From Depression to Globalization:

Reconfiguring 20th Century American Machinery and Machine Tool Building

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Prologue

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Let's talk about Machine Tool Making.

1. The industry is Capital Intensive. A machine tool maker has a huge amount invested in plant and equipment.

2. The industry is Labor Intensive. Almost all the workers are highly skilled and not only that, each worker has to have significant experience working in the specific shop making that company's machines.

3. The Industry is cyclic. Some years there is a big backlog of orders. Some years, there is hardly anything for the skilled and valued workers to do.

4. The "Technical" competition is Brutal. As soon as a new machine design is fit for production, some competitor brings out a newer design with faster spindle speeds or faster motions or some other feature that he touts relentlessly in the trade publications. A Machine tool can be rendered obsolete by the time the first article is being crated up on a maker's loading dock.

5. The reverse of this can happen. A machine tool maker can devise a highly sophisticated design that just doesn't sell. Giddings and Lewis has had this happen to them several times and Davenport Machine had it happen with a servo-controlled, multi-spindle automatic bar machine.

6. During slow times, a machine tool manufacturer can be in competition with slightly used machine of his own manufacture. This is happening right now.

None of the above points have anything to do with the government, and the best of the foreign competition suffers all of the above situations. For most of its history the machine tool industry has been stodgy and steady. Now, it has been dragged into the world of dizzying change and brutal competition. I am amazed that any maker can stay in business at all. JimK

Six Epigraphs

“Never have there been so many technical advances made in so short a time as during the past four years of war, and it is safe to say that the design of machine tools has advanced at least fifty years in that time.”
H. E. Linsley, Machine Tools Editor, *Iron Age*, January 1946.¹

“Out of the research on alloy steels, necessitated by the many and rapid advances in aircraft design during the war, has come the superalloys. These were developed to furnish necessary high strength at high temperatures. To a considerable extent, the veil of secrecy surrounding these important developments has been lifted during the past year.”
J. M. Hodge and M. A. Grossman, R&D Division, Carnegie-Illinois Steel, October 1946.²

“A recent trend has been to subordinate the clear-cut distinction between general-purpose and single-purpose machine tools... first in order to obtain the savings of high production techniques on smaller lots and secondly to install equipment adaptable to change in design of the product.” *American Machinist*, March 1946.³

“Where Taylor had hard, medium, and soft steel, and hard, medium and soft cast iron to machine, the present-day field covers literally thousands of types of steels and nonferrous metals... There are many carbon and alloy steels, plain and alloyed cast iron, malleable and pearlitic irons, and many high- and low-strength nonferrous metals of copper, aluminum, zinc, and magnesium, and a great variety of types and forms of nonmetallic plastics. Dozens of these metals are now being machined at hardnesses not even thought of by Taylor.” Orlan Boston, College of Engineering, University of Michigan, April 1946.⁴

“The advance noted between the 1947 and the 1955 machine tool shows was unbelievable. If the industry continues this trend, and there is every indication that it will, who can say what lies ahead?” George H. Johnson, President, Gisholt Machine Co., February 1956.⁵

“Since the end of World War II, dual trends appear dominant in metalworking. One is toward greater productivity and more automatic operation. The other is for greater precision and reliability. Spur to the first are the vast production demands of the auto industry. The second may be in response to the needs of defense: higher-speed aircraft, missiles and space projects. But resulting improvements are spilling over into all industry.” E. R. Eshelman, Associate Editor, *Iron Age*, August 1960.⁶

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Introduction

Periodically since 1927, U.S. machine tool and machinery builders have gathered, first in Cleveland, and from 1947, in Chicago, to place before their industrial publics (purchasing agents, owners, executives, colleagues/competitors, foremen and engineers) the fruit of their innovative labors since the last National Machine Tool Show. Some 96,000 visitors attended the first post-1945 exposition, distributed across half a million square feet in the vacant Dodge-Chicago plant, “world famous for its production of engines for the B-29 bomber.”7 Earlier in 1947, the National Machine Tool Builders Association (MNTBA) had embraced and absorbed the forming tool makers’ association, joining organizationally America’s lathe and drill builders with its press and forge producers. Soon after the Show, the Dodge plant housed the design-intensive, but marketing-challenged Tucker Motor Car Company, a post-war startup/failure beloved by car buffs, and memorialized in a stylish Hollywood film (Francis Ford Coppola directed). By 1955, when the next Show opened at Chicago’s International Amphitheatre, the Dodge-Tucker plant had rejoined the aircraft propulsion business; Ford’s Aircraft Division occupied its sprawling domain, assembling Pratt and Whitney J-57 turbojet engines. The exposition remains a Chicago phenomenon, nowadays every two years, but in 1990, managers changed its name to the International Manufacturing Technology Show. On these incidental hooks hangs a tale of an industry perennially entwined with auto and aeronautical production, gradually discovering that it was no longer national, but international, and that it was no longer defined by machine tools but by multiple metalwork

7 These were terrible engines, though – overweight, leaking oil, snapping rods, catching fire, and hugely unreliable. See Kevin Cameron, “The Cost of Doing Business,” Torque Meter: Journal of the Aircraft Engine Historical Society 3(Winter 2004): 34-36, 39.
manufacturing technologies. It is that transformation, those linkages, and to a small degree, that discovery, that this essay seeks to outline.  

The conveners of this conference have invited colleagues to consider a series of key questions about the course of 20th century machine tool history: how “spectacular” increases in capacity arose in various countries; how contemporaries interpreted changing metalworking “products and processes”; how information flowed, especially internationally; and how ideas about modernity were embedded in this ongoing industrialization process. Framed as transnational questions, they will be difficult to answer in the absence of collaborative, similarly-framed and anchored transnational research. We may get to that stage; I’d hope so. But in commencing to think about these issues, I’ll be focusing chiefly on the United States in its (brief) triumphal age, highlighted in the epigraphs and the Introduction’s opening, when something like 70 percent of the world’s tools were American-built.

In a way, doing this research seems odd, as surely there ought be a shelf of studies already chronicling and analyzing the high era of U. S. global dominance/leadership in machine design and innovation. Regrettably, there does not seem to be such a body of work. Nearly all historical studies considering American machine tool and machinery development either focus on the century or so before 1950, or are a generation or more old, or both. The only substantive work on Cold War era tooling is David Noble’s learned polemic about numerical control, General Electric, the US Air Force, MIT, union/worker

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resistance to deskilling, the marginalization of innovator John Parsons, and most of all, in my view, high modernist hubris about mastering control through engineering and science.\textsuperscript{10} Noble’s extensively-researched study will observe its 25\textsuperscript{th} anniversary this year; yet although it initially triggered much discussion (in part due to its theoretical reliance on Harry Braverman’s late Marxist frameworks\textsuperscript{11}), it spawned no successors, unlike comparably significant books in other domains of social, technological, and labor history. This is distressing, but may well have resulted from the near-contemporaneous “deaths” of production-focused history of technology and Marxist-based studies, displaced by the scholarly rush to researching gender, culture, and consumption.

For our purposes, however, Noble’s analysis has several limitations which in part derive from his methodological and conceptual commitments. First, in \textit{Forces}, the dynamics of machine tool innovation are compressed into U.S. engineers’ and managers’ utopian search for the automatic factory and their enchantment with the military and with the power numerical control could deliver to management. Much else of significance was emergent at the time; except for enthusiasts, it may be plausible to see NC as a technological side-show, much anticipated but under-performing and commercially marginal, until its mid- to late-1970s transformation into CNC.\textsuperscript{12} Thus we might well return

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\textsuperscript{12} Noble acknowledges this; see \textit{Forces}, 212-13. What he does not do is to ask what was happening technologically with the 99\% of US machine tools that, in 1973, were not numerically-controlled. This is the sort of issue that resonates with David Edgerton’s \textit{The Shock of the Old}, New York: Oxford University Press, 2006. NC was hard wired, whether using vacuum tubes, transistors, or boards, whereas CNC was flexibly programmable through external microcomputers and, later, PCs or networks. See J. F. Reintjes, \textit{Numerical Control: Making a New Technology}, New York: Oxford University Press, 1991. Reintjes, a MIT insider, rejects Noble’s analysis and related arguments by Seymour Melman, noting that: “Any link between the decline of the US machine tool industry in the 1980s and the original numerical control technology itself is far-fetched.” (180)
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to the late 1930s and World War Two as a starting point, so as scan a more inclusive landscape of machine tool and machinery initiatives, including those which accelerated the creation of new materials which in turn generated complex challenges for processors.

Second, Forces configures an environment where giant corporations, federal bureaucracies, and research universities were the actors, a setting which poorly matches those on-the-ground situations where the vast majority of American machine tools were produced and used. Well over 90 percent of tool builders, across the Cold War decades, were quite small enterprises, generally employing under 100 workers, whereas the top dozen larger enterprises did not often have workforces above 1,000, except in war emergencies. Bringing a diversity of makers and users onto the stage would enrich and expand the range of actors bearing on the industry’s trajectory.

Third, though the Air Force and federal contracts surely directed the path to NC, the state was not the sole source of innovation “push.” As E. R. Eshelman noted in the 1960 epigraph above, the automobile industry was also rich and demanding throughout this period, seeking automaticity from a quite different vantage-point, until serious mid-1950s shifts and reverses brought a slight measure of convergence concerning types of machinery envisioned by auto and aerospace buyers – the magic word being “flexibility,” differently parsed in the two domains, to be sure. Last, just as historians’ attention to consumers has obscured producers in recent decades, so too those few scholars researching machinery and process transformations have rarely been concerned about the materials on which industrial

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13 Three of the dynamic dozen were involved in the Air Force’s 1955-57 procurement of n/c tools, particularly aircraft wing skin mills: Cincinnati Milling Machine, Kearney and Trecker, and Giddings and Lewis. (Ibid., 202.) We learn next to nothing about them outside this relationship, however, from Noble.

technologies worked.\textsuperscript{15} Yet as Hodge, Grossman, and Boston noted in the 1946 epigraphs, materials’ diversity was accelerating at war’s end; the ranges and varieties of metals and non-metals subject to processing continued to broaden at least through the 1960s.\textsuperscript{16} Bringing in the stuff tools pressed, cut, bored, and contoured should help us understand one contextual dimension so often missing, material culture.

With that said, let me outline what this essay will undertake to achieve. I’d like here to try to evoke, conceptualize, and analyze the rapidly-evolving dynamics of US industrial materials processing (which had global resonances as well) over a long quarter century roughly from the late 1930s through the mid-1960s. Materials processing is a term intentionally used here, though I exclude extraction (mining, logging, et al.) and flow-based practices (refining oil or ores, chemical processes re liquids and gases), along with the constitution of materials themselves (devising alloys or plastics). Thus we will be considering a subset of those solids being shaped to commercial and military ends for institutional customers.\textsuperscript{17} Not all solids will come into view, though. Here metallic objects are the principal focus, supplemented by occasional discussion of non-metals which arrived on the production scene, ca. 1930s-1960s. This approach will permit me to locate machine tools within the larger machinery-building sector and to finesse boundary questions, like:

\textsuperscript{15} Aluminum, alloys, and materials are absent from Forces’ index, though brief discussions of materials do appear at a number of points in the text.


\textsuperscript{17} A parallel transformation of materials and materials processing likely took place in relation to solids for direct use by consumers, including plastics and synthetic fibers on the materials side, along with food and packaging machinery, sheet-metal cutting and shaping devices (for household electrical items) and much else. I have not encountered work discussing these shifts inclusively, though.
“Are high-energy-rate forming devices machine tools or not?” This approach also channels discussion toward an emphasis on processes and problem-solving, rather than data on orders, exports, or sales, as so much of the social science literature on the tools industry seems to do. Should this prove an promising approach toward at least some global issues the American experience highlights, its angle of attack may hold some value for colleagues thinking cross-nationally. It also may illuminate some aspects of the larger project’s central questions about rising capabilities, production practices, information flows, modernity, and industrialization.

I will commence by reviewing five interactive dimensions of industrial materials processing challenges as depression gave way to war and Cold War, what I’m currently calling the “structure of flows”: 1)vectors of innovation in machine tools/machinery; 2) new materials; 3) new processes and substitutions for machining; 4) new or newly-prominent firms; and 5) cross-national issues/institutions bearing on flows of information and devices. The main exposition will follow in four chronological sections, in part anchored by the trade’s massive Chicago Machine Tool Shows: 1) From Misery to Victory (c. 1935-1945); 2) Autos, Aeronautics and Accumulating Innovations (c. 1945-1955); 3)

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18 HERF is a process which concentrates a burst of energy (early on, explosive charges) on a target object, which is transformed almost instantly to conform to the shape of a receiving die. This process was used in the 1950s and 1960s to create missile fuel tank dome-tops. See Gary Benedict, *Nontraditional Manufacturing Processes*, New York: CRC Press, 1987, Ch. 8.

19 Economists and policy analysts rely on trade association and government data, at least in the US, but rarely seem to have any substantive knowledge of the production processes involved. Among those produced the last decade’s declinist literature, UMass-Lowell’s Robert Forrant clearly “knows tools,” in my view, but he has focused chiefly on regional industrial erosion (Western Massachusetts), not on technological dynamics. Bo Carlsson’s work in the 1980s and 1990s on technological dynamics, factory automation and machine tools is equally well grounded, though Carlsson (Case Western) has moved on to questions of entrepreneurship and biotech over the last decade.

20 I will not be discussing industrial relations, training and education, state policies and institutions, except tangentially, though these are significant elements in large trajectories. My concern is that we do not as yet have anything like an adequate bare-bones narrative of U.S. machine tool history in the Cold War, and thus am attempting to articulate a preliminary skeleton here.
Detroit Automation vs. Aerospace Precision (1955-1965); 4) Substitution and Internationalization (1960s and after). The Conclusion will summarize core issues this exposition has explored, will consider this analysis’ relation to conceptualizing globalization, and will identify themes for ongoing and comparative research.

The Structure of Flows

Three basic conditions confronting solid materials processing equipment builders should be recognized at the outset. These enterprises faced demand that was doubly-derived and radical in its cyclicality. Hence, firms commonly worked closely with clients to develop innovations and improvements that corresponded with users’ current or projected technological needs. Last, given the sector’s boom and bust pattern, companies accumulated order backlogs and cash reserves in busy years, then used slack periods to develop new features or new lines, a strategy which enabled them to keep teams of core workers and engineers together, doing more than repair and replacement tasks. Doubly-derived demand captures the distance between equipment builders and consumer markets: they sell devices to firms, devices which create components for industrial or commercial goods, which then are assembled into final products, often by a third tier of enterprises. If consumer demand rises, orders for auto axles can first be filled by running extra shifts, until growth reaches a point where only new, higher-production, machines can resolve rising

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21 This was the case from the latter decades of the 19th century through the 1970s. For the earlier period, see Philip Scranton, Endless Novelty, Princeton: Princeton University Press, 1997, Chs. 6 & 9. The crash of the early 1980s, however, led to the eradication of many leading machine tool firms, which have not been replaced [Arthur Alexander, “Adaptation to Change in the U. S. Machine Tool Industry and the Effects of Government Policy,” RAND Note AD-A257-668, September 1990]. It is also the case for all capital goods producers, though makers of machinery for paper, chemical, glass, basic metals, et al. industries cannot be considered here.
backlogs. Thus machine builders are late to the boom, but also meet the bust early.\textsuperscript{22} When markets fade, equipment users quickly cancel orders for machines, press builders to stretch out deliveries, and at times, delay or default on payments due. This cyclicality is radical because when demand for plastic tubing rises 20 percent, for example, extrusion machine orders may double or treble, whereas on the downside, as sales contract amid perceptions of overcapacity, machinery orders race toward zero.

Hence, builders who can shift towards fast-expanding sectors as market signals arrive are well positioned for long-term survival. Alternatively, as 20\textsuperscript{th} century America illustrates, builders could follow a course informed by the needs of massive purchasers (steel, electrical, auto, and the state), relying on long-term alliances to carry them through retrenchments and dry spells. In either case, being intimately familiar with clients’ needs and wishes proves a leading asset; relations between builders’ “sales engineers” and users’ purchasing or procurement sections must be richly developed. Keeping veteran skilled workers active working on prototypes in slack years did more than confirm manly fraternalism; given respect, shop-experienced machinists offered many a corrective to designs in process and rigorously tested-through-use new devices before offering them to potential clients.\textsuperscript{23} This pattern of innovation in recessions/depressions broke form only once, during the Second World War, when firms went to three shifts and off-loaded equipment production to near-amateurs in machine tools (printing-press builders, general machine shops). Yet laboring to meet urgent (and changing) demand brought lessons about


\textsuperscript{23} Here is another situation where demand was “derived.” Builders’ design staffs routinely discounted sales engineers’ “puppy-dog” eagerness to please buyers by drafting special tool specifications, even as surveys showed repeatedly that clients’ purchasing agents rarely had authority to place equipment orders, which had to be confirmed by persuading corporate bosses, who thus sat at three removes from tool designers.
machinery and information shortcomings, fabrication ‘kinks,’ and the performance of new materials, which began to percolate through design offices once production for war contracted gradually after mid-1944. These basic elements of the machinery-building dynamic help us understand why the periodic big Tool Shows punctuated sectoral history as exclamation points. The shows represented “coming-out parties” for ten-ton debutantes, whose unveiling audiences much anticipated and wildly celebrated.

Given this context, identifying “vectors of innovation” in materials processing is the first order of business. In machinery trades, vectors (or trajectories) have an input-output duality, reflecting equipment builders’ alertness to users’ requirements. Clients push builders to create capabilities, embodied in devices and controls, which prove both enabling and constraining for both parties (one might think of this as flexible path-dependence, given many builders’ capacity to shift targets and design objects). What users’ wish may not be feasible, technically, reliably, or at a price they imagine, yet what builders can achieve given clients’ demands may reflexively shape users’ practices in production and design, enabling certain actions while sidelining others. Reciprocally, what builders do accomplish in innovation and improvement enables them to think forward, around and beyond each gain, so as to recognize and confront other deficiencies of the machine (or machine system). Meanwhile the same technical gains deepen firm-specific knowledge which constrains information exchange, substitution, and standardization across equipment from various builders (sometimes profitably). Vectors are the cumulative trails/traces of user-builder exchanges; they do not have momentum of themselves (which actors often
assume), cannot be extrapolated (though often are), and are subject to decisive shifts and
displacements from external sources (too rarely detected or anticipated).

Three such vectors bubble up from the sources: automaticity, precision/flexibility,
and substitution. Appropriately for technological history, they twist back and overlap
with one another as time flows on. The first two have well-recognized foundations; the
third though is a stealth fighter, operating diffusely under the radars of machine tool
executives. On the first count, automotive corporate leaders, with visions of the automatic
factory dancing in their heads, sought to combine machining operations in various
conveyor-connected tool sets, denoted as “transfer machines,” the heart of Detroit
automation. Though assailed as job-killers and robot producers, these devices demanded
sizable crews of attendants and repairmen, and generated hosts of problems in use.
Nonetheless auto industry demands for dedicated engine block lines pressed builders to
design speedy, durable, and accurate drills, borers, or horizontal millers, all of whose
working surfaces were keyed to core design parameters and work-sequence planning.
Automaticity saved floor space, time, labor costs, and in many cases capital, as installing

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24 This section draws on many conceptual “fathers,” but seems to me to derive significantly from Anthony
Giddens’ and Bruno Latour’s theoretical investigations. It leans away from Hughes also, I expect.

25 This is not exhaustive. Surely other vectors might be identified as research continues, especially in non-US
environs.

