning with film animation software, the motion of the plane was designed inside the building information model (BIM) of the terminal building. Careful attention was paid to creating an elegant, continuous trajectory; almost 50 iterations were honed before the final movement, satisfying structural and aesthetic demands, was found. Smooth motion, logically, gave rise to a more harmonious (and easier to fabricate) form. The completed animation consists of 300 frames, similar to 300 Muybridge-like 'snapshots' of the motion, only in three dimensions. Using a series of scripts to process the large datasets involved, the trace of each vertex in the aircraft over the course of the 300 frames was formed into a spline describing its motion. The splines were then 'Gilbreth-ed' – joined by the script in sequence to create a series of ruled, developable, continuous ribbon surfaces.

The generation of the sculpture from the source motion is rational, but the resulting form, though beautiful, in construction terms is highly irrational. By comparison the form of an aircraft is predicated by function, and usually largely symmetrical; however each point on the *Slipstream* sculpture differed, often markedly, from every other. Nevertheless, drawing on the language and software of the aerospace industry, it was possible to develop an integrated model of more than 30,000 unique pieces, generated by parametric modelling together with complex custom scripts, running many millions of operations.



Price & Myers Geometrics, *Slipstream*, Terminal 2, Heathrow Airport, 2013
Exploded view of a typical unit showing steel armature, plywood ribs, bulkheads and skins, and aluminium cladding.

Due to its length – equivalent to a Jumbo Jet – and in order to segue with the main contractor's sequencing, the sculpture was split into 22 cassettes that were manufactured off site. The size of each cassette was dictated by what could be transported on a standard low-loader truck. A custom script calculated the minimum bounding box dimensions of each cassette.

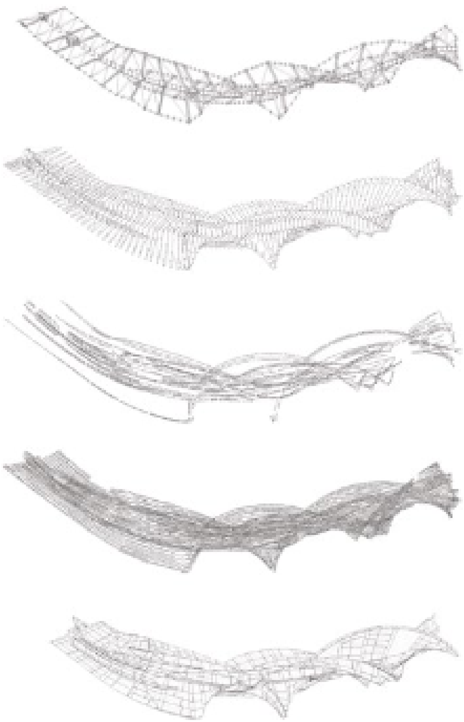
Construction began with the 76-metre (249-foot) steel skeleton, onto which were attached a series of 110 OSB bulkheads – effectively vertical slices through the sculpture – threaded like jigsaw pieces around the steelwork. Linking these together are a series of plywood spars, or 'combs' – so called because of their notches and edges where they form leading and trailing extremities – which set out the complex surface of the sculpture. A dual layer of thinner, curved ply forms the continuous skin of the sculpture; each panel is dovetailed into its neighbours, and has CNC pre-drilled holes corresponding to the edges, combs and bulkheads below to ensure accurate alignment. Onto the upper layer of ply is scribed the setting-out pattern for the aluminium panels, effectively printing the sculpture's instructions upon its surface. Each piece of OSB, plywood and aluminium has a unique ID that is written onto its surface via CNC. Generating the sweeping lines of rivets that delineate the movement through space of vertices on the aircraft's surface involved the creation of over half a million points in space, each with a its own unique ID.

Scripts were used to generate the plywood skin components and the aluminium panels, adding the dovetails and pre-drilled holes to the former, and the rivet cut-outs to the latter. In addition, where the generated pieces were larger than standard sheet sizes, the script added dovetailed splices and calculated the optimum placement of the piece on a sheet to minimise wastage. These complex scripts needed to deal with input pieces that displayed a high degree of variance in shape and size, and several million unique operations were required to generate the complete set.

A Rhythm In Four Dimensions
In a warehouse on the outskirts of Hull, the strange hulks of cassettes are aligned, in various states of completion. Several are bare steelwork; skeletons awaiting the timber flesh and aluminium skin that will make them corporeal. Further along the assembly line, timber frames are in evidence. The bulkheads echo with the shape of the aircraft, abstracted by motion. Seams of dovetail joints allow the steel tubes to pass through them. Notches in the comb and edge spars slot into corresponding notches across the bulkheads. This ensures that one corner of each comb touches the outer skin layer; a continuous line of setting out for the subsequent two layers of plywood deck. Accuracy established by the combs allows CNC-drilled holes in the first ply layer to line through and fix into them. Where pieces are larger than a standard-sized sheet, dovetail joints split the panel. The construction is intelligent, low cost and beautiful.

