The Compound Helical Cone as Kinematic Trace

Emanuel Jannasch[1] and John Macnab[2]

[1]Dalhousie University School of Architecture, Halifax; jannasch@dal.ca
[2]Halifax, Canada; https://johnmacnab.com; jmacnab0@gmail.com

Abstract

A cone may be spirally fluted. If the fluted body is itself wound helically toward the apex of a conical envelope, both the cone and the helices are compounded. A series of works by John Macnab explores the expressive potential and intellectual history of this proposition. The imagery traditionally manifest in Solomonic columns, heliconical spires and cosmological diagrams is aspirational, even mystical. The computation reaches back to the kinematic/ parametric thinking of Albrecht Dürer but is developed in novel directions. That the astonishing forms are encoded and executed mechanically, outside the mainstream preoccupation with the "digital" can be seen as heretical.

Machine and Form

A woodworking lathe is like a potter's wheel: it constrains the transverse form of the worked object to a mathematical circle while leaving the longitudinal aspect to be freely formed by hand, eye, and tool. John Macnab's compound conical helices are made on machine tools, so their forms are defined entirely by mechanisms. There's no electronic computation anywhere in the system, whether digital or analog. The parameters of a given form are encoded in a mechanical configuration; independent variables are set by means of changeable gear or sprocket ratios, indexing patterns, cutter diameters, and the like. Antecedents for some of the mechanisms can be found the highly adaptable milling machines of the mid-twentieth century, the rose engines and ornamental turning devices of the Victorians, and the *Ars Tornandi* of the Baroque – notably examined by Joseph Connors [1]. Some constructs in Albrecht Dürer's *Underweysung der Messung* [2] of 1525–Figures 9(a) and 9(b)–exhibit kinematic and parametric thinking without showing the implicit machine. Macnab's *Lathe of Specific Intent* incorporates mechanisms unprecedented in the arts of turning. Interlinked, even a few such elements can generate astonishing complexity. The fluidity and vigor of the finished works belie their mechanical genesis. Some results are surprising even to the maker, and one is tempted to consider the forms, though wholly programmed, as substantially emergent.

(a)

(b)

Figure 1: *Work and tool: (a) mechanically generated form, with part of generating mechanism in background, (b) "root-stock" of mechanism showing timing chains and belts, optional elliptical gears.*

Four Early Trials

The piece in Figure 1(a) is non-compound: a simple cone exhibits helical flutes. The axial pitch is uniform. Accordingly, the helical slope reaches infinity at the materially unachievable apex and approaches zero at its unimaginable base. It was made on a patternmaker's lathe fitted with a leadscrew, a device coordinating longitudinal movement of the tool to the rotation of the workpiece. The cutter isn't static as in a conventional lathe, but active as on a milling machine. The tailstock was offset to establish the cone angle and the headstock fitted with a universal joint accommodating the offset. The cone was turned first, and the flutes inscribed as a second phase of work. This process lies squarely in the Victorian tradition of ornamental turning. But as the flutes progress from bottom to top they transform from ornamentation to another realm of work. At the base, the flutes are cut into the cone as ornament or elaboration, in the manner of a Roman column. Toward the apex, the flutes run into each other at ridges or arrises, as in a Greek column. The flutes thus become the only definition of the surface, integrating form and elaboration.

(a) (b) (c) (d)

Figure 2: *Early examples: (a) helically fluted cone, (b) concave-tapering openwork form, (c) compound conical helices (d) bent hyperboloid.*

Considered separately from the helix or spiral, even the plainest physical cone has monumental power. JM: *A cone in itself is thrilling to me, even if it is free from helical lines, they are implied a way. I think Miro knew this when he commissioned the large concrete cone on a hill in Barcelona and poured blue paint on it.* A mystical aspect of the cone is revealed to mathematicians who see a material semi-cone defining its imaginary completion overhead. Spirals and helices are more commonly understood in a mystical light evoking cyclic but progressive existence, with beginnings and ends sometimes definable but not always reachable. [7] JM: *I have always been inspired by the wondrous aspect of a spiraling form. I believe that this motion and emotion is widely recognized by mystics and even by an institution like the Catholic church as some sort of link to the firmament.* On a shallow cone we see a "spiral" and on a steeper cone we see a "helix", but the primordial form would be traced on a hyperboloid, which could degenerate to produce the cylindrical, conic, and planar derivatives. The openwork form shown in Figure 1(b) represents an effort to engage more actively with ordinary inhabited space and emphasizes that the figure in question is a surface rather than a mass. The geometry balances the upwardly distension or lightening against the upward constriction of radius. This piece isn't conical and doesn't appear to indicate an apex. Whether the slight concavity of taper is asymptotic, converging on a cylinder upwards, say, and on a cone or an annulus downward is unclear. Could this form represent a torus patch taken from a fat donut with a tiny hole? Could the curve swept about the vertical axis be a spiral?