26 See Bo Carlsson, “The Development and Use of Machine Tools in Historical Perspective,” Journal of

27 In time this gave way to theorizing about “flexible automation,” which seems to have been adopted early
by Japanese vehicle manufacturers, such that different models (of say, Kubota tractors) could be assembled
sequentially on the same line as orders appeared. This of course in turn depended on just-in-time parts
contracting, through which fast and highly-flexible n/c tooling made machining quite short runs a standard
practice. See “Metalcutting: cells and machining centers,” Manufacturing Engineering 125(August 2000): 28-
Also, so far as I’m aware, we know next to nothing about machine tool demands for the non-auto sections of
vehicle production: trucks, buses, fire engines & emergency vehicles, farm equipment, and the like.
linked, dedicated tools proved to be cheaper than purchasing equal capacity in separate borers, millers, and grinders.\textsuperscript{28}

Seeking precision and flexibility leads in quite different directions than designing automaticity. Along this path, we find recurrent struggles about materials, tolerances and redesigns, for these problems in part defined the challenges aeronautical and aerospace enterprises had to engage. Such problems of course were not confined to aero-world, but during this generation, spanning World War II and the first decades of the Cold War, aeronautical roadblocks and the funding to attack them (coming from the Air Force and the Navy) focused both builders and non-auto tool users on these issues.\textsuperscript{29} Given that \textit{Iron Age} estimated that most postwar machining work was done in batch lots, flexibility mattered to tool users far away from Douglas, Lockheed, and Grumman. M.C. Chamberland concluded that “[As] American industry mass produces less than 25 percent of the parts going into assemblies, there is no choice but to accept the remaining 75 percent as short run requisitions.”\textsuperscript{30}

Precision is a bit different, as it concerns the repeatability of mechanical operations to some measurable degree of exactitude, with demands and measurement capabilities changing through time. Though expectations grew tighter over the decades, automotive (and automatic) machining long operated so as to create what John Staudenmaier calls “good enough technology,” workable fits with, by the 1940s, tolerances to hundredths of an

\textsuperscript{28} See Hounshell, “Automation, Transfer Machinery, and Mass Production.”

\textsuperscript{29} The Army focused more on missiles, once the USAF separated. Missiles, being single-use devices, involve quite different design parameters than aircraft, and consequently different materials and machinery requirements (substantial use of composites, powder metallurgy, sheet metal work on a heroic scale). These cannot be adequately considered here.

inch, not ten-thousandths or hundred-thousandths. For cars, reaching such levels would be neither necessary for effective engine functioning, nor cost-optimal. The latter, fine-tolerance arena was where aeronautical specifications thrived, as demands for precision escalated to the point where AM and other technical journals would publish articles about “Machining to Millionths” by the 1960s.\(^{31}\) The feedback bonus from precision work to job shops was that machining to close tolerances yielded components that fit solidly without extra (costly and potentially damaging) finishing work. Innovations that heightened precision, most of which had little to do with NC, could simplify and ease production in high-performance electrical fixtures and valve structures, just as in aircraft and space projects. In this sense, the spill-over from the precision and flexibility vector to the wide community of tool and machine users/operators likely was more general than that from automaticity.

Substitution presented a multidimensional, silent threat to American machine tool and machinery enterprises. It flowed through production along at least three streams. First, spatially, substitution involved the displacement of American-fabricated drills and mills by imported rivals, purchased by U.S. enterprises, and conversely, the displacement of exported U.S. tools by those firms in “other” industrial nations built (Japan, UK, Germany, Italy, France) for local/regional use or for third parties in the industrializing world. Second, substitution heralded the replacement of machining functions (cutting, shaping, contouring, etc.) by other processes, some classic (forging, pressing, casting) and some brand new (electrodischarge and chemical milling, HERF, injection molding). Third, substitution had a materials dimension. Whether for capabilities or costs, product designers increasingly

\(^{31}\) T. G. Lewis, “Machining to millionths,” The Tool and Manufacturing Engineer, 49(February 1962):65-68. (I’ve no clue whether anyone could then actually accomplish such work consistently, but for current-day discussion, see Appendix I.) Mathematicians distinguish sharply between precision and accuracy, but in my experience neither tool-builders nor machinists often did so.
chose to set aside the usual ferrous and non-ferrous metals (iron, steel, aluminum, copper),
instead adopting novel non-ferrous metals (titanium, beryllium), alloys (plain and fancy),
ceramics, composites, and plastics. These moves simultaneously reduced the scope for
customary machining technologies and set up sharp challenges for processing these new
materials (Who can make parts out of this stuff? at what production rates? with what
techniques? and at what costs?). Substitution thus was a divergent, yet deeply-significant
vector, moving through multiple modalities to redefine situationally what was an effective
manufacturing technology. Its prevalence and reach, I’d argue, informed renaming the
National Machine Tool Show as the International Manufacturing Technology Show,
though by that time (1990), the show was just about over for American tool builders.

The remaining four dimensions of industrial materials processing can perhaps be
treated more briefly. New materials have been mentioned a good deal already, but the
contextual reasons for their emergence merit some discussion. Alloys date to the Bronze
Age (literally), but in industrial times took flight in the latter 19th century as a part of
manufacturers’ search for stronger, more durable steels and for reformulated bronzes (re
naval and plumbing uses). A vanadium alloy famously made the Model T’s frame more
resilient (1908); soon after Henry Brearly cooked up the first stainless steel (1913, adding
just under 12 percent chromium and keeping carbon below one-quarter of a percent). Both
alloys were British creations; the UK was an early center for innovative metals, just as was
Germany for chemically-based materials, here chiefly plastics. World War Two demanded
U.S. alloy improvisations, as nickel shortages became severe and a number of generally-
used elements became nearly impossible to import (e.g., chromium, tungsten). National

32 See for example, “How to Machine Plastics,” American Machinist 94(26 June 1950): 89-96, a special
section providing information to address “the fact that plastics are generally considered difficult to machine.”
(89). That year, Machine Design also offered a special section on using plastics for parts in light-use
Emergency Steels, especially those containing a very small proportion of nickel (under one percent), plus chromium and molybdenum, proved effective in multiple military uses. As well, postwar “intellectual reparations,” technological documents, knowledge and practices gathered by the UK/US BIOS, CIOS, and FIAT looting teams, delivered a generation of materials advances from Germany, Austria, and Czechoslovakia to Allied hands (and with the publication of reports by the thousands, to US universities and corporations).

Here then were the mechanisms reinforcing the search for new materials, even as the uses calling for attention were myriad. Engineers needed lightweight materials, especially in aeronautics, but eventually in autos, where aluminum alloys replaced some steel elements, before being joined by stable, shock-resistant plastics. Corrosion was a perennial problem, pressed forward by the extraordinary expansion of the US chemical industry in the 1940s and addressed in part by chemical products, particularly phenol-formaldehyde plastics and polyvinyl chlorides (as thermosets, they were corrosion resistant in many situations). Metal users sought high-strength materials that were durable at high temperatures, encountered either for short or long terms, though the resulting alloys were often brittle and extremely hard. Hence, machine tool users eagerly welcomed cutters that could shape these tough and expensive materials, starting with tungsten carbides in the

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33 For a small, perhaps diminishing number of scholars, reading wartime issues of the technical journal Metals and Alloys is both fascinating and enlightening. More than a decade ago, I rescued a decade’s run of the journal from becoming landfill, when the Franklin Institute auctioned its library. No one bid on M&A, so I hauled stacks of issues and bound volumes home.


35 Warren Beecher, “Competitive Battle between New and Established Metals,” The Magazine of Wall Street 80(27 September 1947): 710-11, 725-27; A. J. Tuscany, “The Pattern Shop and Our National Economy,” Foundry 75(January 1947): 79, 216-24. Tuscany argued: “We are witnessing today an entirely different type of competition than was prevalent some years back. The individual is no longer competing with his individual competitor; rather, he is competing with other industries seeking to replace his markets with their materials.” (79)
Thirties, moving in the Forties to cermets (mostly metal oxides, which were harder than most superalloys), and then edge-less cutting in the Fifties and after. Firms also “applied [ceramic coatings] to low-carbon steels for high temperature use.” Composites, starting with fiberglass embedded in phenolic plastics (Douglas Aircraft), multiplied to solve weight, strength, and metal shortage difficulties during wartime, introducing honeycomb sandwich materials, filament winding, and metal-non-metal bonding, which both military and NASA aeronautical and space programs used.\(^{36}\) As one indicator of the materials flood, in March 1952, *Iron Age* published a special section revealing specifications for “more than 400 tool steels, die steels and carbides introduced since 1949” in the US and UK, a list excluding new alloy steels for other uses, non-ferrous compounds, and non-metallics.\(^{37}\)

As materials proliferated and demands from designers and users for speed, economy, reliability, or accuracy escalated, new processes, both operational and organizational, entered the field. Gary Benedict terms these “nontraditional manufacturing processes,” explaining that they distinguish themselves “either by utilizing energy in novel ways or by applying forms of energy heretofore unused for the purpose of manufacturing.”\(^{38}\) Several have already been mentioned, like high-energy-rate forming or injection molding; but though their numbers are considerable, there’s not enough space

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\(^{37}\) “New Tool Steels and Carbides,” *Iron Age* 169 (6 March 1952): 228-276 (quote from 228, emphasis added). Each variant was described as to purpose, composition, and maker, for users’ convenience - e.g. “ACX: A super tungsten high speed tool steel containing Co. 11.00 [%]. Atlas Steels, Ltd.” (228).

here to flesh out their practices, capabilities and histories. Some techniques which expanded dramatically were pre-war innovations, like powder metallurgy; others such as die casting, forging, sheet-metal stamping/cutting dated further back, but found broader uses, both in precision and rapid, large-batch production. More fanciful is electrodischARGE machining, where electrodes take the place of cutters in a process of reverse plating (removing metal electrically rather than depositing it), and chemical milling, a radical upgrading of etching initiated at and patented by North American Aviation in the late 1940s. Unlike photochemical milling, which was key to creating semiconductor circuits & computer chips, chem-mill is a physical process in which part of a surface is covered with a non-reactant mask before immersing the object in a usually-acid bath, removing metal from the exposed area, leaving no cracks, internal stresses, or machining scars.

Of course, the most discussed innovation within machine tool processing would be numerical control, which built out from long experience in profiling and tracer control (in essence, physical processes that echoed 19th century pantographs or copying lathes). Equally creative efforts produced a wide range of other controls, though few of them have received comparable attention. Finally, these and a host of other innovative techniques depended, profoundly, on rapid improvements in a fundamental background technology –

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39 Large-batch here is a situational term, usually referencing identical items made by the thousands to tens of thousands without design changes. Yet at least one observer indicated that rapid stamping, for example, could turn out 200,000 small items in a batch, before changing dies to process a different part. One dividing line between large batch manufacturing and mass production, in technical terms, would likely be the absence of dedicated machinery in the former case and its presence in the latter. See Chamberland, “Contour Machining” (n25).

instrumentation and measurement capabilities. If instrumentation could not reliably “tell” control devices “how hot,” “how deep,” “how far,” the effectiveness of the entire technically-advanced setup would be minimal.\textsuperscript{41} Parallel track innovation, then, on solid industrial materials processing capabilities and on instrumentation to monitor those processes and prove their reliability, was essential to the viability of new techniques.

In all quarters, new firms (or firms newly-prominent) regularly brought forward crucial innovations. Alliances with automakers built the Cross Company’s fortunes; it sold its first transfer machine in 1946. Greenlee Brothers (Rockford, IL) supplied dedicated multi-tool arrays for Wright’s and Studebaker’s wartime piston aircraft engine plants, then moved rapidly into electrical and auto applications after 1945. Airframes’ technological complexities spotlighted firms building machines for precision tasks, like Huffard’s aluminum stretch-formers or Mesta Machine in Pittsburgh, which became central to the Air Force’s heavy press program for large, accurate forgings.\textsuperscript{42} On another front, in 1948, Machine Design profiled fourteen firms making novel plastics machinery, four of which were machine tool builders branching out, the rest either new starts or non-tool firms venturing into the business. Similarly with NC controls in the late Fifties, when Factory introduced thirty-one systems for manufacturers’ review, tool firms offered a few (Fosdick, Pratt & Whitney, National Automatic, Warner & Swasey), Westinghouse and GE each


presented a version, priced at $10,000-$15,000, but the rest came either from relative unknowns (Electrosystems, Burbank, [$14,000]; Electronic Control Systems, Los Angeles [$20,000]) or from expanding instrumentation and computing enterprises (Hillyer Instrument, New Jersey [$6000]; Cleveland Instrument [$15,000]; Wang Laboratories, Cambridge, MA [no price].

43 It should be noted that most general purpose machine tools at this time cost from $6,000 to $12,000, without special add-ons; early numerical controllers alone were as or more expensive.

It is plausible that many of these “unknown” firms were engineering-specialty spinoffs from leading firms in tool and machinery building, electrical and aircraft production, commenced by clusters of wartime subcontracting startups seeking trade in the emergent peacetime economy. This was a well known feature of the Southern California aircraft (later aerospace) industry, and a less recognized element of its die casting sectors, which expanded from a few firms in the late 1930s to over 100 by 1955. 44 In 1956, Steel noted that “Many new companies are coming into the special tool business,” moving, like Cleveland’s Zagar Tool and Detroit’s Michigan Drill Head, to serve clients outside the automobile production, the heartland of specials. 45 It would be valuable to research these newcomers’ trajectories, but that work lies beyond this essay’s scope. Their activities,


however, should remind us that the boundary between machine tool and materials processing machinery grew increasingly porous after World War Two, just as the distinction between general purpose and special tools blurred.

Last, in exploring “the structure of flows,” we visit those cross-national issues and institutions that mediate, channel, or obstruct the movement of information and machines. Nation states are the most obvious institutions here, facing in postwar Europe massive tasks of reconstruction in an environment of financial prostration, which in some cases took a full decade to overcome.\(^{46}\) Dollar shortages, currency restrictions, the Marshall Plan, the quest for building national champions – these and other issues shaped a broad European determination to welcome assistance from the US while striving to avoid dependency.

American machine tool trade policy was open-door-ish initially, when US builders were exporting 25-30 percent of their output, but as this proportion fell toward ten percent and as non-US tools gained favor at home, quotas and tariffs returned to favor.\(^{47}\) Private sector institutions like the US NMTBA lobbied vigorously for speedier tax amortization of capital goods, technical education, military purchases of tool reserves for use in war emergencies, and in time, protection. Most important, the NMBTA sponsored and organized the major American tool shows from the 1920s into the 1990s, significantly shifting in 1970 from a five year to a two year cycle because the pace of manufacturing technology change and the role of non-US firms in innovation had soared.\(^{48}\) Standards authorities, labor unions and


\(^{48}\) *IMTS News*, 2004, 3-4. The NMBTA was hardly alone in sponsoring industrial congresses (another weakly researched topic in industrialization studies). For example, the American Society of Metals convened
international labor organizations (the IAM and the ILO), trade-financing institutions (public and private), national and international technical and professional associations (e.g., ASME), and the technical and trade press (including publishers of catalogs, manuals, and used machinery bulletins) all provided threads supplying the elaborate web of technical information flows as machinery markets and relations for provision became global.

Transnational issues and debates concerned measurement systems, patents, licensing, and copying/design theft, taxes and restraints on imports/competition, training schemes, labor- and cost-saving tactics (along with labor displacement), venues and topics for materials research, machine capabilities and characteristics (rigidity, power-use, feeds and speeds, et al.), contracting, subcontracting, and military contracting, marketing, innovation, and redesign. The complexity and depth of these discourses is arresting, but only glimpses of their texture, their political-economic commitments, and their unacknowledged assumptions can be presented here. Suffice it to say that the classic mode of industrial discourse, “progress talk,” flowered richly through these exchanges, perhaps blocking recognition that the flow of new materials, new techniques, new competitors, shifting market demands, and enhanced machine capacities could swirl into a series of hurricanes that could (and would) sweep away the American machine tool industry’s hallmark enterprises, one after another.

From Misery to Victory (c. 1935-1945)

the National Metals Congresses starting about 1919. At the 17th meeting, in early October 1935, the ASM welcomed the American Welding Society, the Wire Association, and over 200 exhibitors to Chicago’s New International Amphitheatre, just before the Machine Tool Exposition in Cleveland that month. See Metals and Alloys: National Metal Exposition Issue 6(October 1935). M&A’s editorial director was H. W. Gillett, director of the Battelle Memorial Institute in Columbus, OH and former chief chemist for the National Bureau of Standards. Though it cannot be treated here, the comparably-propulsive role of contemporary machine tool shows in the UK, Germany, Japan and elsewhere, could offer a valuable node for research.
Midway through the Great Depression, *Fortune* elegantly characterized U.S. machine tool builders, noting that the trade had no one geographical center nor any core firm that characterized it. Moreover:

Most of the companies [have] developed around the mechanical genius of their founders. Nearly all are owner-managed, often by the son or the grandson of the original proprietor; and the principle of not getting into the hands of the bankers (or the public) is still one of the industry’s guiding lights. Nearly all the manufacturers are each others’ customers, for there is no industry behind the machine tool industry… As a class, the heads of the machine tool companies represent an aristocracy of U.S. management. They never get rich quick, and they often do not get rich at any time, and they are likely to be much stronger on the production side than on the financial side of the business… Since one of their objects is turning out foolproof tools that anyone can learn to operate, they… round up most of the high-class machinists in the U.S. [to create tools] and constitute a kind of guild, handicraft industry. Startling is the paradox that the industry most responsible for the machine age is itself the epitome of skilled hand labor.49

Consistent with this apt and generous portrait, tool builders in the mid-thirties were optimistic, despite five dreadful years. Those who had survived a 90 percent drop in sales (1929-32, from $175 million to under $20 million) were experiencing a gradual upswing. Although the trade’s “capital and surplus” had shrunk 36 percent in the depression’s first five years, 1935 brought a sharp rebound, with sales expectations nearing $100 million, employment up strongly, and hopes circulating for overall profits in the $10 million range.50 Little wonder that October’s two-week Machine Tool Show in Cleveland was a festive occasion.

*American Machinist* reported enthusiasm “at a high pitch,” with tool sellers surprisingly “unprepared for the eagerness displayed by the visitors who came to study and compare.” Exhibits by 120 machine tool builders and 118 auxiliary firms occupied 235,000 square feet in the Public Auditorium and Exhibition Halls, with *AM’s* 1935

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50 Ibid., 105.
Inventory of Metal-Working Equipment a main feature near the entrance. Accomplished through social-scientific surveys of tool-using firms, the Inventory would become a mainstay of the journal’s perennial “Buy New Tools” advocacy, for it consistently showed that the majority of drills, lathes, and planers were older than ten or fifteen years (in 1935, well over half, the only exception being fewer than half in 1945, after massive World War II tool production).\textsuperscript{51} Clients seemed ready to buy, not least given the widely-shared belief that this show “represented a turning point in mechanical history.” Along key parameters (accuracy, productive capacity, convenience of control), visitors reported impressive improvements over both the machines offered at the 1929 show and those in visitors’ plants. New tools weighed 25-50 percent more than those at the previous exposition, which increased rigidity and made closer tolerances possible. Cemented carbide cutting tools debuted, with a promising if uneven showing. Also, “[e]xperimentation with alloy steels continue[d] in an effort to get ones that respond best to heat treatment,” as selecting tougher materials now informed everyday practice.\textsuperscript{52}

On the users’ side, GE initially sent its “manufacturing committee” to take stock, following up the second week with “150 of the superintendents and other tool men.”\textsuperscript{53}

\textsuperscript{51} The \textit{American Machinist} inventories continued at least into the 1980s and their data have anchored much of the economic and policy research on machine tool usage in the US. A 1960s government sponsored study outlined its dimensions thusly: “\textit{American Machinist} magazine, a publication of McGraw-Hill, conducts an inventory of metalworking equipment every 5 years. Detailed breakdowns of 167 machine and equipment types for 24 geographical areas and 44 using industries are given. Age categories—less than 10 years old, 10 to 20 years old, and over 20 years old—are also reported. For the 1963 survey, questionnaires were sent to 34,000 metalworking plants; 7,370 responses were received. The McGraw-Hill survey of anticipated plant and equipment expenditures generally provides data on investment flows only. Sometimes questions on the type of the investment such as replacement and modernization or expansion for buildings, motor vehicles, and machinery and equipment and on capacity, utilized capacity, and age of installed capacity are included.” George Washington University, Wealth Inventory Planning Study, \textit{Measuring the Nation’s Wealth}, Washington, DC: GPO, 1964, 629.