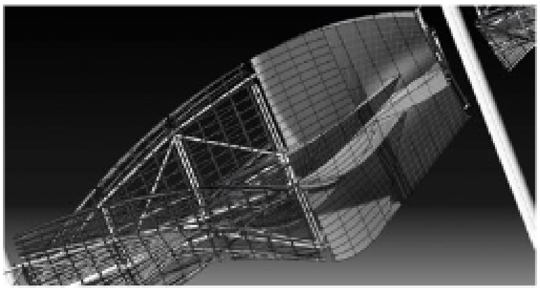
At the far end of the workshop, the twisting volumes are clad in aluminium. Some of the ribbons of metal strips are shallow, others curved tight, thin, intricate. The planes' motion is revealed as a complex four-dimensional form: the pattern of rivets illustrates the passage of time – closely spaced where the speed is low, spreading apart where the aircraft moves fast.

Structuring the Slipstream
There are generally two approaches to the structural design of a sculpture: add strength to a weak or brittle material with an internal armature, or use the strength of the sculpture's material to make it structural in itself. The scale and complexity of *Slipstream* demanded the internal structure approach. The armature weighs 35 tonnes and is 76 metres (249 feet) long, and enables the sculpture to be supported at four points, 18 metres (59 feet) apart.



Views showing separated component types.

Trial erection of three units in Hull.



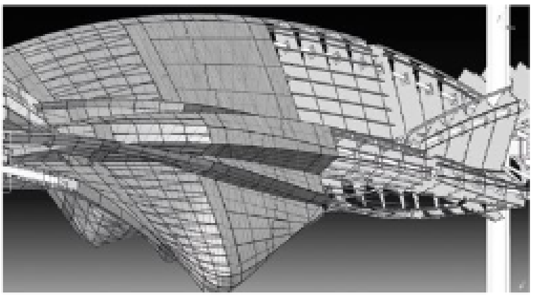
View of Catia model showing the steel structure under the plywood and aluminium skin.

The envelope of a building usually has plenty of space for a structure; for example, with a bridge the size and form of the structure informs the visual design. For *Slipstream* it was necessary to undergo a three-way iterative design process of controlling the form via the plane's flight path, understanding the volume created, and checking that a structure of adequate strength could fit inside. It took 48 versions to arrive at a form with a structure that could be accommodated.

Structural engineering is fundamentally about creating load paths between any part of a building and the ground. For *Slipstream*, a structurally sound load path has to link any part of the sculpture and the ground. The load path starts from the outer aluminium skin and continues through a plywood stressed skin, into plywood ribs, through OSB bulkheads and into the central steel armature. From here the load passes along the steel armature – formed from 22 bolted truss sections spanning like a contorted bridge through the sculpture's volume – to supporting bearings fixed on the steel columns that hold up the roof of the terminal building, and finally down into the ground. The challenge of creating a structure where each element is unique in shape was solved by developing a system of structural joints between each element in the load-path hierarchy that essentially does the same job. Materials are screwed, slotted, tied and bolted together in such a way that the geometry will always fit within these structural connections.

Material choice is based on both structural and fabrication considerations. The fabrication principle was to assemble notionally two-dimensional plywood and OSB parts into a complex three-dimensional shape. Flat timber panels were fundamental to allowing the unique shapes to be cut. For the armature, steel is the only material that has the strength, stiffness and adaptability to fit within the sculpture's skin and allow it to be manoeuvred and lifted easily. In common with the other elements in the sculpture, the steel armature is standardised but customisable. Divided into 22 similar but different units, the structure weaves and undulates through the volume. It is based on a central 400-millimetre (16-inch) steel box section core, with arms at either end that extend towards the surface of the sculpture. Steel bracing tubes join the arms to each other and back to the core. This simple system, joined with bolted 20-millimetre (0.8-inch) thick steel plates, gives the sculpture strength and crucially connects to all the bulkheads. The strong steel core allows each unit of the sculpture to be lifted, moved and erected without affecting the plywood and aluminium.

With installation of the sculpture underway, over three years of prototypical research and development, testing and construction are entering their final phase. Encompassing art, architecture, engineering and construction, *Slipstream* is a novel addition to that pantheon of works reflecting on the ephemeral tracks man leaves while moving through his world.



View of Catia model showing the aluminium and plywood skins over the bulkheads.