The third piece (c) shown in Figure 2 is compound in a sense that the others aren't. First, the white body of the piece is conical and helically fluted, and this body is then coiled on a helical path within an invisible conical envelope. Both helices have a constant pitch measured along the primary longitudinal. The mechanism is simple: a planetary headstock (or "rootstock" in a vertical machine) traces out a trochoidal curve in plan; one per flute: The trochoidal helices progress toward a single apex defined by the fixed center of the tailstock. Patterns of interference occur between adjacent flutes as they pass over different phases of the coil, even to the point of erasure. For us, these patterns are difficult to predict or even characterize, suggesting a high level of emergence. The last piece, Figure 2(d), was generated by giving both the tailstock and headstock differing planetary actions: the tool paths thus generated are among the most complicated and most difficult to envision in all Macnab's opus, but closest to the primordial hyperboloidal helices.

Tool and Master

The textures in Figure 3 show cuts made sequentially across the flute: traces of the maker's hand and eye. The cutter removes material along its rim, as a saw does; it can't cut efficiently on the flat, on its circular face. The operator therefore makes a steady succession of plunge cuts as the workpiece presents itself to the tool. It is not enough, here, to speak of hand-eye coordination. The entire arm is acting as proprioceptive sensor, assisted by the eye, the ear, the pressure sensitivity of the palm, and possibly the vibration sensitivity of fingertips. All the information thus sensed is integrated with an internally generated sense of rhythm and translated to the actuating function of arm and hand. The coordination required seems to be partly conscious, partly unconscious and may to some extent bypass the central nervous system altogether. The human mastery of a physical medium is visible in the physical results. When the medium is code and the output is generated at metaphorical arm's length, the kludginess or the elegance remain hidden.

Figure 3: *The flutes are formed by the operator's successive plunge cuts.*

The pieces described so far were turned on a conventional lathe fitted with various adaptations, but with the primary axis oriented horizontally. This imposed absolute limitations on length and unnecessary constraints on slenderness. Transverse cutting loads and self-weight applied to the helical length of the bent body could cause it to fail. A specialized vertical lathe was built, almost two stories high, and with an easily reconfigurable head or root mechanism. The planet can spin opposite to its orbit. The elliptical gears shown in Figure 1(b), for example, maintain constant input and output rotation while varying the orbital radius but can also be set up to vary the relative rotations maintaining a constant combined radius.

Three Intermediate Forms

Case (a) in Figure 4 exhibits a certain rippling of the flutes. It may be reminiscent of the complex fluting in the previous case, Figure 2(c). However, in this case the effect can hardly be considered emergent because it's quite directly imparted, through a longitudinal stop, somewhat analogous to a taper attachment. The taper attachment on a machinist's lathe is in principle parallel to the principal axis of a turning but can be skewed slightly so that a tool limited by this edge generates tapers. Lathes have been built to turn spars for sailing vessels. These spars may incorporate a bulge or entasis as well as a taper, and, in the horizontal yards of a square rigger, the bulge is central and the taper symmetrical to both extremities. A gently curved stop is created by springing a steel bar into an appropriate elastic curve. In the case of Macnab's piece, the longitudinal stop is a carefully plotted and shaped decaying sine wave, perhaps more akin to the template governing the tool path in a copy lathe. With each flute, the template was indexed an appropriate increment higher with each flute, so that in one revolution the template was elevated a full wavelength. The rippling of each flute is directly and encoded in and transferred from the template, and it is in this sense that we can't observe much in the way of emergence. But the ripples themselves, advancing longitudinally one wavelength with every revolution of the workpiece do generate a third, implicit helix, that the eye can trace more easily than the explicit helices of the flutes.