\textsuperscript{53} Ibid.
Chrysler president K. T. Keller admired the “growing appreciation of the necessity for precision… as well as the new developments in measuring and gauging equipment.” Yet these multi-track advances caused some unease as well. More than a few shopmen began “to wonder how they were going to educate operators in the handling of these new units. On some of them failure to concentrate for as short a period as a second or two might lead to an expensive tool failure or worse. Our readiness to leave the problem of training for some one else to solve may cost us dearly.” Reflecting on his visit, Army Ordnance Chief, Major General W. H. Tschappat cited three things that stood out: “rugged construction,” “the great increase in speed ranges,” and “the adaptability and ease of operation of these machines.” Still, at least one dissenting voice could be heard; R. J. Goldie, from Timken-Detroit Axle, argued that insufficient attention had been given to tools for “manufacturers who have a large volume of work in a number of different models or types.” Rather than sheer speed, or careful accuracy, such firms needed “quick set-up changes… without sacrificing production capacity.” Tools which blended general and special purpose capabilities did not exist (at least in the US) in 1935. They would be much sought after in the coming years.

The second crash of the US economy, in 1937 after the Roosevelt administration cut back on deficit spending and public works programs, struck a blow at metalworking’s incipient moves toward prosperity, but war fears, then war planning turned the economic tide decisively. A terse announcement in the program for the November 1938 Metals

57 Bo Carlsson argued in 1984 that blended tools, i.e. flexible rather than dedicated transfer machines emerge only in the 1970s. Efforts to create these started however in the late 1950s, as will be noted below. Carlsson, “Development and Use of Machine Tools,” 102.
Congress, this time in Detroit, quietly indicated the shape of things to come. Announcing that “the visit of the British metallurgists, which was to be a highlight of the Congress, has been cancelled because of conditions in Europe,” took the edge off technical panels and the show’s 240 exhibits concerning new alloys and new uses (e.g., NiChromes and initial work on titanium). Once war fever spiked, US tool builders received reams of orders from British and French governments and enterprises; with the June 1940 fall of France, firms redirected Gallic requisitions to the UK. According to the War Production Board Tools Division’s postwar review, over 200,000 machine tools went abroad, 1940-44, while 800,000 found use in US war plants, as the trade’s annual production value jumped from a hundred million dollars or so to above a billion. Machines shipped in 1941 through 1943 totaled $4.2 billion, which “nearly equaled the combined machine tool output of [the] three decades prior to the war.” This surge was far from unproblematic, however, as serious troubles surfaced in at least three interrelated domains: materials, organization, and production capacity (workers, subcontracting).

By mid-1940, federal preparedness planners began to document shortages in key metals, “notably in copper, nickel, zinc, and tungsten.” Their initial responses included attempts to develop US low-grade ores, to import from regions as yet unaffected by warfare, to track “consumption statistics and trends, and to allocate the supply of each individual metal,” particularly guaranteeing supplies that would create materials meeting Army and Navy specifications, which “remained sacred cows.” Substitutions soon

60 Sasse and Nolle, “Aftermath for Machine Tool Builders,” 1. According to the Conference Board, no other sector’s production soared as much as machine tools, which rose 650%, 1943 vs. 1939, not even aluminum. Claims did appear that magnesium production rose 5000%, however.
followed, in three phases. First, private sector users shifted from scarce or unavailable alloys to others with similar qualities (as high-nickel steels vanished, metalworkers sought chromium-vanadium steels instead). Second, alloy makers began fiddling with their formulas: once vanadium and tungsten “became tight... molybdenum was the life saver.” Finally, relaxation of military specifications proved unavoidable, clearing a path for introducing National Emergency steels, what H.W. Gillett (Battelle Institute) called “these new Irish stew steels.”

NE steels drew on supplies of recycled alloy scrap, providing “small amounts of several alloying elements,... a trace of special seasoning, whose effectiveness is just being realized by the metallurgist, though he still doesn’t understand the reason.” Materials improvisation, in the absence of adequate foundational knowledge, much less scientific theory, represented best available practice. As Gillett noted, contingencies were standard, “feasibility relating primarily to the available alloy scrap and to the momentary availability of particular alloying elements to provide a few tenths or hundredths of the sweetening that may be required.” Gillett’s repeated analogies to cooking indicate that when standard recipes couldn’t be followed, intuition, experience, and the creative use of available raw materials were paramount in the emergency.

Still, where securing specific properties and performances was mandatory, War Production Board teams fashioned “emergency specifications,” revised and hopefully-stable wartime formulae. Some involved plain substitutions like steel for brass in cartridge

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62 Ibid.
cases (and for copper in the 1943 penny), others the replacement of regular alloy steels for gears, transmissions, crankshafts, engine blocks, or aircraft propellers and engine forgings (most with nickel or chromium), with one or more of the sixteen NE steels configured in 1941 and introduced by spring 1942. Half the NE novelties omitted nickel and chromium entirely, substituting manganese and molybdenum; the other eight used (on average) half a percent each of the scarce Ni/Cr elements, plus about one percent Mn and a trace of Mo. Alloy steel production soared in wartime, reaching 9 million tons in 1941, 11 MT in 1942, then peaking at over 13 MT in 1943 – one third of which was NE steel, according to the American Iron and Steel Institute. On the materials front, the NE steels proved to be both a wartime hit and a postwar opportunity, as they laid the groundwork for ongoing alloy experimentation.

Not only did NE steels save the nation many tons of scarce metals, they taught metallurgists a lesson – they had been overdoing alloy additive proportions. Said one engineer in late 1944: “There is no doubt that for many years alloys have been used in excess of requirements and the use of these special steels is going to make us … apply the proper steel to do the job rather than supply a steel much too good for the application.” Alloying was a decisively empirical craft, despite columns of impressive names and variant numbers (SAE and AISI rosters); and the war forced extensive learning-by-doing, with positive results. NE materials replaced prewar combinations effectively in tractors, bulldozers, railway equipment, truck transmissions, cam shafts and much more, users

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63 “Will Steel Cartridge Cases Rust?” Metals and Alloys 17(January 1943): 5.
discovering them “to be in no way inferior.” As the war ground toward a close, Metals and Alloys surveyed “leading materials engineers, metallurgists and production men,” asking what they would identify as the most important “engineering materials and methods developments” during the emergency. NE steels ranked first on their list, just ahead of innovations in special materials and “precision manufacturing methods for turbo-supercharger and gas turbine components.”

So, in wartime, precision partnered substitution as key elements of metalworking practice’s development. Flexibility and automaticity also found places near center stage. Concerning flexibility, though the myth would later circulate that “mass production won the war,” production directors knew better. Redesigns were continuous, as feedback from problems with weapons in use necessitated manufacturing changes. Fisher Body’s general manager explained in 1943: “We cannot operate in war on the ‘steady flow’ basis of peace. Frequently engineering changes are required immediately to meet changing conditions on fighting fronts… Sometimes schedule changes must be made in the middle of a day’s production to meet an emergency requirement.” Hence both organizational and operational flexibility were critical to fulfilling military contracts and necessitated securing machinery that could handle the flux surrounding manufacturing. Organizational miseries also came when matching urgent tool orders with machinery producers and their capacities.

67 Charles Parker, “Applications of the NE Steels,” Metals and Alloys 17(January 1943): 94. For a view of the complex flows involved in securing “controlled materials” during the war, see Appendix 2, a chart depicting this dynamic as of January 1943 (Ibid., 6.)

68 Cone, “War’s Foremost Achievements,” 916-17. Machine tool builders had the highest priority for materials acquisition, but tool users dealing with the new steels had multiple problems, especially with materials for cutting tools and substitute versions’ shortcomings, including chatter, breaks, and resulting defects in workpieces (“making scrap”). In the postwar, materials substitutions derived from wartime inventiveness would pose a series of accumulating challenges to classic machine tool capabilities.

In the late 1930s, firms individually pursued tool building contracts from European governments and enterprises, but in the run-up to Pearl Harbor, predecessors of the WPB Tools Division tried to coordinate this chaotic process. In May 1941, as J. L. Trecker (Kearney and Trecker, Milwaukee) later observed, the government “wisely adopted the pool order procedure for machine tools.” With pooling, firms went about producing tools of all varieties for use in military production, but without having specific clients for them. Trecker thought this a sage tactic, as did Howard Dunbar of the Norton Company (Worcester), who reinforced his view through critiquing the earlier approach:

We tried [in 1940-41] to find every kind of machine tool that would cut metal… Great pressure was put on us. As a result… we took from the shelves of the country all kinds of machine tools regardless of vintage, regardless of type, and we put them to work. [Soon] we ran into a situation where 23 different types of machines were “critical.” We scoured the country to find them. We [revived] firms who had been out of business for years but who could, by virtue of stored patterns, make such machines as the big boring mills of the vintage of 1914. We all know the technological improvements that have occurred in machine tools since those days, but we had to have something to cut metal. On our tank program, the principal item was a boring mill for the turrets. We found in the Chicago District fifty old machines that were used for turning tires for locomotives and they were converted into machines that could be used on the turret job. That is not efficient production … Pool orders came to the rescue; and in the brief period of January to June [1942] 1.3 billion dollars worth of pool orders were issued in the machine tool effort.

The WPB reduced chaos to mere confusion, but that represented a major gain. With orders in hand, tool builders’ difficulties centered on production matters: users’ labor and knowledgeability shortages and their implications, plus the necessity of subcontracting.

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70 These predecessors included the War Resources Board (1939), the Advisory Commission to the Council of National Defense, and its Industrial Production Division (1940-41), Industrial Materials Division (1940-41) and Labor Division (1940-41), plus the Office for Emergency Management’s Office of Production Management (1941-42), Priorities Board, (1941) and Supply Priorities Allocation Board (1941-42). See http://www.archives.gov/research/guide-fed-records/groups/179.html#179.1

71 Army Industrial College, Department of Research, “Seminar: War Production Problems of the Machine Tool Industry,” Transcript, 27 June 1945, 5 [in Cincinnati Milacron Papers, Archives Section, Box 7, Cincinnati Historical Society].
With millions of American industrial workers drafted into the military (but not “essential” workers in machine tool plants – until 1944), general metalworking faced a “relative shortage of skilled machinists” at a time when high volumes of metal components were needed for defense. Cincinnati Milling Machine staff researchers observed that this crunch “intensified the swing toward increased use of automatic machines for a wide variety of… operations, and in an increasing number of industries.” Those new to factory work (chiefly women and rural male migrants) and factory veterans new to metalworking (from non-essential industrial trades) did not have the experience to make complicated components after a few weeks training – hence the resort to mechanical automaticity (or its informational equivalent, “new, concise machinability rating charts,” not open to workers’ adjustments). Yet little of this was automation, in the 1950s sense, except perhaps the aero engine transfer machines at Wright/Studebaker. Rather, within the flexibility and precision domains, “continued growth in the use of automatic machines in the aircraft industry remained outstanding.” Here machine tools did “profile milling, using sensitive tracer control from a master or template”; these were precision copying machines whose object of duplication could be changed readily, with semi-skilled workers basically loading blanks, monitoring metal cutting, and unloading finished parts. Hence “very high, continuous production is maintained.” Here as well we see one early amalgamation of the special and general purpose machine tool, for tracer profiling could be indefinitely repeated, for long runs if needed, even as the part being traced could be replaced at will, adding flexibility. “Automatic” itself proved to be a persistently “flexible” term.

72 Hans Ernst and M. E. Merchant (CMM), “Machining,” Metals and Alloys 17 (January 1943): 68-69. After the war, M&A would change its title to Materials and Methods, again indicating the broadening of metalworking’s frontiers.
On another labor-related production front, once the military judged that the peak for machine tool needs had been reached (late 1943), WPB notified Selective Service to being pulling deferments from machine tool workers and instructed firms to seek subcontracts from companies tasked to build diesel engines, aircraft parts, etc., so as to continue contributing to war production. This WPB assessment proved wrong – orders for tools continued to pour in – but given that tool workers were being inducted, new orders could not be well serviced. As J. L. Trecker commented, “A great deal of information went out… that the machine tool job was done… The Army wanted the facilities and Selective Service wanted the men out of the plant; and whereas up to that time we were able to do a fairly good job of keeping our forces together, they just fell apart then.”

Subcontracting was a related and equally ambiguous challenge for machine tool production. Given that demand multiplied by nearly an order of magnitude, tool firms that had survived the Depression had neither the facilities nor the workforces to manage such volume. Cincinnati Milling, one of the sector’s largest firms, had been diversifying its product lines in response to slack times, but dropped many models and sizes to coordinate with national defense needs. Still this simplification wasn’t sufficient. Nor was moving to two, then three shift operations. Subcontracting was the next step: By “early 1943, there were 150 companies machining for us parts which under ordinary circumstances we machined ourselves. There were 27 foundries helping to make our castings.” This proved a common experience among tool builders.

Reviewing the war experience at the Industrial College Seminar, General Donald Armstrong, Commandant of the Army War College, acknowledged that the “Germans held

74 “A Review of the Activities and Contributions of the Cincinnati Milling Machine Co… to the War Effort,” 1 April 1944, CM Collections, Archives Section, Box 9, 10, CHS.
out as long as they did [because] they decentralized their industry much more than we did.” J.L. Trecker replied that, though difficult, US tool subcontracting also had been essential: We “understand that subcontracting costs more money. But, after all, war is waste and money doesn’t mean so much if you get the materials with which to fight the war. I doubt whether any of the machine tool builders made a dime out of subcontracting. I know we didn’t.”

Large enterprises, printing press and electrical manufacturers, had contracted to build entire milling machines, but most inexperienced tool builders encountered cost overruns and/or technical deficiencies. Exceptions included United Shoe Machinery and American Machine and Foundry, which “built accurate tools and…did a swell job.” Meanwhile small firms generally ‘lacked the “know-how’” to build “whole machines.” As Norton’s Dunbar noted, unless schooled in tool building practice, they would run scrap: “The small firms can make parts. You can pick out a sample part and give it to a small shop. They will make it, all right. To be sure, you will throw away 25 percent of them and have to make all the rest over again because they won’t be made accurately. You have got to train their organization. You have got to put on some men to train them.” Warner and Swazey’s Stillwell concurred: “We had to allocate some of our best men from our own machine departments to take charge of two or three little alley shops. When we had 45 or 50, or at one time 65, subcontracting jobs, it very badly weakened the supervision in our own shops and our efficiency dropped.” James Scott (Van Norman Tools) added that this wasn’t only an issue for small subcontractors: “Our company used the Bigelow Carpet Works and the Beechnut Candy Company to make gauges, and you [had] to take your own men right out of your plant and send them over there to train the subcontractors’ labor force

75 Army Industrial College, “Seminar: 1945,” 44.
– six men here, and ten men there.” Thus improvisation continued beyond materials and methods and the search for floorspace into labor/management practices for subcontracting, with attendant troubles for prime contractors.

Assessments of wartime materials innovations and the machine tool surge began well before the war’s end. Recognizing the major shifts in materials processing that war substitutions had reinforced, Mill and Factory delivered a three part “Introduction to Plastics” starting in September 1944. Metals and Alloys commenced its long and valuable series of Materials and Methods Manuals in July of that year, with “Selecting Production Methods for Small Parts,” including sections on powder metallurgy and molded plastics. Its 1945 Manuals addressed, among other things, “Materials for High-Temperature Service,” “Permanent Mold Castings,” and “Heat Treatment of Steel,” all crucial sites for wartime empirical experimentation, especially in aircraft fabrication. American Machinist’s editors summarized the trajectories of wartime learning in machine tools. Light metal work showed “optimum” cutting speeds at “thousands of surface feet per minute, instead of hundreds” with steels, through using cemented carbide tools. Infinitely adjustable hydraulic feed (depth of cut) controls and variable speed electric drives proved their superiority over pre-set feed indexes and two or three speed motors. Even though automatic tools gained wide use, including successful implementation of transfer machines, “a machine tool designed to accommodate a variety of short runs must be arranged for quick and easy machine settings by the operator... late advances in electricity and by hydraulics...give

76 Ibid, 45-48, 51.

needed flexibility, including the application of electronic controls.” Several promising war-designed tools could operate both manually and automatically, allowing workers to “make the changeover from one to another in a matter of seconds.” The war also had taught producers that reducing machinery “down time” is “particularly vital.” Last, war production brought new demands for precision. CMM devised a special centerless grinder that “ground and lapped” aircraft engine fuel-injection plungers “to unheard-of tolerances of seven millionths of an inch.” More routinely, “[Proximity] fuse components, aircraft parts, and communications equipment, such as radar, to name only a few, called for tolerances to tenths and hundredths of thousandths of an inch.” Shops meeting these standards “discovered that amid all the headaches, there were advantages too. Precision-made parts could be assembled more easily and ran more smoothly.”

H.E. Linsley, at Iron Age, looked forward with some anxiety, however. Firms needed to readjust to building machinery types dropped during the emergency. Many had added floor space that would need to be utilized somehow, and the late war disruption of their labor forces looked serious. “Despite the daily release of thousands of men from the armed forces… there is a severe shortage of skilled manpower.” After their war production experiences, tool builders were especially seeking those autonomous “craftsmen who can be relied upon to do their work with a minimum of supervision and who do not need to be given detailed step-by-step instructions.” The postwar strike wave bypassed machine tools almost entirely, but three other problems loomed. A castings shortage suggested that foundries were having similar problems recruiting and perhaps that their veteran workers, after stints in the military, were searching for better and different employment. The

wartime “swing to the use of stampings and weldments” in aircraft has revealed a serious
“shortage of press capacity throughout the country,” and those in place were “showing
definite signs of wear.” Brisk business for press and forge makers was assured, but the
longer term implications of replacing machining and casting with presswork remained
ambiguous. Most important, the government now owned hundreds of thousands of
suddenly-surplus machine tools whose disposal menaced the postwar market for new
machinery. 79 The war had ended, but the struggle for markets and innovation continued.
Gordon Ashmead, a presswork process developer, remained upbeat: “If we can keep our
war attitude, remembering that scarcely anything is impossible, adapting what we have to
what we need and redesigning as quickly as the need requires, we will be in the correct
receptive mode that can only lead to success.” 80 Progress talk, certainly, but progress talk
informed by wartime urgency and improvisation. Soon, there would be ample room for,
but uneven success by, those believing that “scarce anything is impossible.”

Auto Production, Aeronautics and the Accumulation of Innovations, 1945-1955

In 1945, US industrial plants held 1.7 machine tools and over a quarter million
metal forming tools, roughly double the 1939 estimate. In dramatic contrast with the mid-
1930s, one million (59%) of these tools were less than ten years old, the highest proportion
of operating “new” machines at any point in the twentieth century. Aircraft assembly,
airframe, and aircraft engine plants held 276,000 cutting and shaping tools, more than the
244,000 lodged at motor vehicle and parts factories (none of which yet were making
private cars). Machinery builders’ own shops contained 91,000 tools and 14,000

79 “Machine Tools,” 104-09 (n1)
forges/presses, with precision manufacturers operating another 84,000 and 22,000 respectively. At war’s end, NMTBA members estimated that a half-million or more GOCO [government owned – contractor operated] tools lurked somewhere around the country. With blizzards of war contract cancellations, many of them would become idle, few being “adopted” by their current operators, and thus most would be dumped onto US and foreign markets, crushing demand for years to come.81 This concern bubbled through early post-war machine tool dialogues, along with speculation about what shape peacetime markets might take – certainly decisively different from those surrounding the last Machine Tool Show, but in what ways?

This section will undertake to sketch the ongoing trajectories of automaticity, flexibility/precision, and substitution, with special attention to aeronautical innovation (especially military airframes and jet engines), moving narrative and analysis forward through the 1947 Show and the Korean War, stopping just before the 1955 tool exposition. Attention to new materials, processes, and companies will continue, but we shall seek to avoid a teleological rush to document the origins, precursors, and exemplars of numerical control. Innovation had many venues during this decade (and others); reducing the process’s multiple and interactive moments to a march toward computerized numerical control (CNC) in the 1970s would be historically inept (and inappropriate).

As the 1940s slid toward a close, the United States shifted from hot war to Cold War, not instantly and not seamlessly. Military reorganizations (emergence of the Air Force from the Army Air Forces, creation of the Department of Defense, major procurement revisions) accompanied deep and comparable restructurings in the private

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81 American Machinist Inventory of Metalworking Machinery, 1945, AM get date and pages; “Surplus Tools,” Business Week, 17 August 1946, 35-37.
sector (at a minimum, postwar diversification by wartime prime contractors, the first phase of conglomerate formation, extensive small firm startups in manufacturing, construction, and services, and massive GI Bill-funded veterans education benefits [which swelled college enrollments and likely promoted entrepreneurship] and homeownership programs [which supported suburbanization]). Industrially, among newly-important materials, plastics rocketed to sustained rates of expansion that fueled trade journalists’ boosterist rhetoric, whereas magnesium slipped back to the shadows, not making the grade as the light metal of the future. (That metal would be titanium.\textsuperscript{82}) Military spending, which had underwritten virtually all materials research in wartime, looked to shrink just as rapidly as would armed forces’ personnel. But in unanticipated ways, politics saved the day for technology development. From Yalta through the Berlin blockade, and a continent away, from the Red Army’s resurgence through the Kuomintang’s flight to Taiwan, geopolitical tensions steadily reconfigured what US leaders perceived as the nation’s threat situations. Funding would flow again, richly.

Meanwhile, back in the shops, tool builders contended with their clients’ adjustments to peacetime demand. Through the NMTBA, firms pressed toward two objectives: first, devaluing and scrapping surplus war tools, then enticing tool users to view, test, and buy replacements for their obsolete and worn-out equipment. The first part went fairly quickly, but the second took some years. Early in 1946, the War Assets Office published a review of surplus machine tools on hand, counting just over 90,000, sixty percent constructed since March 1941. The WAA also approved nearly 800 used equipment dealers to handle sales, domestic and foreign. By August, tools purchased for $82 million had been liquidated for about half that sum, but no interest surfaced from non-

US operators, some of whom reportedly remembered that thousands of tools “in bad condition were unloaded on unsuspecting foreign users” after World War One. Second, after closer assessments, the number of surplus tools listed for sale tripled, to 266,000, with the final total expected to reach 325,000. Outside this pool, the military set aside and retained another 75,000 tools, as reserves for current and future requirements, 85 percent for the Army and Navy air arms.\(^83\)

Despite hundreds of thousands of machine tools overhanging the market, the anticipated wave of demand for them only partly materialized. Three reasons seemed most plausible to contemporary observers. About a quarter of the surplus tools were “specials,” dedicated machines for rapidly making shells or small arms ammunition, or for boring gun barrels – not adaptable to other uses without major rebuilding. Second, many used tools were very used; run three shifts and seven days for years, they needed extensive repairs and refitting before being again effective in shopwork. Third, metalworking firms stalled purchasing these five or ten year old grinders/drills/millers, anticipating big new things from the first postwar Tool Show, initially expected at Cleveland in Fall 1946, but relocated to Chicago for Fall 1947 on a site twice the size of that required in 1935.\(^84\)

Users were not disappointed. The Show was dazzling indeed; nearly 100,000 attended. As *Iron Age* editor T. E. Lloyd reported:

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One lasting impression is that the machine tool industry entered this show in deadly earnest. Not only in the new equipment unveiled for the first time was this indicated, but also in the setup of the exhibits, in the stress on operating units so that claims could be substantiated. The industry, in its pre-show statements, promised that machines of new and startling productivity would be shown. They were! Another impression was the overwhelming trend to automaticity, the fully automatic cycle, one of the few avenues still open to industry for reducing its production costs. 85

Show organizers had urged builders to present not just functional machines, but functioning machines; with the Show inhabiting a vacant aircraft engine plant, power hook-ups and sturdy concrete floors were right at hand. Thus, “every basic type of machine tool [was] demonstrated under power: from great planers to the smallest bench-type drilling machines.” A. G. Bryant, a tool company president and NMTBA officer, enthused predictably, “We have scarcely caught our breath in absorbing the techniques of the 20s and 30s, so the shock of these changes of the 40s leave[s] us gasping.” 86

So what were these changes? Two were immediately visible. Builders had agreed (for the moment) to paint all tools battleship gray; thus the Show was all about business, yet it did not lack color. That September Cincinnati Milling introduced its reusable, pink, water-based cutting/tool-cleaning fluid, Cimcool, as Maurice Gormley recollected in 1983:

Hayward Gay put on a drive to line up the machine tool exhibitors to use Cimcool in their machines and this is where the pink color comes in. Because he had apparently decided to dye the product pink to make it distinctive… So he and his people sold, in advance of the show, Cimcool service on the machines, free Cimcool, changing it at night, and keeping it [available] and so forth. And people


walked into that machine tool show, the whole place was pink. Pink fluid in all the machines, tremendous impact, a great publicity stunt.87

Moreover, “The Mill” offered a staggering diversity of new tools and new types, many of them employing hydraulics in novel ways. Its exhibit featured:

Universal, plain and vertical milling machines; plain high speed dial type, universal high speed dial type, vertical dual power dial type, plain high power dial type, plain dual power dial type milling machines; plain automatic, rise and fall automatic, duplex automatic, duplex Hydromatic, plain tracer-controlled Hydromatic, and special eccentric type milling machines; single-ram Hydro-Broach broaching

Cincinnati Hydromatic (from http://www.machinerybrochures.com/shop/media/mh.jpg)

machines, duplex Hydro-Broach, and horizontal two-way Hydro-Broach broaching machines: 4-spindle 360 [degree] automatic profilers; die sinkers; vertical Hydro-Tel profiling and die-sinking machines; automatic depth control attachment, vertical Hydro-Tel automatic positioning machines; universal cutter grinders [and eleven more tools, all provided in a variety of sizes and weights]\textsuperscript{88}

Profusion, precision and innovation would carry the day.

American Machinist’s E. J. Tangerman previewed the show, identifying scores of highlights, some well worth noting. By 1947, seeking flexibility within automatic work, builders were attempting “to provide special machine advantages for limited production without excessive setup or investment.” One solution created tool instrumentation such that the device “can be operated either manually or automatically, the change-over being made in seconds.” Alternatively, in what seems a first try at “record playback,”\textsuperscript{89} instruments “set the automatic cycle as the operator handles the first cycle manually,” facilitating duplication. Also striving for automaticity with flexibility were turret lathe attachments that duplicated operators’ practices: “The first piece is machined manually, the automatic control being locked for each tool setting, and the machine is [then] set for automatic cycling.” Note these all appear to have been mechanical means to replicate operators’ initial work so as to generate multiple parts. Still, with the turret-lathe, “the operator can interrupt at any instant to vary a dimension or to machine a different piece,” thereafter returning to automatic running.\textsuperscript{90} (See following illustration.)

Automatism informed displays of active transfer machine lines, along with smaller efficiency improvements, including automatic lubrication, mechanisms which brought

\textsuperscript{88} “The Cincinnati Milling Machine Company – Booth 306,” 1947 Machine Tool Show Visitors Guide, Dodge-Chicago Plant, September 17-26, 1947, Cleveland: NMTBA, 1947, unpaginated (exhibitors listed alphabetically, with products on display and staff attending). Over 100 CMM engineers, technicians and tool operators, plus all the firm’s executives, were listed as tending the booth (and attending the show, of course).\textsuperscript{89} For full discussion, see Noble, Forces of Production, 147-92.

“several tools to the piece at once,” and accessories reducing “machine down time”

( interchangeable tool heads so one head’s cutters could be sharpened while the other

Sheldon turret lathe (ca. 1950) with push-button controls

[Image: http://www.mfg.mtu.edu/marc/primers/turning/turret.jpg]

worked; quick-acting clamps for piece holding). More general-use innovations included chip conveyors, “less-brittle cemented carbide [cutters], dial indicators for speed, load, feed, [and] more extensive use of anti-friction bearings.” Closer tolerances demanded refined instrumentation, here “electrical gage heads which measure directly and stop the grinding cycle with tolerances of a tenth of a thousandth.” 91 Precision attracted less emphasis; with its deep and classified links to military demand, precision tooling was not largely a market phenomenon. The Show seemed overwhelmingly targeted meeting challenges coming from automobile circles, where major re-equipping was under way.

Substitution did surface, though. Steel editor Guy Hubbard commented on “the competitive effect of new methods of forging, press forming and casting, which in many cases do away with [machining] roughing cuts but which demand extra speed and precision in finishing cuts.”

So where were the aeronautics specialists? Huffard wasn’t an exhibitor, nor were Mesta Machine and Cleveland Instrument, key suppliers for airframes, heavy press work, and measurement devices. One reason for their absence was the radical post-war contraction of aircraft building. With wholesale cancellations of military aircraft and engines, prime builders laid off workers by the tens of thousands, liquidated or vacated surplus plants, and looked to diversify into promising peacetime production, much of it well outside aeronautical applications. The 1949 Machinery Inventory tells this harsh tale clearly. That year, airframe and engine builders employed 277,000 workers vs. over a million during the war; those workers ran just 55,000 machine tools vs 276,000 in 1945. Two hundred and twenty-one thousand tools for aircraft and powerplant fabrication had either been scrapped, resold, or sat idle in 1949. No surprise then that neither major airframe contractors nor key specialist tool builders showed up at Cleveland; this was an automobile show. Nationally, the AM Inventory demonstrated that four years after Japan’s surrender, America’s tool stock stood slightly above the wartime peak (1.76 million, up 5,000 from 1945). Given that motor vehicle sectors had dumped another 105,000 tools,


93 None of the three appear in the 1947 Tool Show catalog. Cleveland Instrument, a veteran firm in precision work like Philadelphia’s Brown Instrument, was founded before the turn of the 20th century.

94 Fill in book cites.
firms in other segments of the industrial economy had installed at least 325,000 machine tools; some of them transfers from surplus, others part of the $1 billion in new tools US builders shipped, 1946-49. There would be better days for aircraft innovators and their tool suppliers, arriving with a rush in June 1950, but the last years of the 1940s proved grim for all but those doing military development work.95

In aircraft firms’ narrow, risky territory, jet engines and the reinvented airframes they necessitated were propulsive, literally and figuratively. They moved planes at unimagined speeds while symbolizing a dramatic shift technically and culturally; “the jet age” became a stock phrase. Voluble, legendary designer Clarence “Kelly” Johnson offered a stock-taking overview of first-phase “major jet aircraft development problems” exposed as he struggled to achieve reliability and effectiveness in Lockheed’s P-80A “Shooting Star” straight wing, single-engine fighter.96 Core issues for airframes (or planes as an entirety) included “improved take-off performance from better wings, flaps or boundary layer controls,” “reliable anti-flutter devices,” better landing gear, canopy defrosters, and fire detection/extinguishing equipment. Not trivial, but not staggering. For engines, the troubles list was longer and more serious; they needed “better overall reliability… lower fuel consumption, more take-off thrust, better acceleration from low rpm, more reliable governors, better power controls… less fuel leakage, [and] better starting characteristics, particularly at altitude.” Johnson did not share his much harsher (and classified) comments on deficiencies in the GE-made I-40/J-33 centrifugal turbojet

95 “American Machinist Mid-Century Inventory,” AM 93(3 November 1949): 129-224. Aircraft firms displaced 37,000 drills, 60,000 grinders, 55,000 lathes, 21,000 millers and 48,000 other tools, 1946-49.

96 Johnson also designed the U-2 and the Blackhawk stealth fighter. For overviews of his career, see Clarence L. Johnson, with Maggie Smith, Kelly: More Than My Share of It All, Washington, DC: Smithsonian, 1985; and Ben R. Rich and Leo Janos, Skunk Works, Boston: Little Brown, 1994. One of his many sharp observations on aircraft development was: “Build it, then draw it.” (Kelly, 23.)
engine, modeled on Frank Whittle’s wartime W-1, but they were scalding. Rather, in closing, he simply opined: “There seem to be enough problems left to keep us all busy for some time to come.” Indeed there were, and new materials, tools, and processes promised ways to solve them as the Forties gave way to the Fifties.

Jet airframes had an unsettled relationship with jet engines. Every pound added to a plane’s structure lessened the flying range the engines could provide; every efficiency gain in fuel use extended that range. At high speeds, jet propulsion spread potentially fatal stresses through airframes and at the operating temperatures necessary for high speeds, engine operations generated internal stresses which could destroy the propulsion system. At high altitudes, airframes experienced less air resistance, thus less drag, but at those altitudes oxygen supplies to support combustion thinned rapidly. Yet gaining fuel efficiencies and higher thrust could most readily be done by hiking operating temperatures (and compression ratios\(^98\)), areas where urgent demands for high-temperature materials arose in jet propulsion development. During the war, turbosuperchargers\(^99\) demanded alloys that

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\(^{97}\)Clarence L. Johnson, “Development of the Lockheed P-80A Jet Fighter Airplane,” *Journal of the Aeronautical Sciences* 14 (December 1947): 659-679 (quotes from 679). Johnson’s earlier memos on engines for the P-80 are part of the declassified microfilmed record attached to Historical Office – Intelligence, “Case History of Turbo-jet Engine J-33 (I-40) Series,” Air Material Command, July 1947 (Microfilm reel A2078 – Maxwell Air Force Base History Office, Huntsville, AL), which was the Air Force’s project history of the I-40/J-33 engine. “Better starting characteristics, particularly at altitude” referred to turbojets’ tendency to “flame out” for no obvious reason while aloft; devising a reliable means to restart the engine before a crash was plainly an urgent challenge for design engineers.

\(^{98}\) The compression ratio expresses the extent to which a nominal cubic volume of air is squashed into an appreciably smaller space. Early jet ratios were 4:1 or 5:1; by the 1960s ratios of 10:1 were expected; greater compression provides both higher potential energy for combustion and higher amounts of oxygen per unit of compressed air. For a particularly lucid discussion of turbojet engine principles and design challenges, see Arnold Redding (Westinghouse), “Current Problems in Developing Major Components for Aviation Gas Turbines,” *Aeronautical Engineering Review* 5 (December 1946): 30-35, 91.

\(^{99}\) A turbosupercharger is an exhaust-driven turbine which helps maintain high air intake pressures (rates) for piston aircraft engines flying at high altitudes (exhaust moves through the turbine, driving a compressor which feeds additional air into the carburetor, hence supercharging the oxygen inflow). For details, see [http://rwebs.net/avhistory/opsman/geturbo/geturbo.htm](http://rwebs.net/avhistory/opsman/geturbo/geturbo.htm), which reproduces a 1943 GE technical pamphlet. For a fabricator’s discussion, see C. H. Smith, “Precision Forging of High Temperature Alloys,” *Iron Age* 158 (26 November 1946): 42.
retained strength characteristics at 1200 to 1350 deg Fahrenheit, but developers confronted
“still more elevated temperatures in gas turbines and jet engines.” Non-ferrous alloys
showed promise in such “severe service,” including a cobalt-based metal containing about
63 percent cobalt, 23 percent chromium, and five percent molybdenum – a long way from
NE alloys with one or two percent of recycled nickel or chromium, as well as much more
expensive and tougher to machine.\textsuperscript{100}

Precision forging and precision presswork drew sharp interest as alternative means
to shape these materials. First-generation steel turbocharger turbine buckets (which caught
a portion of exhaust gases, turning a shaft that drove the compressor) initially were
produced as “blacksmith forgings… [striking a heated blank] under flat dies in an open
frame hammer.” This approach was unacceptable “because of the vast quantities of
machining necessary” after forging. “For production quantities, the expense of removing
large amounts of costly, difficult to machine metal, was prohibitive.” And slow, one might
add. A substitute tactic was drop-forging, using sets of dies contoured to the final (or near-
final) bucket shapes. Yet when this was tried with new alloys for jet turbine buckets and
compressor blades, multiple difficulties appeared. First, designed to resist high
temperatures, when heated for the forge, these alloys declined to become “plastic” and
frequently proved “non-forgable.” Second, blade/bucket shapes had complex contours
along two axes, thus were “difficult to obtain by forging operations.” Third, as tolerances
were very tight and the new alloys frustrated machinists, the only practical way to finish a
rough-forged blade was through grinding. Unfortunately, mechanical grinding more often

\textsuperscript{100} Hodge and Grossman, “What’s New in Alloy Steels,” 68-69.
altered the desired shapes than achieved them, whereas hand grinding took forever, with little improvement on accuracy.  

After several years of shop experimentation, multiple-strike, multiple-trim precision drop-forging provided a solution, employing specially-designed furnaces to heat blanks white-hot (with “controlled atmospheres” to prevent oxidation), a series of perfectly-sunk sizing and contouring dies (regularly replaced), drop hammers and trimmers kept in perfect alignment, and specialized precision gages to test contours and blade thicknesses. The result – durable blades with no machining. As turbojet compressors demanded “almost 2000 blades” per engine, resolving the machining bottleneck was a national security priority. Efforts to precision-cast blades from liquified alloys did not yield satisfactory results initially, but a decade later “investment casting” (or “investment founding”) would become valuable for working with another set of new materials indifferent to machine tools. Meanwhile, The USAF Heavy Press program aimed toward work at the large end of the parts spectrum forging, for example, 460-pound aluminum alloy impellers for Whittle-type centrifugal engines on an 18,000 ton Mesta hydraulic press, essentially liquefying a heated blank while forcing its metal into precision dies. (See Illustration below)

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101 Smith, “Precision Forging,” 43-44. Smith added: “The accuracy required in balancing a turbine wheel revolving at 12,000 rpm and the aerodynamic problems involved in passing hot gases through nozzles and against turbine blading moving at almost supersonic speeds, suggest the reason for the close tolerances required on this work.” Blade contours were so complex that a complete drawing “would contain anywhere from three to fifteen blade cross-sections, together with plan views.” (44)


103 Rawson Wood and Davidlee Ludwig, “Precision Investment Castings Replace Parts Produced by Other Methods,” Materials and Methods 31(September 1950): 49-54. Here designing for the process was key, for this provided “economies of cost, mass and design… superior to those obtainable by the best combination of alternative approaches.” Wood reported “several aircraft manufacturers designing small “ferrous and non-ferrous parts, formerly machined from forged blanks,” for investment casting, done by his firm. It does not appear that Wood worked with superalloys and the like. (Illustration is from LIFE magazine’s online files.)
If new materials triggered process shifts displacing machining at mid-century, jet aircraft design imperatives led to new, often-huge devices that barely resembled familiar machine tools. J.D. Kindleberger, legendary CEO at North American Aviation, explained:

High speeds and terrific power have brought with them a large number of new troubles – structural, aerodynamic, thermodynamic, electronic, and so on. The heavier structure, the need for more accurate form, the use of heat-resisting materials, and the conditions encountered at higher altitudes have all [generated] requirements for new and different types of production machinery than those that made the much simpler airplanes of the past… A good example of a machine that grew up in the aircraft industry, using a new conception of material forming, is the Huffard stretch-forming machine.\textsuperscript{104}

\begin{figure}
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\includegraphics[width=\textwidth]{image}
\caption{Air Force Heavy Press, 18,000 ton Mesta Hydraulic, at Wyman Gordon, Worcester, 1952}
\end{figure}

The fifty-ton Huffard held a sheet of aluminum alloy between pincers, facing a convex die block. Long, hydraulically-controlled arms holding each end, when activated, stretched and wrapped the sheet “over a die made to the required contour.” Fuselage frame sections up to four feet wide could be shaped in moments, eliminating hours, even days of hand- and machine-work. Large pieces not needing “splices” (welds, rivets) were noticeably stronger; a Huffard could also reduce the total number of fuselage sections, cutting costs as much as one-third. Existing metal-forming tools could not accomplish such tasks and, notably, the Huffard did not emerge from “regular” tool firms.  