(a) (b) (c)

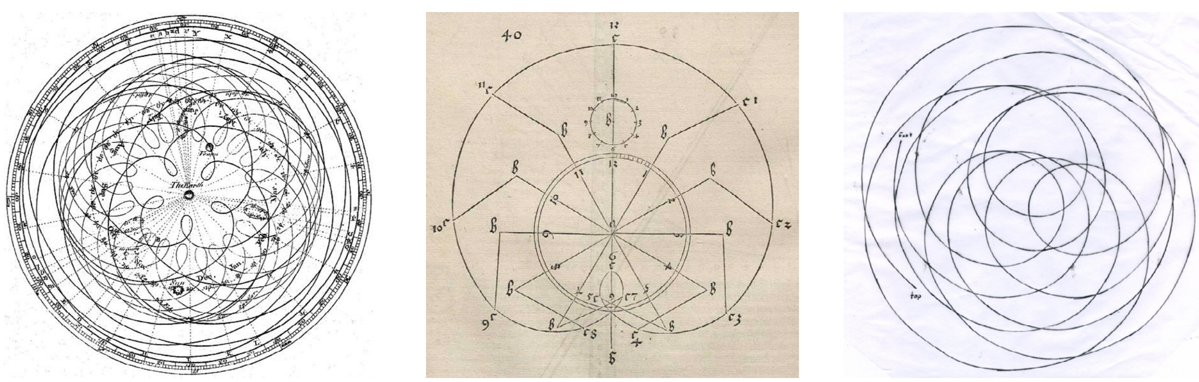
Figure 4: *Intermediate examples: (a) compound conical helices with rippled flutes. (b) compression of helical pitches–four flutes–inverted cones, (c) compression of helical pitches–four flutes.*

The pieces in Figures 4(b) and (c) are characterized by axial pitches lengthening toward the apex. In both pieces, both pitches increase in concert: that of the winding or corkscrew helix of the body in its enveloping cone, and that of the flutes on the body. This is achieved by a fusée mechanism inserted between the root-stock gearing and the leadscrew. A fusée consists of two pulleys or drums, the input drum gathering in a cable and the output drum (arranged to offer resistance, thus keeping the cable taut) which turns as the cable unspools. If one of the grooved drums is cylindrical and the other is conical, then the effective "gear" ratio between them gradually changes. If both drums are conical and opposed to each other, then the acceleration or deceleration of the output drum is intensified.

The split piece in Figure 4(b) is inverted from the conventional position of a cone. The void cleavage and the diameter opening as it rises implies a vessel rather than a flame, a flower rather than a shoot. At the base the body of the piece approaches a cylindrical form with the almost vertical flutes suggesting an ordinary Greek Doric column. The body of the piece fattening as the pitches compress changes the proportions entirely, evoking the Solomonic columns in the Baldachino of St. Peter's. The earlier columns now framing the crossing niches, or gothic columns at, for example the west front of Orvieto, also exhibit helical bodies and flutes of constant pitch and radius, but photogrammetry of St. Peter's shows a certain diminution. Compared to the earlier pieces, the flutes shown in Figures 4(b) and (c) remain distinct even as they grow shallower. This is accomplished by changing the attitude of the circular cutter, as it climbs the leadscrew. A drive-slot in the screw drives a pinion, which, acting through a gearbox, a flexible shaft, and a quadrant gear, rotates the angle-grinder driving the cutter up to 90˚ about its longitudinal axis.

Cosmography

That compound orbits trace out trochoidal paths has been long understood. Ferguson's sky-chart in Figure 5(a) below shows astronomical trajectories interpreted as geocentric orbits [3]. Albrecht Dürer's "spider-line" is in the grip of eight apparent arms, each with an elbow joint, and with a forearm shorter than the humeri [1]. In fact, the arms represent phases, 30˚ apart, of a single instrument that becomes invisible in its two straight and vertical moments. That the elbow and shoulder rotations can be coordinated by different functions is shown by the two dials. As an illustration introducing kinematics to the world the ratio of the imaginary gearing is 1:1. In these and related diagrams, Dürer consistently divides cycles into 12 or 24 hours, which makes the celestial reference quite explicit. Figure 5(c) shows Macnab's machine used not to move a workpiece relative to a tool, but to move a sheet of paper under a pen. We can see patterns emerging that never get to complete themselves before the vertical portion of the machine reaches its apical limit [5].



(a) (b) (c)

Figure 5: *Celestial trochoids: (a) Ptolemaic orbital paths as visualized by Ferguson in 1770, (b) Epitrochoid constructed by Dürer, (c) graphic trace of Macnab's* Lathe of Specific Intent*, 2005.*

Buckminster Fuller [4], in Figure 6, shows a three-orbit system of the moon about the earth about the sun about our galactic center, implying smaller and larger cycles at either end of the scale. A memory of this image, in fact, contributed to the idea of the planetary headstock [6]. Presumably for clarity, Fuller doesn't show the influence of "third" gravitational bodies. Nor does it show either the expansion of spirals, whether from the big bang or other explosive event, or their decaying to a terminal point as orbital energy is lost to collisions and other effects. Fuller's text completes the image with the observation that systems add or subtract features, elements, and influences to and from one another and that they are "self-annihilative."