Moving to wings, Kindleberger pointed out that the stresses they encountered at great speeds and altitudes no longer permitted use of traditional wing designs, because uniformly thick sections, sufficient “to carry the maximum load at the aircraft fuselage are much heavier and stronger than necessary at the tip.” For jets, fabricators needed to “sculpture” one-piece wing skins, 30 or more feet long, reducing weight by using a specialized milling machine (on a flat planing bed) to carve out irregular thickness variations in relation to stress patterns (a process termed “tapering”). NAA accomplished this through tracer control on “a battery” of Cincinnati Milling’s Hypro flat-beds, specially fabricated for the company. With a taper of just five hundredths of an inch, a 30 foot skin’s weight would be reduced by 42 pounds, without loss of operational strength. In this case, the tool industry’s largest firm partnered in a specialty co-design process, starting in 1946, and as well, began custom design work for automobile companies, creating enormous

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Broaching machines\textsuperscript{106} for rapid work on cylinder heads and combined-operation transfer machines for milling V-8 engine blocks. CMM’s assertiveness in entering new fields during the relatively slack late 1940s was unusual, if not unique, among leading machine tool builders; this strategy, plus its tools’ quality reputation, would serve the company well over the long term.\textsuperscript{107}

The Korean War broke the pattern of downward machine tool demand, decisively. For all machinery, orders quadrupled by mid-1951, compared with January 1950; for machine tools, they quadrupled during 1950 alone. Much of the tools surge followed the June invasion of South Korea, but before that moment, non-defense oriented firms had been calling for new machines in large numbers. Immediately tool firms experienced difficulties in securing raw materials, which created delivery delays, stresses in the defense establishment, and revelations that “most of the government-owned machine tools held in ‘mothballs’ since the last war are now completely obsolete.”\textsuperscript{108} In this situation, The Magazine of Wall Street suggested that for investors “Cincinnati Milling seems the most attractive [company,] based on steadiness of earnings in a generally volatile industry, and also on a favorable financial position, with current assets five times current liabilities.”\textsuperscript{109} Meanwhile, Lockheed announced that its “Hall of Giants” was now operational, over an acre of huge machines costing, with their shed, $2.75 million. Kelly Johnson’s bosses had

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\textsuperscript{106}Broaches are a version of a boring, planing or keyway machine in which cutters on a shaft, each slightly larger than its predecessor are drawn through a hole or across a surface, enlarging the hole or cutting into the surface steadily and precisely in one pass. See http://en.wikipedia.org/wiki/Broach_(metalwork).


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plowed $400,000 into a state-of-the-art Giddings and Lewis skin mill, “the only machine of its type to fabricate self-stiffened skins”; using contour profiling, it would taper 10 feet by 32 feet stock for the latest fighter jets’ wings. The G&L miller had multiple heads which “spew[ed] out a blizzard of chips… about 600 cubic inches per minute.” This investment reflected management concerns about availability and effectiveness of the USAF’s heavy presses (and the cost of dies). Machining was making a serious comeback in aircraft work, and like CMM, Giddings and Lewis was pushing the cutting edge.\(^\text{110}\)

Just a year later, American Machinist celebrated its 75th anniversary with a special issue, looking back and ahead. On the machining front, the editorial team argued that “the trend is away from the rigidly tooled production machines,” that recent transfers have “flexibility not characteristic of the early machines.” Automaticity was slipping a bit, even as elite magazines and academics fretted about the horrors of automation. AM identified nine core trends, many of which, unsurprisingly, resonated with those of the immediate postwar situation: “high speeds, greater horsepower, increased [base] rigidity and [cutting] accuracy, automatic or semi-automatic control, more extensive use of contour following or tracing mechanisms, adjustable speed drives, more attention to chip disposal, and increased use of better materials.” The first three were “probably long term trends,” as “tremendous emphasis is being placed today on precision.” In AM’s view then, perhaps conditioned by Air Force war demand, the dominion of automaticity was uncertain. Precision copying seemed a wide-open field. Regarding tracer control: “Duplicating devices of this type will compete with tape or card controls in turning, milling, and grinding… Tapes may be punched, magnetic, drafted, or photographic – all are definite possibilities.” Innovation

generated uncertainty about alternatives and outcomes, but nothing approximating closure was yet evident.111

Discussing tool types, AM’s assessors noted that “Lathes in general have about twice the power they did ten years ago.” Expected soon were automatic mechanisms “simple enough for lots as small as 25 pieces,” along with chip clearance, gaging and auto-load and –unload. “Recent developments in milling have been spectacular.” Greater speeds and deeper feeds than ever recorded had been achieved in test runs, even as a “variety of contour millers” reached users, some with hydraulic controls, others with 360 degree profiling units, able “to handle irregular shapes in three dimensions.” Also celebrated were the aircraft skin millers noted above, able “to hog a ribbed wing section from a slab of aluminum. Contouring devices are built in, to produce a machine requiring 450 horsepower, weighing about 500,000 pounds and costing half a million dollars.” If aircraft had ceded the main stage to autos, ca. 1945-50, it was gaining fast (once again) in wartime.112 Military demand spurred new machine tool orders to record levels: $1.67 billion in 1951, followed by $1.06 billion in ’52 and $850 million in ’53.113

The 1953 Machinery Inventory, taken after war contracting’s peak, shows several trends that fed makers’ innovation vectors and users’ patterns of demand. Metalworking nationally that year occupied 6.1 million workers, running just under two million machine tools, 200,000 more than four years earlier. Machinery builders now employed 300,000 men and women, up 50 percent over the pre-war 1949 slump, though their machine tool total had increased just over nine percent while forming tools dropped seven percent.

111 “What’s ahead the next ten years in Machining,” American Machinist 96 (Mid-November 1952): E1-E7.
112 Ibid., E-9-E14.
Precision instruments and related sectors appeared less volatile by comparison, workforces rising 19 percent to 268,000 employees, the tool count down nine percent. A great deal of idle capacity, unsurprisingly, had been put into service as the war intensified. Meanwhile, though auto corporations’ calls for automaticity swelled after the 1947 Show, labor-replacing mechanisms failed to make a dent in employment. As in machinery, US motor vehicle and parts workforces increased fifty percent in four years, reaching a 20th century peak – 1,010,000. Tools on hand, which included transfer machines, totaled 171,000, one quarter above the 1949 count. Auto firms’ operations had spiked, with war production in car and parts plants perhaps diverting the drive toward control through automation, even as new consumer models continued to roll off the lines.

For aircraft and engines, the glory days had returned. Employing over 100,000 machine tools, 58,000 forming tools, and 664,000 workers, Douglas, North American, Boeing, Republic, Chance Vought and their rivals and engine suppliers (Curtiss-Wright, GE, Westinghouse, Allison, Continental, et al.) recorded four year gains, respectively, of 85 percent for tools, 180 percent in forming, and 140 percent in workforces.¹¹⁴ From the 1920s, airframe and propulsion building had been just as boom-and-bust a trade as machinery construction. The Cold War would end that pattern, though not recurrent uncertainty about design, performance, and cost, for more than twenty years, commencing in 1950. The 1955 Machine Tool Show captured industrial materials processing’s crossing vectors, so that’s where we will turn next.

Detroit Automation vs. Aerospace Precision, 1955-1965

I had received my training in Germany. Going back to the fifties I started working for a large machine manufacturer as a tool & die maker in Chicago. My very first impression (2 weeks off the boat [ca. 1955]): "Holy smoke - this equipment is old!" But being 22 years old I was willing to learn. First problem: inches, pound and gallons!!! … After a few months I got the hang of it and things started to get better. Language was not a problem. After a while working with inches was not so bad. I started to like our old machines. They had character these old Hendey Lathes or Monarch or SB [South Bend]. Sure we had newer machines in Germany - thanks to the British, who after the war decided to take all the old machinery to England, (thank you for that) but the American machines were made to last a long time. It was good equipment and you could fall in love with it.

Being in Chicago, it was policy in our company to send skilled people, foremen and engineers to the Chicago Machine Tool Show taking place on the lake front. In those days Companies like B & S [Brown and Sharpe], Warner & Swasey, Kearney & Trecker. Bridgeport, Cinci - Milacron etc. took up most of the floor space. The American Machine Tool Industry was dominant. German, Swiss and Swedish Companies occupied small corners on the floor and Japanese and other far east manufacturers could be found in the basement. [juergenwt, February 2, 2008 at http://www.practicalmachinist.com/vb/archive/index.php/t-151582.html]

Juergen’s reminiscences capture several key elements of the transnational machine tool situation in the mid-1950s: US metalworking and machinery building firms operating acres of elderly machinery, other nations running newer tools thanks to replacing those destroyed or looted in wartime, the centrality of US companies to the Chicago Shows, the marginality of international competitors, plus ongoing in-migration of skilled machinists to the hub of world tool innovation. Yet having evoked this rich environment for colleagues in Practical Machinist’s discussion boards, Juergen next wrote “SO WHAT HAPPENED!!” This and the following section will try to frame a response, starting with the rage for automation and the uncertain introduction of NC capabilities at the 1955 Show, followed shortly by USAF decisions to contract for hundreds of huge precision tools and later by unpleasant reversals for automatic factory advocates.

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115 Things had not deteriorated much as yet in the tool age area, however. Given the rush of war purchases, just 52 percent of US cutting and forming tools were ten or more years old in 1953. By 1963, this proportion would rise to 64 percent. See Seventh and Ninth Inventories, American Machinist.
The late 1950s brought recession, military procurement reorganization (and cutbacks), political squabbling over the “missile gap” with the USSR, and in 1960, a contested transition in national leadership, which provided the occasion for Dwight Eisenhower’s “military-industrial complex” speech. Three years later, with nearly two-thirds of cutting and forming tools over ten years old, President John F. Kennedy wrote American Machinist noting that this situation “is unsatisfactory, both in relation to our needs and in relation to the recent record of other industrial nations. A nation cannot long maintain its technological leadership if it responds slowly to the continuing rapid flow of technological advances.”

A series of tool company buyouts and mergers had commenced amid evident sectoral stagnation, not in innovation, but in sales. As Table One indicates, machine tools rested at the bottom of Steel’s assessment of the U.S. machinery industry’s development, 1954-1961. Trouble was brewing.

Table One: 1961 Index of the Dollar Volume of Sales for Selected Types of Machinery

<table>
<thead>
<tr>
<th>Industry</th>
<th>1961 Index</th>
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<tbody>
<tr>
<td>Plastics Working Machinery</td>
<td>242</td>
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<tr>
<td>Paper Industries Machinery</td>
<td>190</td>
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<td>Textile Machinery</td>
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<td>Printing Industry Machinery</td>
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<tr>
<td>Rubber Working Machinery</td>
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<tr>
<td>Construction &amp; Mining Machinery</td>
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<tr>
<td>Oil Field Machinery</td>
<td>106</td>
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<tr>
<td>Metalworking Machinery</td>
<td>100</td>
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As Steel’s editors concluded: “The machine tool industry of 1970 apparently will bear little resemblance to that of today.” They were correct.

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118 Ibid., 47.
The 1955 Chicago festivities offered visitors not one, but three shows. The main NMBTA exposition at the International Amphitheater presented “917 metal-cutting and metal-forming machine tools, using 15,000 horsepower” while operating. Many displays “consisted of automatic, high-production machine tools… it was not unusual for a visitor to go into a booth and say to the attendant, ‘I want to see whatever you have here that is automated.’” More than a thousand “foreigners” attended, a third of them from Canada, together with representatives from Fiat, Opel, and English Electric, among others. Next, the first Production Engineering Show, located at Midtown’s lakeside Navy Pier, housed the main show’s overflow of “mechanisms, instruments, and equipment contributing to greater automaticity.” One ticket admitted browsers to both venues. Third, the Manufacturing Machinery and Equipment Show lodged its 100 exhibitors at the Coliseum, a late 19th century pile once the site for Chicago Blackhawk hockey matches, but lacking a main tenant in the 1950s. To this inelegant location migrated non-NMBTA firms, “not qualifying” for the other shows, including those presenting “[f]oreign-made machine tools, particularly Italian and German.” Trade journalists huffed that this show, featuring non-NMBTA firms, “had no official connection whatsoever with the other two exhibitions.”

Non-US buyers were plainly more welcome than non-US sellers. (However, Juergen’s recollection of European company displays in the corners and Japanese booths in the basement does not refer to 1955 or 1960; non-US firms were admitted to the main building only in 1970, a delay which speaks volumes.)

Automatism dominated the 1955 Show as “Everything is aimed at cutting fabrication costs.”

John Weldon, in The Magazine of Wall Street, rhapsodized about Ford’s new Cleveland Engine plant:

There, six-cylinder engine blocks are conveyed automatically through various machining processes. The entire set-up constitutes a line approximately 1,600 feet long, occupying 46,200 square feet. A crankshaft drilling machine drills 20 different holes while moving the shaft through 43 separate operations. Another unit performs a series of drilling, milling, chamfering and tapping operations. All together, through careful research and planning, 41 automatic processes and 80 transfer units were combined to perform 530 broaching, milling, drilling, reaming, and tapping operations on each cylinder block casting in an automatically-timed sequence.

Invoking key values of high modernity, rationality and control, most commentators, like Weldon, could hardly restrain their enthusiasm for the ‘push-button’ factory, which would eliminate drudgery, replace most line workers with technicians, and cheapen product costs for eager consumers. Several years earlier, auto firms had challenged builders to “assume the responsibility for automating their machines.” The results were clear: a range of self-loading and –unloading tools, plus “numerically-controlled, tracer-controlled, and self-resetting machines.” The Show also featured “a much larger number of transfer machines” than in 1947; Cincinnati Milling presented “full automation” on several grinders, along with push button controls on a new line of millers. Confirming the rush to Detroit automation, American Machinist declared, “everybody has automation.”

Jones and Lamson head H.H. Whitmore reflected early the next year:

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The Machine Tool Show was a significant revelation of the status of development of the industry… Higher horsepower and higher rates of stock removal were everywhere in evidence, with the heavier machine structures necessary to make this possible. Control systems, electrical, electronic and hydraulic were emphasized and were more comprehensive and complex than previously. An impressive amount of automatic gaging was displayed… In some cases the gaging indicated corrective action to the machine to make the process self-regulating.123

Given auto production’s dominion and automation’s magnetism at the Show, any concerns about substitution faded into the background,124 though precision would soon have its day. Still, there were dissenting voices about automation. Writing for Metal Progress, metallurgist Arthur Allen discussed “the automatic control of a cycle of operations… by punched tape.” The Air Force, MIT, and GE were working on this procedure, based on a “more modern concept” than Ford-style mechanical transfer. The numerical control team viewed “automation as a centralized ‘brain’ which electronically controls the production of a part.” However, this was “for the present, little more than mental exercise for academicians unfamiliar with the hard realities of the metalworking industry.” More troublesome, “the delicacy and fragility of complex electronic equipment are looked upon with suspicion by many machinery builders and plant operators.” Allen also found it “disturbing” that there were far too few design engineers who had mastered the advanced mathematics electronic automation necessitated. Worse, some having those


124 At the Show, CMM introduced its new electrical discharge machining tool, the Electrojet “for tool sharpening, surfacing, forming, piercing, die-making or polishing,” and the technical literature continued to publish sheaves of articles on chemical milling, ultrasonic machining, new alloys, and especially plastics. See “Chicago Machine Tool Show, 1955,” 175; N. Clark and J. Aloisio, “Ultrasonic Machine Tool for Cutting Hard Materials,” Tool Engineer 32(April 1954): 77-80; Sanz, Removing Metal.”
skills would have to be “elevated to management positions,” lest such efforts collapse, accentuating the shortage in design lofts and quality control.\textsuperscript{125}

Mechanical automation had severe shortcomings as well, chiefly “the inordinately high cost of equipment,… inability to handle diversified production,… difficulty in adapting to finishing operations and to final assembly,… high costs of maintenance,” and the need for skilled personnel to design, install, repair and operate these setups. Though Ford’s Cleveland Engine facility was a marvel, Allen recognized that “[f]ew of the 12,000 odd plants in the metals industries operate at a volume anywhere near the automotive level.” G. M. Stickell of Landis Machine concurred, presciently: “The real danger [from automation] is the possibility of the machine tool builder overlooking the needs of a substantial segment of the metalworking industry – the need of better general-purpose machine tools… many industries, including ours, cannot justify the cost of automation.” Combining economic and cultural themes as few others did, Allen concluded that it would be “sheer folly” to devalue current-day tools “merely to achieve the workerless plant, to say nothing of the sociological implications of such a revolution.”\textsuperscript{126} Ideology and enthusiasm threatened to override common-sense engineering and management.

Especially fascinating about automation fever is that initially, advocates and critics alike assimilated electronic control to mass production formats, presuming that program-guided cutting could simply be run indefinitely on standard parts, replacing machinists with attendants. However, NC had been devised not for this, but to deal with complex airframe

\textsuperscript{125} Arthur Allen, “Metallurgist Assesses Impact of New Automatic Control Mechanisms,” \textit{Metal Progress} 65 (March 1954): 65-70, 168-72 (emphasis in original). Not quite 50 years later, in an interview John Parsons dismissed MIT researchers’ handling of the initial n/c milling machine demonstrations as “ridiculous, because they didn’t know machining.” (Richard A. Thomas, \textit{History of Numerical Control}, 72.) Reviewing J. Francis Reintjes insider history of the MIT project (\textit{Numerical Control}) readily confirms this judgment; the Institute’s proto-computer scientists evidenced little knowledgeability about tools and materials.

\textsuperscript{126} “The Builders’ Viewpoints,” \textit{Steel} 137(29 August 1955): 140; Allen, “Metallurgist Assesses.”
and engine parts made singly or in small lots, often impossible to machine manually. Mechanical reproduction by self-repeaters (as with the classic 19th century screw-cutting machines) proved effective, more reliable for decades, and far less expensive than electronically-guided tooling.

The forces of precision were not absent from the 1955 Show, but their big news came just a few weeks later. Early in 1955, Iron Age had reported on the “Machine Tool Modernization” plan, an estimated $100 million in Defense Department funds to build state-of-the-art “reserve tools and facilities.” Technologically the most venturesome service, the Air Force claimed $85 million of this sum. AMC didn’t “want much in the way of standard tools,” nor did airframe and engine builders need transfer machines. Rather the USAF sought large, long-date delivery, high-precision equipment “which only a comparative handful of builders are qualified to produce.” Following the Show and before 1955 closed, procurement officers issued contracts for “$40 million worth” of heavy tools, skin mills and profilers, chiefly to three prominent firms, Cincinnati Milling, Kearney and Trecker, and Giddings and Lewis. Among electronics suppliers, General Electric secured orders for 35 to 50 numerical control systems, still in the development stage (only four working n/c boxes were at the Show, all from GE). CMM scored the following orders: 110 milling machines, 80% standards; 55 special heavy-duty Hydrotels, and 21 (of 24 total) “Wing Skin Mills with two heads on the rail and with tape control.” W. D. Averill, from CMM’s Engineering Design unit, estimated that just the skin mills would require “20,000 engineering hours for mechanical units plus 20,000 engineering hours for tape control units. The shop hours on all 21 machines will total in the neighborhood of 445,500 hours.”

Air Material Command estimated the total cost of procurement for just the 105 skin mills and profilers, along with development of their numerical control systems, at $30 million.  

Cold War spending on aircraft innovations suffered a policy setback in the middle 1950s, as the defense administration adopted missile-centered nuclear warfighting strategies, shifting the technological frontier to one-time use, pilotless, space vehicles, to miniaturization (hence, electronics), to sheet metal work, solid fuel development, and guidance systems. Nonetheless, the Air Force had sponsored over a decade of path-breaking engineering development by the late 1950s and had pushed the boundaries of possibility well beyond what military planners imagined in 1942. AMC intended to continue such efforts, especially in refining the B-52 bomber, which became operational in 1955. The B-52, powered by eight GE/Allison J-47 engines, was huge; its wings stretched out nearly 200 feet from the fuselage, with a total surface area of 4,000 square feet. Empty, the plane weighed over 90 tons.

In this context, Convair’s J. H. Famme addressed the necessity for close tolerances in machining aircraft designs. “A long range bomber requires 0.8 lb. of fuel for every

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129 See Allen Puckett and Simon Ramo, Guided Missile Engineering, New York: McGraw Hill, 1959; Jacob Neufeld, The Development of Ballistic Missiles in the United States Air Force, 1945-60, Washington, DC: GPO, 1990; Donald Mackensee, Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance, Cambridge, MIT Press, 1990. Battles over program and funding occurred within the Air Force, between the Air Force and the Army (which had Werner von Braun’s Huntsville, AL operation), and between both of them and the Navy, which was steadily creating a nuclear submarine fleet with submerged missile launch capabilities (Polaris). The Air Force aircraft tool modernization program may well have derived from recognition that missiles were becoming the new leading edge technology, the basis for the MAD strategy (mutually assured destruction).
pound of aircraft weight” at takeoff; weight savings added speed and range. Reducing wing skin tolerances from 0.04” to 0.01” on 2,000 sq. ft. of wing could easily save 2.5 tons of total weight, or five tons for each B-52; on a fighter jet, similar tolerance reductions would save 600 pounds. In part, procuring numerical control mills and profilers represented a means toward reaching such goals and increasing aircraft performance, but it was costly. One alternative showed promise, chemical milling, potentially “a radical means of machining. We need a miracle of sorts to overcome incremental metal removal. Making chips is an expensive operation.” Despite using massive, precise milling machines, “the aircraft industry produces more chips – both in quantity and in weight – than it does parts.”\(^{130}\) Another option had proved useless, though, as technological changes had made it obsolete. The Heavy Press program was supposed to forge entire wing sections without machining, other than trim work. Yet by the time the presses became operational, “the weight [reduction] problem became critical and it was necessary to remove all surplus material in order to save the original [aircraft] performance guarantees. We now find that we have defeated our economy plans by milling forgings [to reduce weight]. At present up to 70 percent of the metal in forgings is wasted.”\(^{131}\)

Nonetheless, by 1958, major innovations had emerged from aircraft experimental production. Steels with up to 280,000 psi tensile strength were now available, along with new non-ferrous high-temperature, high strength materials (beryllium, titanium, plus NiCr and cobalt alloys). Reinforced, laminated plastics had found their place in radomes, electrical insulation, and nose cones, and were stable up to 500 deg F. A $1 million USAF


\(^{131}\) Ibid., 70.
project with Chance-Vought was under way, seeking means to create high strength castings up to 300,000 psi, so that castings could replace the now-disgraced forgings. Chem-milling was producing “a great variety of parts, economically… doing some jobs that are otherwise impossible, such as creating “a tapered cross-section on an H-beam for a wing spar 22 feet long.” Stretch-forming had expanded its role, with both “quite elaborate forms” in stainless steel and magnesium being made. NC was “coming along… rapidly” with Boeing leading the airframe companies in developing applications. Finally, Hughes Aircraft, working with Kearney & Trecker, developed “a transfer line of great versatility, operating at special machine production rates” for airframe components. Actually, it was a prototype machining center, featuring three tools (miller/drill/borer) all controlled by a single tape which “schedules and organizes all three. Thus, a change of job involves only a change of tape and fixture…” There was no “line,” but the crossover between automaticity and flexibility/precision merits attention.\textsuperscript{132}

These were substantial and substantive achievements, but machine tool functions remained a major bottleneck, as Famme had argued. Due to new techniques, particularly the cermet cutting tools, “ultra-hard metals, cobalt, nickel, and titanium alloys can be cut today, but only at the speeds of 25 years ago – 60 to 100 sfpm [surface feet per minute].” Unless there were breakthroughs, aircraft plants would have to increase their machine tool complements fourfold, perhaps even an order of magnitude, to get adequate output. To avert this at least four tracks of current research had been framed. Engineers were trying to design parts “that require little or no machining.” Lockheed, under an AMC grant, was studying “all known theories on high speed cutting.” Others were implementing ultrasonic

machining (but would find that it wasn’t fast), and Douglas experimented “with an ultra-cold cutting fluid (-40 deg F).” Soon this set of problems would be described as the “materials barrier,” following a 1960 National Academy of Sciences/National Research Council report. “There is a glaring mismatch” between available materials and the requirements “for ‘new’ materials in projected systems for previously uncharted environments in defense, aerospace and oceanography.” By the mid-sixties, both government and private markets had provided substantial funding to address this problem, generating “an onrush of materials and related information.” That said, prospects in 1958 looked bleak.

With the economy in recession, machine tool orders plunged again. Congressional complaints about the scale of military spending had accelerated; in harmony with the President’s wish for cut-backs, procurement orders for most materiel and experimental development stagnated or shrank. Yet the loudest moaning came from the automobile industry, whose production and marketing initiatives had collided in “the horsepower race.” Detroit automation had been erected on concepts of standardization and stabilized (or “frozen”) designs. US manufacturers had invested an estimated $1 billion in transfer lines and dedicated tools since the late 1940s, but marketing campaigns focusing on ever more powerful (and manly?) engines generated competition centered around the size of auto power-plants. This meant redesign and retooling, yielding huge costs. Ford reported that:

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133 Ibid., 53-54.

134 Sidney Feldman, “Reliability Goals Depend on New Materials,” Electronic Industries 23(December 1964): 100-05 (quote from 100, emphasis in original). See also Irwin Stambler’s appraisal, “How can we hurdle the ‘Materials Roadblock?’” Aviation Age 30(August 1958): 18-93-97. Stambler quoted a Convair official: “about 70 percent of the cost of most advanced airborne items – from black box to missile structure – goes for the development of new materials and new ways of processing them.” (18) Stambler also observed that “the variety of potentially useful metals now threatens to overwhelm the designer.” (“Materials Progress: Metals,” Aviation Age 30(August 58): 54.
Until recently an auto engine was designed to have a ten year model life. Now it is desirable to reduce that model life to four years, in order to remain competitive and to take advantage of fast-moving technology. [AU: pun here, intended or not?] On the other hand, production lines have become much more expensive and rigidized... The mass producer is thus hamstrung by the very equipment that has made it possible for him to manufacture at a satisfactory price.¹³⁵

So did this generation of Ford managers, like Henry before them (and like Carnegie before him), move to tear out the obsolete machinery, commission new tools, and figure fresh prices on the basis of this rapid depreciation? Hardly. Did they repeat their bizarre threats from the mid-1920s to build their own tools and hire away skilled machinists, unless machine tool firms collaborated in designing high production machines? No, for thirty years earlier tool builders had coolly pointed out that when such collaborations were attempted, Detroit firms soon put the designs up for bid, selecting the cheapest producer. No loyalty and no reciprocity meant no collaboration; “Go ahead, build your own tools,” said the trade. Automakers declined, but the did reconfigure that tactic later.¹³⁶

In 1956, ailing car companies tried to peddle a reformulated snake oil solution, co-designing line tools with standard dimensions, which secured enthusiasm from dependent transfer machine companies and polite indifference from mainstream builders. Citing the need to “introduce flexibility” into in-line transfer and high-production machines “to make car-model changes less costly,” Ford offered the concept of “building block” tools, which, all having the same dimensions (like building blocks), could be wheeled in and pulled out of lines as needed to implement making redesigned components, chiefly engines. Piously, Ford claimed that “No thought exists that users should dictate design features to machine-tool builders,” seeking voluntary cooperation while planning to avoid “frozen designs.”


¹³⁶ Scranton, Endless Novelty, 312-14.
Recognizing that tool firms “might believe with a certain amount of justification that standardization… will open up the market to all comers and perhaps stultify design achievements,” and that such tools “would have a longer useful life,” hence diminishing future equipment demands, Ford offered—nothing (other than a claim that the need for its plan was “already painfully evident” to auto corporations). As well, the company proposed that “in slack times, the builder can manufacture for stock,” a wonderful option that entailed carrying inventory for Detroit, along with the risk of technological obsolescence.¹³７

Eighteen months later, Ford had ordered a first set of standard-dimension machines from a transfer-line maker, but though representatives from “the Big Three [had been] informally visiting builders to try and sell the idea,” resistance generally remained firm. Ralph E Cross [Cross transfer machines] put a positive gloss on the situation, saying the whole metalworking industry needed to deal with “the requirements of frequent changes in products,” which were increasing, in his view. His firm and others were “actively and aggressively” standardizing; Greenlee Brothers and National Tool, working the same transfer field, concurred. Two commentators disagreed sharply; however, both chose to remain anonymous—one sign of the auto giants’ sway. Standardizing design means losing “most of the advantages stemming from research and development,” said one, as it would conceded power and control just about completely to the Big Three. The second argued that the notion of building blocks “is about as new as Noah’s Ark… our standard machines are

¹³７“Ford Says,” 113-17; Hounshell, “Automation, Transfer Machinery and Mass Production.”
not made to the same dimensions as those of our competitors. They should not be, for a sweeping standardization would be a serious deterrent to new, beneficial designs."\textsuperscript{138}

Warner and Swasey president Walter Bailey concurred. In any such effort:

improvement of the product will be greatly hampered by the complexity of making any change in design. A change in design will affect every machine tool maker making the components. The drawings, records, parts in process and parts in stock will have to be considered [industry-wide]… any error in the process of revision will be reflected in every machine using the component. Design changes will have to be completely ruled out… [Moreover,] there would be considerable loss in economy through an overall building block program, as every component would have to be over-designed to meet the maximum requirement that it might be called upon to [handle. Finally,] to launch an overall program of the type programmed by Ford would entail millions of man hours of preparatory work… The expense of these man hours could not be assumed by private persons [and firms]\textsuperscript{139}

Given that Ford had not volunteered to cover such transition expenses, Bailey regarded the entire approach as “highly impractical.” A Giddings and Lewis engineering VP dismissed building blocks for a quite different reason: “a new concept in machine control (numerical control) is coming into being and… the whole design of machine tools will probably change in the next few years.”\textsuperscript{140}

Follow-up discussion indicated that General Motors had lost 80 percent of a $1 million investment in a rapidly-obsoleted transfer line, and that, industry-wide, this had become “fairly typical.” Yet some transfer firms who had begun collaborations weren’t thrilled with the process: “Why expect us to disclose our trade secrets [?] After all, they aren’t willing to open their books to Mr. Reuther,” or “We will standardize when all auto firms are willing to settle on the same engine block.” Experienced auto parts manufacturing


\textsuperscript{139} Ibid., 149.

\textsuperscript{140} Ibid., 148. Not in a few years, but in the longer term, for certain.
managers asked where they were supposed to store building block tools pulled from the line: “Our yards are full of tools and dies now.” How would these insertions and deletions be made (“There’s little space – or time – to do the job”)? Perhaps most telling, “How flexible will building block automation actually be? Can you convert an engine line to make transmission parts?” It would be gratifying to learn that Detroit automaters set this clumsy idea aside, but that would be incorrect. Instead, they convened a Special Machine Tools Standards Committee and pushed their objectives through it, gaining acquiescence from at least their auxiliaries, the transfer machine firms. David Hounshell elegantly summed up the final phase:

Paradoxically, by the time the manufacturers of transfer machines had fully accommodated the objectives of users like Ford and by the time Ford and other users had fully furnished their engine plants with SMTS transfer machines, the horsepower race had nearly played out, and engine block and head designs had become relatively stable.

Not the last major-league Detroit misstep…

Giddings and Lewis’s reference to NC while dismissing building blocks brings us to the opening segments of electronic technology’s complex relationship with machine tools. Though it all started with Parsons, MIT, and the Air Force in the late 1940s,


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NC’s commercial relationship with the machine tool industry surfaced at the 1955 Show, where four electronic boxes ran tools. A fifth tool was supposed to be in action as well, a five-axis Giddings and Lewis wing skin mill, a prototype for those the Air Force bulk-ordered late that year. (See above illustration.) G&L planned a June 1955 public demonstration at its plant in Fond du Lac, Wisconsin, and the MIT Servo Lab delivered the “director” in late May. However:

staff had difficulty in getting it to run reliably, mostly because of thermal expansion problems with the feed-through rivets in the printed circuit boards. Between the heating and cooling cycles, the soldered joints at the rivets would break loose and disrupt continuity through the boards. A near-calamitous fire also broke out in the magnetic core storage units during debugging. Evidently the enamel insulation on the wire used for the windings contained nicks; eventually the short circuits that developed at the nicks caused the cores to burn up.¹⁴³

¹⁴³ Reintjes, Numerical Control, 70.
The MIT “gang” rewound cores and rebuilt the controller over a four day period, the initial demonstration went off well, but G&L determined not to present the NC miller in Chicago. Instead the firm “arranged to fly interested parties to Fond du Lac for on-site demonstrations” in September.144

With the Air Force orders for electronic controls on its “elephant” tools, NC technology and its producers (chiefly GE, Bendix, and in connection with CMM, Britain’s EMI) got a publicity boost. The trade press profiled Bendix’s system for Kearney & Trecker’s 50-ton milling machine at Martin Aircraft and the entire NC program. American Machinist soon published its “Production Man’s Guide to Numerical Control,” author William Stocker announcing that NC “is ready, right now, to offer fabulous advantages for Metalworking.” The Economist was dubious. Presently (1957), “some of the more spectacular developments in automatic control of machine tools… are justified on economic grounds. These claims… sometimes have a ring of a posteriori justification of engineering enthusiasm – occasionally it is the growing prestige of innovation and its emulation that seem to tip the decision to develop or buy new automatic equipment.” When one takes into account the high first cost and the need to prepare “numerical data rather than dimensional drawings,” the proposed labor savings did not appear compelling. The only way to make these devices pay would be to “achieve an abnormally high load factor,” well above that commonly experienced in metalworking facilities.145 This caution

144 Ibid., 71.

was well placed, even as The Economist’s correspondent overlooked reliability, durability, service, and obsolescence as additional factors suggesting restraint by possible adopters.

Dun’s Melvin Mandell offered a more detailed assessment in summer 1958. Yes, during any given hour, the NC cutter could be at work up to 85 percent of the time, rather than the “usual 20 to 25 percent.” This should cut delivery time, perhaps in half, for metal components and machines. However an array of difficulties loomed. The cost was high, while complicated controllers were “not yet standardized.” Older tracer controls remained “superior where deflection of the workpiece…cannot be predicted.” Integrating these devices into production entailed expenditures of time and money; for example, “tool engineers and factory management must be retrained,” not just workers. Providers seemed to be coming and going rapidly, which made technical support uncertain (this favored GE and Bendix, of course). Three sorts of recording media competed; which was best wasn’t yet known. Much-needed reliability data was fragmentary because “[t]he first machine has actually been in use for only about 18 months.” For those considering retrofitting older tools with NC systems, this maneuver cost from one half to two-thirds of the original tool’s price, could not be done effectively in the owner’s factory, and involved lengthy downtime plus the cost of shipping the tool to the NC maker’s facility (backlogs for controllers averaged six months). Preparation of tapes or cards had to be located somewhere, and creating what was then termed the “manuscript,” a tool-work planning document, “takes longer than any other single step in making a part by NC – sometimes weeks or months.” Mandell did not mention tape errors or their effects, which proved significant.

Complex parts, like jet engine compressor blades could not be NC machined at all, Mandell noted, unless makers purchased an Ex-Cell-O special NC combined miller and precision grinder, which revolved the piece while the cutter moved in three axes. This, however, cost $185,000, more than ten times a turret milling machine (hence the appeal of forging and casting solutions). Also, in operation, tools wear down and precision fades away. “Various schemes for compensating for the inevitable wear on the cutter have been suggested but only one – the British EMI controls adopted by CMM Co. – offers it at present.” Moreover, in the shop, “it may take many months to shake down” new NC tools. Finally, the machine may stop due to control panel failures: “one or more of the tens of thousands of connections may have worked loose.” After all, among the variety of NC systems on the market, only one “is made entirely without vacuum tubes.”¹⁴⁷ None of these reservations was far-fetched.

By 1959, some of NC’s initial glow had faded. Understandably, reliability had been an issue for early installations, AM’s Stocker agreed, because it “is a function of complexity – of the number and relationship of the components in a system.” Continuous-path NC systems “are at least an order of magnitude” more complex than earlier positioning systems, hence reliability issues emerged. Managers reiterated points Mandell and The Economist raised: “Will we wind up with a number of non-standard, incompatible systems? Can we find enough work to keep the equipment busy? How much time and money will it cost to train my employees? Will maintenance specialists have to be hired to keep the units working?” Yet Stocker retained his promotional stance assuring readers that maintenance was no big problem, training required just a few days, users had more work for NC tools

¹⁴⁷ Ibid., 67-68.
than hours to run them, etc. Still, H. W. Mergler, a researcher at Case Institute, agreed that reliability was the central problem, which would improve once “solid state and magnetic devices are used more widely.” Their current prices “only aggravate the cost problem.” Significant changes in NC were indeed in process, being hammered into place for the 1960 Machine Tool Show.

In Chicago, General Electric introduced solid-state, printed circuit boards as the basis for second generation Mark 100 Series NC devices, but the route to the exhibition proved complicated. A series of related technological maneuvers filled GE-NC’s 1955-60 period. Until 1956, all GE custom-designed all NC boxes for users; thereafter though custom work continued, standard models began to reach the market. Standard controllers at first guided point-to-point work (two-axis, flat, mostly for drilling); this was GE’s Mark II line, introduced in 1956-57. Thirty sold by September 1958, not an overwhelming result. GE soon released three, four and five axis Mark versions for more complex, three-dimensional point-to-point work, and with the extra axes, profile contouring. All were vacuum tube based (Thy-Ro-Trons) and tape driven, as readers for the first-phase card system proved far too slow for effective machining. Thus the shift to solid state logics did not change the tape drive; all these systems depended on detailed manual translations of design drawings into numbers that oriented “the order and directions of cuts to be taken.” This was labor-intensive; in one MIT study in the mid-Fifties, the ratio of programming time to machining time ranged from 18:1 to 52:1 (the latter for a propeller blade template, almost entirely curved surfaces). The solution was the APT (Automatically Programmed Tool) language, which eventually became a world-wide standard. It radically reduced

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programming costs, was a flexible platform, and resulted from a partnership between a computer designer who knew nothing of machine tools and a veteran Boeing engineer who had worked with K&T skin mills.\(^{150}\) GE’s ongoing partnership with Kearney & Trecker was invaluable as these improvements were tested and refined in Milwaukee. In consequence, the Mark 100 series controllers, revealed in July 1960, became one of the hot items at the 1960 Show – 28 systems installed on tools from 16 different manufacturers.