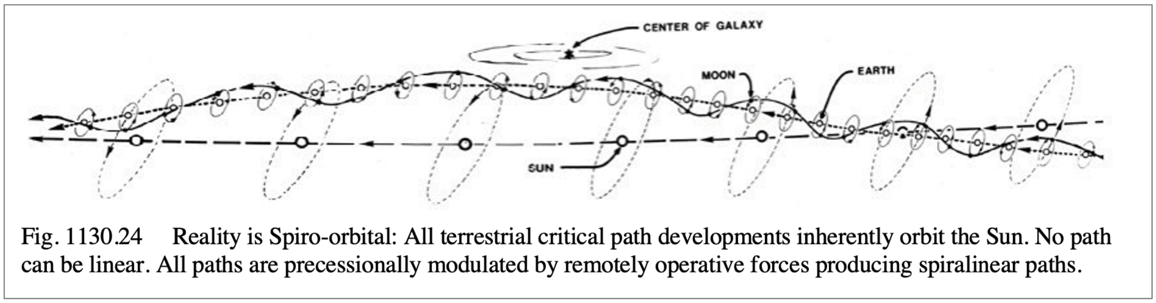


Figure 6: *Illustration of Spiro-Orbital reality from Buckminster Fuller's* Synergetics 2 [4].

Double-Ended Pieces

The conventional orientation of pieces described above restricts their formal associations to other vertical and grounded figures: the human, the plant, the flame, the obelisk; what have you. Wall-mounted horns or recumbent seashells were considered but seemed even more inclined to pictorial interpretations. Helices expanding from one extreme and contracting to the other could be more comfortably suspended than placed on a pedestal, expanding possible understanding of the pieces into broader and more abstract realms.

Figure 7: *Compound helices appearing and disappearing.*

Woodworkers will recognize the geometric and craft virtuosity required to make the pieces in separately halves brought together so that both the body helices and the flute helices pass smoothly and unbroken over the material seam. Setting up the machine and laying out the out the pieces to enable such a fit is all the trickier when the helices graduate in pitch over the length of the piece. The suspended piece in Figure 7 is enveloped by a symmetrical pair of cones that transition into one another through a middle barrel form. As the enveloping radius passes through its single wavelength, the coincident pitch of flute and corkscrew helices expands four times–or contracts to a quarter. Macnab has made five or six forms in this family, each one exploring a different relationship between envelope radius and body diameter and between bodily wind and fluted twist. Like all the pieces, that in Figure 8 records the external motion of tools against workpiece but it also becomes a marine or interstellar body defining its own Brancusian propulsion.

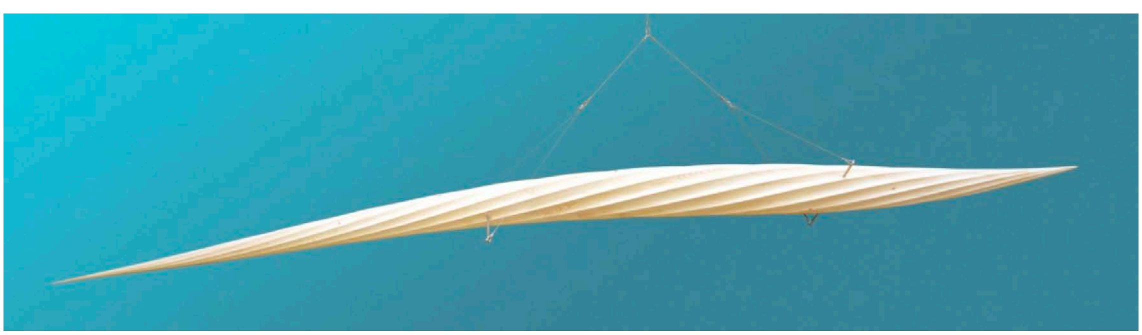
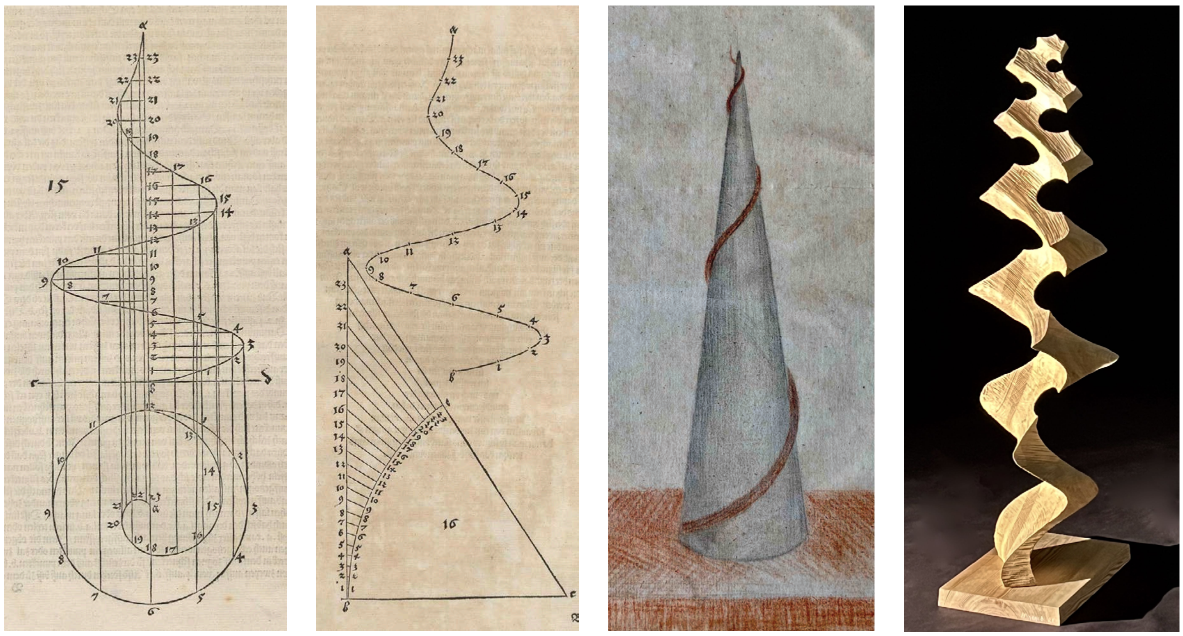