Even so, the punched tape remained a weakness, and could create havoc when errors escaped proofreading. Here’s one account of a Lodge & Shipley NC from the 1960s, “the flying eight inch, eight foot shaft”:

The machines had the GE 100S control [introduced in 1964]. They were using indexible carbide tooling and [were] able to rough out 1.000” on the diameter per pass, yes .500” depth of cut, we’re making chips here….The original design tailstocks would fail and the hydraulic pressure would go away, [then] the shaft would dig into the tool and snap the center off, and bam, the shaft would fly out over the operator’s head and into the aisle… scary. Lodge changed the design…and it never happened like that again… UNTIL the tape reader’s [electronic] fingers skipped a hole in the tape and sent the machine crashing, snapping the center, sending the shaft flying, again. It was not impossible for machines to skip a block in the tape, always a nice crash. There were many ways for an NC machine to give problems – write a program, punch it on paper tape, prove it out on the machine, edit, re-punch, have a good program, transfer it to mylar [tape] (they never ran production on paper tape), prove that tape, it worked great, run the job, what a crash, check the tape. Oh, the punch was dull and left a hanging slug that pushed back in and the [tape] reader never saw it.\(^{151}\)

\(^{150}\) Richards, *History of Numerical Control*, 17,44-45, 167-69; Reintjes, *Numerical Control*, 78-80. See also Richard Thomas, “The Languages of Tape,” *American Machinist* 114 (6 January 1964). The MIT person was Donald Ross and the Boeing engineer was Edward Carlberg, whom Reintjes fails to mention. Noble regarded APT as overly complex and as transferring power over machining to engineers, seeing the earlier record-playback system as more progressive (as noted above, machinists made the first piece, with each step recorded, then repeat pieces could be machined automatically). Reintjes contested this interpretation. See Noble, *Forces*, 206-11, 225-27; Reinjes, op. cit., 176-79.

\(^{151}\) D. Thomas, K&T Milwaukeematic Mill thread, *Practical Machinist*, 27 March 2004 (http://www.practicalmachinist.com/vb/archive/index.php/t-113966.html) (accessed 17 January 2009). Here a hanging slug is the tape equivalent of a hanging “chad,” a term made famous in Florida, following the 2000 presidential election. The result was the same; information was garbled and the machine failed to operate correctly, in the tool case, with potentially deadly results.
In 1967, John Glavin, running an NC Giddings and Lewis mill reported, similarly:

There’s pressure, because you hope that the man who made this tape didn’t make it wrong. You hope that, even though he made it right, there isn’t an electrical malfunction in the machine where it’s going to injure you. You are always at the controls with both hands up like a monkey reaching for a limb – so you can grab read quick to shut everything off. The other day I had a tape that had 80 positions on it. When it did the operation for position 39, it skipped the next position and went on to 41. This was the fault of the [Friden] flexo-writer who punched the tape…. This particular machine is what they call Tab-sequential; you’ve got to know this because [it] works in conjunction with the tape. Each tab number indicates whether the table moves in a certain direction. If the tool is inside a hole the programmer may tab it up three inches and tab the table sideways two inches. But supposing he’s tabbing the table to move first… He tabbed it [backwards] one time and we were in a hole. I had a two inch drill and was seven inches in the hole. The machine took off and it threw that drill fifty feet down the shop. It weighed two pounds and it just missed me; it went over the helper’s head and took his hat off. So after that I said, “I’m going to know this thing, because it might kill me.”

On Practical Machinist, JimK recalled early NC operations and their erratic quality:

I used to say that those old NC’s would catch a fever. They would get a bit hot and then they would get a mind of their own. Many of the old NC’s,… when they were idle, they could take a notion to start. You wanted to have a quick way out at all times when working around those machines. The first GE Mark Century controls were tape readers, that’s it, no macros, no canned cycles, nothing….. Thwack, Thwack, Thwack, one bit at a time on the Frieden Flexowriter. Hope what you saw on the paper was what was actually punched on the tape. No way to dry run except on the machine. Yeah, buddy, the old NC’s wuzz a job for a Manly Man. Your nerves had to be a better alloy than the steel you were cutting.

Critical to reducing this source of mechanical programming error was shifting from tape drive to electronic memory-based controls, though program errors remained dangerous.

Hence machinists undertook to learn everything possible about NC tools and their foibles.

The 1960 Show did more than introduce NC to large audiences; it helped brighten the spirits of machine tool enterprises after a number of disappointing seasons. Most firms had not matched Korean War production and earnings during any of the following seven

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152 Noble, *Forces*, 245-46. The episode quoted was originally published in the union journal, *UE News*.

years. Publicly-traded stocks had fallen steadily in value, and price competition had begun to surface. “Price increases do not hold up as producers eager to increase their volume are sometimes willing to make concessions to get new orders.” Automobile firms directed orders to new and specialist builders, while other users “have been able effectively to remodel their old machines, extending their life… which is on average amazingly long.” By the mid-Sixties, this rebuilding move would broaden, sparking an after-market in adapting 1950s tools to NC controls, expanding the demand for directors and limiting sales of newly designed NC tools that readily cost $50,000 and up. Still, the Show did go on.

Steel’s correspondent judged that the exposition concretized “three trends” in tool building and tool use: reducing labor costs, increasing flexibility, and achieving precision. Servicing the auto industry no longer magnetized designers, nor did NC present the only excitement. Controls of all sorts (hand, automatic, tracer, hydraulic, pneumatic) promised greater precision, whereas NC, dial-up feeds and speeds, and rapid changeover setups offered versatility. Fifty tracer controls were exhibited, some NC, most not. Indeed, electronic controls experienced an unwelcome setback in the event’s opening days, which “were steaming hot… a real test of human endurance.” Temperatures topped 100 deg F and if that was hard on visitors, it was “doubly hard on the controls. More than one builder turned his fans from the customers to the controls. And extraordinary voltage fluctuations didn’t help either.” One of those trying to compensate for the heat was the GE-NC sales force. As Richard Thomas recollected: “Controls were failing everywhere because of the

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heat. George Roger and Leroy Kelling purchased fans locally to keep our systems operating throughout the show – at times the only controls in operation.”

Kearney and Trecker Milwaukee-Matic with drum tool changer and GE controls (1960)

Among the more spectacular operations on view was CMM’s contour milling machine, cutting “the complex profile of an aircraft wing beam with commands from the punched tape on Cincinnati’s Acramatic, three-axis numerical control system” from EMI. New metalworking techniques like chipless machining, explosive forming, shear spinning, and electrical discharge machining showed to perform operations “without benefit of cutting tools.” The more venturesome could trek to area plants to see “huge tools with magazines for cutters” from Sundstrand, Ingersoll, Greenlees and others. Memorable too,

on site, was the deployment of Kearney and Trecker’s Milwaukee-Matics, which featured an automatic tool-changer holding “30 preset tools in coded” slots. (See illustration above.)

Though the sleek, modern “look” of the Milwaukee-Matics was the product of an industrial design alliance with Brooks Stevens, the Milwaukee native who evidently coined the term “planned obsolescence,” machinists found them:

uncomfortable. Their motions were slow and laborious. They did not impress me as particularly good examples of NC automation …Those Milwaukee Matics didn’t look anywhere near as sleek and clean in real life. The addition of the large NC director cabinet cluttered up the setting right away. Add a workbench or two and then a fixture and a workpiece and you’ve got a typical machine shop mess.156

These large devices had electronic controls far less developed than their mechanical components. As Reis observed on Practical Machinist:

The K&T Milwaukematic is interesting to me because… it is an oddball ugly duckling… my guess is that because the period of early tape-reading machines was brief, they were a transitional type of machine, and didn’t work really well from what I have heard. The tape was kind of clunky and slow to program, and most of them like this one [reference is to the photo above] were not usable as a manual machine, so when the NC started to break, or better designs were available, they were gone pretty quick.157

From the mid-Fifties through the late Sixties, makers advertised NC controllers as engineering research’s gift to the metalworking community, breakthroughs that would transform machining, enhance precision and flexibility, and enable management to hire less-skilled workers to tend programmed tools. These buoyant promotions failed to generate avid purchasing; by 1962, seven years after their introduction, just 1800 NC machines operated in US plants. Meanwhile, in 1960, 1500 electro-discharge machining units were operating, milling without cutting; adoptions of this substitute technology rose to 3600 by 1963. Given falling prices, an estimated 7,000 NCs had found homes by late

156 JimK, K&T Milwaukematic Mill thread, PM, 28 March 2004 (n150).

1965, but of these almost 90 percent were basic point-to-point devices, overwhelmingly drills. Just 800 high-end contour-path controls were in place, many associated with military aeronautics and NASA space contracts. Operational difficulties still abounded, though. Just six percent of plants using NC reported “no problems” in a 1965 industry survey; key issues were electrical failures (32 percent of respondents) and down time from “random malfunctions.” One user complained: “our most troublesome problem is finding the problem. This can be from lack of knowledge by operators and maintenance men or incorrect information being received” from providers and service personnel. Designers could “produce yard-long lists of reasons for using NC,” and regularly did so at meetings of the new Numerical Control Society (1963). But top managers balked at prices upward of $60,000, four times the cost of a general purpose tool.158

M.H Bulkin, of Hughes Aircraft’s Aerospace Group, offered a thoughtful overview of installing and operating a numerically-controlled MT-3 machining center at the company’s El Segundo, CA plant (1965). The tool cost $180,000, plus $20,000 for accessories and setup; to amortize this cost Bulkin calculated that for a break-even level, the machine needed to be in operation for 77 percent of each 40 hour working week. The advantages it provided for component lots averaging 60 units included accuracy, repeatability, and “toolability,” which referenced the use of simple tools and minimal tool handling. Yet there were disadvantages:

related to the technical complexity of the machines. Most NC equipment requires a high capital investment, specially trained personnel and special equipment for its maintenance, and programming and computing capabilities for generating and checking out of the paper or magnetic tapes (or other input devices) used in the

manufacturing process. Finally, NC carries a psychological stigma associated with automation of all kinds.159

A decade after its heyday, “automation” now was something of a dirty word, even as it had floated far from its origins in the 1940s. For tool builders, there was another unpleasant dimension to the Hughes MT-3; the company’s Industrial Systems Division had made it, not CMM, Lodge and Shipley or Giddings and Lewis. Midvale-Heppenstall, the Philadelphia steel company was doing much the same, developing its own “electrochemical machining tools.” Midvale took this step because “machining times and tool wear are getting out of hand” for alloys that “are so hard that they virtually defy conventional machining techniques.”160 How commonly user firms built their own machinery is not known, but this was not a good sign for an increasingly troubled trade.

Three further indications of hard times in machine tools were much more important than users’ manufacturing initiatives: a rash of mergers/takeovers, moves toward diversification, and a rising flow of imported tools. In December 1963, Iron Age announced: “Tool Builders Turn To Mergers As Profit Squeeze Tightens.” Consolidations and buyouts had proliferated. Since early 1962 ten tool companies had been acquired by other firms, three by other machine tool builders and the rest by companies outside the industry. Four more tool enterprises had bought competitors, counting on cost reductions, broader product lines, and revenue enhancements to help bottom lines. Familiar names began disappearing: Rockford (grabbed by Greenlee, the transfer machine firm), Morris (by Curtis Manufacturing), US Tool (by Baird Machine), Blanchard (by something called PneumoDynamics, which also bought Cone Automatic Machine) and WF & John Barnes


(by Babcox & Wilcox, the heavy machinery corporation). Baird’s president noted that US Tool’s owner wished to retire and wanted to see the firm he built continue, rather than be liquidated. From Baird’s viewpoint, “the cost of developing new products is getting to be almost too much for smaller companies… Merger or acquisition of a going company is less risky than bringing out untried products.” Greenlee’s L. H. Geddes argued: “There is still a profit famine, at least for many machine tool companies. Price relief is needed or we’ll see more tool companies on the auction blocks.”

None of the Big Twelve builders (such as CMM, K&T, G&L, Warner & Swasey) had vanished; instead, a number of them had begun diversifying into other sectors. CMM, which started adding non-tool products with Cimcool in 1947, by 1963 had moved on to “reinforced plastics, printed circuit boards, heat treating machines, hydraulic motors, gaging equipment, electronic controls, and chemicals,” along with EDM sets. These lines now provided 20 percent of its revenue. Moreover, CMM had opened production facilities in Britain, France, and the Netherlands and had placed “sales engineers… in 93 cities in 43 countries” (with 82 more locations in North America), a relatively-rare internationalization strategy, in this trade at least. Research had begun on designing plastics machinery, as well, but CMM management traditionalists stalled that venture until the decade’s end. Ex-Cell-O, diversified since the 1940s, had pushed into “aircraft parts [and] expendable tools”; machine tools constituted only 20 percent of sales. Lodge and Shipley commenced fabricating “bottle handling equipment and plastic packaging machinery,” while Ingersoll “is making engineering studies on a fee basis, coming up with production systems” that might or might not include its own products. Brown & Sharpe now “makes slicing and

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dicing machines for the electronics industry” (silicon wafer cutting devices) and Jones & Lamson has designed “optical comparators to move into the special photographic equipment field.”162 Veteran sectors leaders began to revised their visions of machine tool markets’ scope and prospects.

Last, and little discussed at the time, imported tools had started nibbling at US makers’ market shares. In 1964, American firms sold $1 billion in tools domestically; importers delivered $30 million worth to US firms, under three percent of sales. The next year, foreign tools’ share rose to five percent, reaching ten percent in 1967. Importer Kurt Ucko made a simple point in an interview: “One trend seems crystal clear at this time. Many American firms have seen their way clear to purchase foreign-made machine tools. Many more will do so in the future.” By 1985, imported tools secured half the market and US firms were collapsing right and left.163 It is toward that dénouement that we now must proceed.

Substitution and Internationalization (1960s and after)

“The proof rests with the customer – if foreign machine tools were better, more American manufacturers would be using them.” Charles Carter, research director, Cincinnati Milling Machine, September 1965

‘When you walk into a big production machine shop, and say to the owner, “Why don’t you buy American?”’, you have to be either Rip Van Winkle, been asleep for 30 years, or just can’t face the fact that there simply ARE no American companies producing a lot of these machines, and haven’t been for around 30 years. The Japanese ate our lunch in the area of machine tools about 1980, when they took the

162 “Machine Tool Industry Broadens Product Lines,” 47-49, 97; “Tool Builders Turn,” 136; CMM European Management Conference (transcript), Vlaardingen, Netherlands, October 10-11, 1960, Milacron Collection, Part 4, Philip Geier Papers, Box 1; Bill Mericle Interview, August 1, 1983, 3-7, Milacron Collection, Interviews, Box 2, Cincinnati Historical Society. See also, “More Metalworking Research and Development Needed.” 139.

high road with CNC development, and companies like LeBlond, Monarch, and South Bend sat and watched and did nothing (except go broke). You ever see a South Bend sinker EDM [Electrical Discharge Milling machine]? It is without doubt the most ill-designed, antiquated, Rube Goldberg contraption ever contrived. It’s not the labor unions or the economy that put these people out of business, or kept them hanging on by their fingernails grasping for imported machinery to sell. Basically it was their own management’s stubborn refusal to change and invest in new technology.’ Pete913, November 2004\footnote{More Metalworking Research and Development Needed,” Machinery 72(September 1965): 139-43; pete913, “Contradictions in Mentality,” PM, 25 November 2004. http://www.practicalmachinist.com/vb/archive/index.php/t-125220.html (Accessed 13 January 2009)}

This is not a story with a surprise ending. The US machine tool industry stepped off a cliff in the early 1980s and despite occasional signs of recovery, has in large measure limped through the Nineties and the opening decade of the new century. Worth mentioning, however, are the conventional explanations for this collapse: labor unions (hence cost differentials internationally), weak R&D spending, market/innovation distortions from protectionism (then shocks with its abrupt end under Reagan), exchange rates favoring imports, and foreign copying of US tools - re-engineered, cheapened and exported back here.\footnote{“Adaptation to Change,” RAND) mentions changing materials, new processes, and increased productivity as influencing machine tools’ declining share of all machinery ordered, but sees trade and macroeconomic policies as affecting the industry “profoundly” (v, viii). The social science literature is replete with errors, many it seems due to serial citation of flawed policy analyses, such as the claim that US firms did “minimal customization” and that they “resisted or ignored the global trend toward closer supplier/client interaction.” Both are false, indeed inverted. Most US tools were customized to varying degrees for buyers, and close supplier/client relations were a standard feature of US builders’ practice from the 1880s. Quotes from Alan MacPherson and Ronald Kalafsky, “The Technological Revitalization of a Mature US Industry: The Case of Machine Tools,” Industrial Geographer 1(2003): 16-34 (quotes at 19). See also Heinrich Arnold, “The recent history of the machine tool industry and the effects of technological change,” Working Paper 2001-14, University of Munich Institute for Innovation Research and Technology Management, pdf available at Münchner Betriebswirtschaftliche Beiträge, 2001 - en.bwl.uni-muenchen.de (accessed 22 December 2003). Arnold advocates “technology shocks” as key to the overall history of the machine tool industry (See his Technology Shocks: Origins, Managerial Responses, and Firm Performance, Heidelberg: Physica Verlag, 2003). This line of analysis centers on NC and shows little awareness that it was not widely adopted for 20 years after 1955 (the first two “shocks”). The industry’s reconfiguration does not reduce to a single cause. Roberto Mazzoleini also works on NC, comparing the US and Japan, using a path-dependence model. See RM, “Learning and Path-Dependence in the diffusion of innovations: comparative evidence on numerically controlled machine tools,” Research Policy 26(1997): 405-28. His contribution is part of a debate among economists about technology diffusion and has little historical content or context.}
financial errors, US tool quality and reliability, or reconfigured demand for solid materials processing. Chiefly, the first cluster of explanations represents views of economists and policy analysts, who not unexpectedly found causality in macro-economic phenomena and government decisions. The second set of factors works closer to the bones of the trade, leading toward exploring the micro-economic dimensions of firm actions and their continuously-shifting technological contexts, the terrain this essay occupies. (As Practical Machinist members sometimes say: “Read ten years of American Machinist and you’ll probably learn something.”) This section will visit the Chicago 1965 exhibition, before briefly assessing the shape of U.S. machine tool use in the Sixties, the course of substitution, and moving frontiers in materials and processes. The closing offers a look back to the Forties and forward past 2000, noting firms vanishing and new, some remarkable failures and striking innovators, ending with comments tool shows and thoughts on categorization.