Figure 8: *Long-wavelength double cone.*

Origins and Destinies

Dürer's ascending curve shown in Figure 9(a) and 9(b) is defined by an unknown spiral in plan, and an obscure function along the vertical axis, described in an explanatory diagram. The two functions are related through 24 points, strongly suggesting the coordination between them is a matter of time, effected by a mechanism of some kind. Discovered well along in in Macnab's process, it's a startling premonition. The



(a) (b) (c) (d)

Figure 9: *Physics and Kinematics: (a) Dürer's 3-dimensional spiral and plan, (b) Dürer's vertical function, (c) Hogarth's line of beauty–marginalium from Hogarth's own copy of* The Analysis of Beauty *(d) four-fluted, non-circular, heliconical trace.*

line of beauty derived by Hogarth from a conical helix also stands as a prefiguration of sorts, though as the goal is a singular plane curve, the ambition embodied is rather different. What Dürer shares with Hogarth is an almost diagrammatic distillation of elegance. One of Macnab's later pieces–Figure 9(d)–shows more complex ambitions: in material properties and mechanisms as well as geometrical concepts, in technical skill as well as visual expression, in rhythmic movement and abrupt changes of direction, and in spectacular patterns of emergence. The suspended piece shown in Figure 10 takes these ambitions even farther, as the progressions of each become even harder to read, and their interactions harder to comprehend. Aspirations

Figure 10: *Four-fluted suspended turning.*

first evinced a quarter century earlier in the straightforward helicone of Figure 2(a) have come to fruition in forms inconceivable in those early seeds.

The spirit of our present time sees information as something ethereal and divorced from the material world, something "digital." It has forgotten that "digital" and "analog" are simply different ways of recording information, whether in electrical, mechanical, bio-chemical, or other patterns. By processing information entirely in macroscopic physical form, Macnab subverts the prevailing sense of the "digital" as invisible and omniscient legislator of progress.

Summary and Conclusions

The spiral is iconic of aspiration: developed vertically on hyperboloid or cone and compounded, all the more so. As the interaction between compounded patterns becomes more complex, the iconicity is less diagrammatic. As pieces are relieved of their bases and vertical obligations, they both complete themselves as bodies and engage more fully with the space around them. As continuous curves begin to oscillate more sharply, the tool path becomes less expressive than the implied movements of the material form. themselves. As the geometry becomes richer and the beats between wave-forms become less predictable– both in location and form, the whole may be more evocative of observer's own lived experience. How or whether these pieces are emblematic of the author's own complex motivations as geometer, machine-builder, mystic, and wood-worker is for the observer to assess. In pursuing these motivations, mathematical ideas have been explored and developed entirely as embodied in material interactions, in the concrete world, without recourse to electronic or other abstraction. What that means to coming times, only time can tell.

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