The 1965 Chicago Show stands as an industry watershed: the last exhibition excluding non-US producers and the first with over 100 NC controls in operation or on display. Happily, color returned to tooling, as firms widely dropped the earlier, uniform gray; gold and sand proved popular for lathes and presses, white and pink a bit more venturesome in other lines. Two hundred builders showed nearly 1,000 tools and busily served clients. “There were pleas about delivery dates; there was no longer any negotiation about price. It was a buying show, not a selling show.” Apart from NC, a key technical trend led toward functional convergence: “Traditional distinctions between different types of machines are blurring as machine capabilities are extended.” The rising variety of tool changers, more reliable and working faster, drew appreciative commentaries, whereas measuring instruments with digital readouts were the show’s novelty hit. Within NC, “the
unquestioned star was General Electric,” which had its Mark Century controls running over 40 machines from a score of manufacturers. Other control specialists also offered their latests models, as did tool firms like CMM, Giddings and Lewis, and Pratt & Whitney, having created proprietary systems.166 Eight months later, the 1966 Detroit Tool Show opened (following a 1963 version). Both need research attention, as years before the NMTBA opened its spaces to non-US builders, 43,000 visitors to Cobo Hall witnessed a wide range of international and unusual devices in operation. “The foreign machine tools were there in force, as usual. Sixteen Japanese builders showed 35 machine tools, give of them numerically controlled (all with Fujitsu Fanuc controls).” A dozen UK producers, along with “the usual number of German, Italian, and Swiss machines” rounded out the global complement, but the trade press bypassed the specifics of non-American exhibits, stressing high-end performers from CMM, Pratt & Whitney, or Giddings & Lewis.167

AM’s Metalworking Inventory data from 1963 and 1968 indicate that users indeed were purchasing high performance tools, replacing older models, but that in most key sectors, labor reductions, if imagined, had not yet been achieved. Overall, tool-users had roughly the same machinery totals in each year (2.14 million vs. 2.18); but in 1968, they employed ten million workers, a third more than five years before. In part this surely reflected surges in military demand for the Viet Nam war, but the details’ divergence is more than a single factor explanation could support. Together, machinery building and precision manufacturing roared ahead, 1963-68, workforces swelling 47 percent from


167 “1966 Tool Show Report,” American Machinist 110(9 May 1966): 104-07. AM noted that US firms joined in, “now that the NMTBA show is past,” taking “advantage of the association’s liberalized exhibiting rules.” This implies that for some period before 1966, NMTBA members were not permitted to take space at Detroit’s show. The text does suggest that US firms exhibited in 1963, the last year non-US firms “did not dominate the heavy machinery part of the show.” (104)
567,000 to 835,000 – figures that bear a closer look than can be managed here, though added shifts for space- and war-related work may be a factor. Tools in use, however, increased just thirteen percent (to 339,000), loosely indicating growing per-tool productivity, but not general labor-saving. Motor vehicles and parts trends in half echoed this pattern: employee numbers grew by 191,000 between Inventories (to 841,000, up 29 percent), whereas machine tool totals fell by 30,000 (to 130,000, down 18 percent). This makes a certain sense if machining centers and flexible transfer arrays eliminated many single-function tools, but why the workforce expanded rests unclear.¹⁶⁸ Last, aircraft and engines, which included NASA-linked manufacturing, mirrored the motor vehicles pattern: increased employment, fewer tools in place. In ’68, these sectors operated with 683,000 workers and 147,000 tools, 27 percent more staff than in ’63 but 21 percent fewer tools.¹⁶⁹

American Machinist sold the productivity argument, while entirely ignoring workforce growth. Though the total number of machine tools in place had risen negligibly since 1963, “the value of production as measured in constant dollars… has gone up by 39 percent.” Also, for the first time since 1945, the proportion of “young tools” (under ten years old) rose, even if just slightly (one percent to 37), with small (and new?) firms more aggressive in purchasing (43 percent of tools at shops with fewer than 50 workers aged under ten). Concentrated in aeronautics and machinery building, NC use had doubled since

¹⁶⁸ Perhaps something here relates to widespread worker discontent, along with UAW-supported job-preservation and job-stretching as Stanley Aronowitz portrayed in Lordstown, but that should have worked to resist technologically-inspired layoffs. A second possibility is that aerospace divisions of Ford and GM reported military production data as belonging to motor vehicles, which should have been classified as Aircraft and Engines. More contextualized research may well clear this up.

1964-65, to 14,000 installations, 2,000 of these doing continuous-path contouring, representing just 0.5 percent of US tools, however.

A later study noted that machine tool builders experienced strong growth in product demand for another five years, at least through 1973. Even so, in 1968 the tool population aged over twenty years was “at an all time high both in percentage of the whole and as an absolute number.”

One way of accounting for this bifurcation could be to imagine two broad pools of tool-using enterprises, one set chasing technological and productivity gains replacing old tools with cutting edge innovations (chiefly aero and car leaders and subcontractors, plus SME specialists), and another group retaining older, less refined machines (30 percent of World War II tools reportedly still operated) while adding new tools and workers selectively. Documenting some pattern along these lines might begin to account for the divergent AM Inventory trends, but of course would only be a starting point for further investigation.

Another reason why machine tool totals in aircraft and vehicle production decayed in the later 1960s could well be substitution, most particularly from plastics, as plastics machinery, for molding, extrusion, cutting and forming, lay outside the Inventories’ scope. Sales of plastic shaping machines were booming; in molding machines alone, deliveries leapt from 38,000 in 1961 to 79,000 four years later. Plastics fabricating firms were increasing twelve percent annually, a rate that showed no sign of slackening. Meanwhile, “automobile engineers continue[d] to specify plastics at the expense of other materials,”


171 See Martin Baily and Alok Chakrabarti, Innovation and the Productivity Crisis, Washington: Brookings, 1988, 76-77. Certainly rising demand for precision instrumentation spurred growth and innovation in that sector, which overlapped only to a modest degree with machine tools. CMM, Brown & Sharpe and Giddings & Lewis did instrumentation work, but most firms in this area were free-standing specialists. For an overview, see Orville Eberhardt, “New Face of Metrology: its Impact on the Machine Tool Industry,” Tool and Manufacturing Engineer 57(July 1966): 26-29 and 57(August 1966): 44-47.
e.g., in grills, tubing, and parts for springs and gears. Plastics output reached roughly six million tons by 1965, and was increasing 12-14 percent yearly; and looking forward, a DuPont researcher claimed that “composite metal-plastic laminates” offered “broad opportunities,” while reducing metal use and weight. Every other year, specialist plastics machinery builders attended the National Plastics Expo at New York’s Coliseum; National Acme, Fellows Gear Shaper, CMM, Van Norman, and New Britain Machine were regular exhibitors, at least by the mid-1960s, as a cluster of tool companies ventured across the border into non-metals. A late starter, CMM/Milacron would outlast all the others.\textsuperscript{172}

The NMTBA by this period had extended its boundaries a second time. Having gathered in metal forming tool companies after World War Two, the Association now again revised its “definition of [a] machine tool” to recognize “many of the newer methods” for metal processing. It began recruiting members firms exploiting “advances in electrochemical forming, explosive forming, Laser and Maser cutting, high-energy-impact forming, magnetic forming and other methods,” many of them newly-started companies outside traditional machining. Such broadening “does underscore technological changes sweeping the industry,” as \textit{Iron Age} observed, but reaching out toward plastics machinery wasn’t on the agenda, not least because it would surely have created sharp conflicts with a brother association, the forty-year old Society for the Plastics Industry.\textsuperscript{173}


Ongoing mutations on the materials frontier also slowly marginalized classic machining processes. Space-age refractory metals and alloys [tungsten, columbium, rhenium, tantalum, et al.] whose “development and application [continued] on a broad scale – and at a rapid rate,” presented “machining problems” of various sorts. Forging and powder metallurgy offered promise here, as did electron beam welding for joining. In 1966, Ronald Khol stressed the increasing role of composites, not just in aerospace, but in general transportation equipment, where plastic-embedded fibers of boron, graphite or silicon carbide provided high-strength, lightweight structures “three times stronger than steel.” No room for machining there. Boron filaments for composites first became available in 1965, and DuPont offered its aramid fibers (Kevlar®) in 1971. “Fibers made from ultra high molecular weight polyethylene were made in the early 1970s. These advanced performance fibers, along with fiberglass and carbon fibers, led to tremendous” elaboration of composite applications. High costs would limit their reach for a decade or more, but composites became an anchor point for major development projects by the 1980s, expanding so broadly that recent aircraft end-uses took up just one percent of materiel production. Thus did creativity in both processes and materials reinforced metals and machining substitutions.\(^{174}\) Machining’s narrowing scope seems a clear trend, and the smash of the early 1980s reinforced the weakened US tool industry’s slippage. As American Machinist summarized:

During the 1980s the industry, in the midst of an unexpectedly deep recession, faced intense competition, particularly from Japanese machine builders. A very

strong U.S. dollar also hampered export sales. From 1981 to 1983, members of the National Machine Tool Builders Association reported a drop of 66% in shipments of U.S.-built metalcutting machines.\textsuperscript{175}

There would be no route back to global leadership; great firms faded gradually, smaller ones just disappeared, and over the next 25 years the US slipped to sixth place as a tool-building nation.

In 1968, Harless Wagoner published a careful overview of US machine tool building in the first half of the 20\(^{th}\) century.\textsuperscript{176} As an appendix, Wagoner listed 1942’s 25 leading tool builders, those having the largest wartime workforces, with CMM, Brown and Sharpe, Bullard, Warner & Swasey, National Acme, and Kearney & Trecker being the top six. (See Appendix Three.) Not quite forty years later, GE controls veteran Richard Thomas compiled a list of just over 100 principal US tool makers – from the 1960s to the early 2000s. Twenty-one of Wagoner’s 1942 leaders appeared on Thomas’s roster, but not as leaders. CMM, having become Milacron, had sold off its tools division to a conglomerate, UNOVA, successor to Litton Industries, long time masters of acquiring and stripping. Brown and Sharpe, now owned by a UK firm, made only measuring devices. White-Consolidated, a diversifying Cleveland appliance company had purchased Bullard, then was in turn swallowed by Electrolux (Sweden), which sold off W-C’s tool firms, American Tool Works, DeVlieg, and Sundstrand Tool, all of which evidently liquidated, as did Bullard. Warner & Swasey, first acquired by Bendix (the controls company), then by Allied Signal (buying Bendix), finally was mixed into K&T in another spinoff. National Acme passed through several owners before closing. Kearney & Trecker took an alternate

\textsuperscript{175} http://www.americanmachinist.com/304/Issue/Article/False/9150/Issue (accessed 5 February 2009).

path, first purchasing several small firms, then Cross (transfer machines). Having acquired
Warner and Swasey, it hit financial shoals in the Nineties and was snapped up by Giddings
and Lewis, which ThyssenKrupp shortly reeled in (1997). K&T’s massive Milwaukee
plant is now closed and vacant.\textsuperscript{177} Among other prominent 1942 firms, about fifteen simply
died before or during the 1980s, either having been sold or failing on their own account.

Meanwhile, just sixteen of Thomas’s 104 late 20\textsuperscript{th} century tool builders mounted
exhibits at the 2004 International Manufacturing Technology Show. Four represented
remnants of the 1942 elite: Milacron, which by then made only plastics manufacturing
equipment; Pratt and Whitney Measurement Systems, the precision tools fragment of a
once-major machinery firm; Landis Tool, a grinder company, also owned by UNOVA; and
Bryant Grinder, which Ex-Cell-O (an early diversifier) had bought and dropped. Bryant
operated from a re-purposed brick factory in Vermont. Nine others were small potatoes –
makers of special tools, small lathes, or cutting tools. The three major US firms at IMTS-
2004 introduce new names to this narrative: Hardinge (lathes, Elmira, NY); Fadal
(machining centers, Chatsworth, CA) and Haas Automation (Oxnard, CA). We will return
to them.

Serial sell-outs by founders and heirs of what had originally been family firms and
partnerships (recollect Fortune’s 1935 assessment) accelerated in the Sixties. As LeBlond
veteran Mike Westerheide recollected, these family enterprises valued “the long lead

\textsuperscript{177} Wagoner, \textit{Machine Tools}, Appendix 12; Thomas, \textit{History of Numerical Control}, 331-39. Note that
Giddings and Lewis, so prominent in the preceding sections, was not a top-25 tool company during World
War Two. ThyssenKrupp’s Metalcutting Group, including G&L was sold to Maxcor (a turnaround group) in
2005, which evidently handed G&L off to MAG Industrial Automation Systems, which in fall 2006 merged it
with Cincinnati Machine (Milacron’s divested tool division) and another firm to create Cincinnati
Technologies which will “provide solutions for the aerospace, construction, oilfield, power generation and
general machining markets worldwide.” See Stan Modic, “Something to be thankful for,” \textit{Tooling and
Production} 71(November 2005): 10, and Derek Kern, “Companies Align,” \textit{Modern Machine Shop}
79(September 2006): 40. Other sections of the Sundstrand Corporation continued in business, making
aerospace equipment.
times” busy periods created, as they could work off their backlogs when demand slowed, using retained profits to develop innovations and to minimize layoffs. Firms regularly “paint[ed] buildings inside and out and [did] other maintenance work” to keep their core work teams together. This changed sharply in the 1960s, when machine tool companies became targets of conglomerates like Tenneco, LTV (Ling-Tempco-Vaught), Bendix, FMC (Food Machinery Corporation), Houdaille and others. Many of the machine tool companies had 3rd or 4th generation owners who no longer had any real interest in the business and wanted to cash out. The conglomerates took over and usually the first thing done was to take the cash reserves put away for slow business conditions and leverage that money into buying other businesses. Then, when business got slow, they had no reserves and had to slash costs and people. After about two slow business periods, [the new owners] usually tried to sell or close the business. In my opinion, that was the death of the American machine tool industry. Today, most... companies that were owned by conglomerates are closed.178

This fast overview confirms that, by the early 21st century, the principal US machine tool builders from the 1930s through the Cold War had shrunk, failed, or disappeared into conglomerates as ownership shifted erratically and transnationally. Like Juergen, we might ask: “so what [else] happened?” Giving some attention to business and technology matters should help supplement economics and policy arguments with some closer-to-the-ground concerns, on one hand, as well as reach beyond the fate of veteran firms to domains where new entrepreneurs, new capabilities, and transnational problem-solving intersect, on another. [Both lines of discussion will be quite tentative, as my in-depth research has not moved much past 1966 (I hear readers saying: “Thank God!”)] Four interactive moments characterize US machine tool builders’ late 20th century decline. In addition to buyouts and asset stripping (above), they include: numerical control follies and machine quality decay and the internationalization of innovation and competitive capabilities. The last was not new, but from the Fifties onward, US enterprises in many

178 Mike Westerheide, “It Has Been A Great Ride,” in Thomas, History of Numerical Control, 327-29.
fields proved slow to recognize the rising capacities of rivals in advanced (and advancing) industrial states – machine tools was one of those fields.

Now for a few specifics. Despite the sales hype and understandable pride about inventing NC, the US numerical control business was a mess for decades after the initial roll-out in 1955. General Electric’s course will, for the present, have to stand for the whole. A leader in designing, marketing and servicing NC devices from the early 1960s, GE introduced its Mark Century 550 Series in 1972, reducing the number of printed circuit boards per control by a third or more. The Excelo 1050 (1974) was GE’s first CNC, using an Interdata minicomputer for programming and microprocessors in the unit. In 1975, GE’s controls division held a 41 percent US market share, 26 percent globally. Six years later, GE NC and CNC sales stood at 23 percent (US) and 12 percent (world). Robert Breihan, who recounted that unfolding disaster at a 1984 GE management conference, observed that the right sound effect would be “a toilet flushing.” The core failure had been in quality. GE did quality control by working backwards from failures revealed in “inspection, testing and problem-solving in users’ plants.” Given that the 550 was “hard-wired,” errors were not terribly hard to detect and fix, but they occurred too often:

[S]ince our domestic competitors operated in the same fashion, dead-on-arrival controls, despite the inconvenience, were pretty much accepted as a fact of life with NC. In fact, machine tool builders actually built special test areas and ordered two extra months of inventory so they could burn in new NC’s and weed out the bad actors, and correct defects before taking systems to their assembly floors to be connected to machine tools….

As the mid-seventies approached and microprocessor technology permeated business thinking, we moved toward a new softwired control, the…1050. I say moved, though stumbled might be a better verb… By 1976 we had lobbed a few premature 1050s into the marketplace, though stillborn might be a better word than premature, because our dead-on-arrival rate then exceeded 100% - with many units arriving with more than one mortal defect.179

179 Robert W. Breihan, “How Not to Succeed in Business,” General Management Conference, 5 January 1984, in Thomas, History of Numerical Control, 229-33. Breihan was Manager of Marketing for Numerical Control at GE’s Industrial Control Department, Charlottesville, VA.
During the late 1970s, a boom time for marketing machinery, GE NC/CNC devices were fast sellers. Unfortunately, the units shipped were “riddled with software and design bugs. Our $20,000 numerical controls were bringing $250,000 machine tools to a halt throughout industrial America.” Were it not for “dedicated” field service engineers, who struggled to right the cascading errors, “a lynch mob might have gathered at our front gates.”\(^{180}\) The result: GE squandered its reputation for innovation and reliability, just as Fanuc, Futjitsu’s controls subsidiary, put out a series of NC units, jointly designed with Siemens.

Breihan explained that a double-edge specific conjuncture forced GE controls nearly to the wall. US machine tool firms had built a sizable orders backlog in the late 1970s, which slowed deliveries and annoyed clients. As this “market vacuum developed,” Japanese firms flowed in, shipping “a flood of machine tools” to the US, “most of them equipped with Fanuc controls, and damned good controls they were.” Second, a major recession struck in 1980, “multiplying our woes.” GE sales crashed, but to save the divisions, “we went out and began to fix the hardware and software problems we should have solved long before we sold those 1050s.” What had started as a $9 million program cost $35 million, but GE did build its next controls series to much higher standards. Nonetheless, within two years of Breihan’s “confession,” GE threw in the towel and concluded a joint development pact with Fanuc. Unquestionably the Japanese controls firm was the senior partner, not least because its software had become the national standard at home, reliable, non-buggy, and conservatively upgraded. “On June 19, 1987, a GE Fanuc bulletin announced that they would no longer accept orders for Mark Century and other

\(^{180}\) Ibid., 230.
[GE] products, including all servo drives. All future CNC products of the venture would be of Fanuc origin."181 Whatever first-mover advantage the US had enjoyed in NC dissipated during its awkward and ineffective transition to CNC.182 That in addition, US developers had created a variety of firm-specific NC and CNC hardware/software packages generated yet more backflash, as any tools fitted with Fanuc controls could be managed within a single operating and maintenance system. Hence, individuality for G&L, P&W, or CMM, once a market advantage, shifted to being a system deficiency, with unpleasant consequences.183 Whether the chaotic state of US NC/CNC reliability was a core breakpoint in the longer term faltering of American machine tool prowess will take more research to establish (or dismiss); but the late Seventies and early Eighties did prove to be the transition period from experimenting with, to functionality for, CNC, and US firms did not come up to the mark.

The acquisition, stripping, spin-off, and collapse of US machine tool enterprises did create unexpected openings for innovative entrepreneurship, however. Sundstrand Corporation, a diversified machinery builder in Rockford, IL, determined to unload its machine tool division in the late 1970s (along with its compressor and fuel oil pump businesses), so as to focus on defense-related aeronautical manufacturing. Two Sundstrand employees soon formed an eponymous company, Bourn and Koch, then purchased the Barber-Coleman company, also a Rockford tool enterprise (1978), and commenced manufacturing “precision tools” on its site. As the slaughter of the Eighties proceeded, B&K purchased “the assets and logos” from no-longer-viable tool firms, finding a special

181 Ibid., 340.

182 Ibid., 231-32, and 54.

183 Where’s the stuff? It’s out here someplace…
niche thereby. As old tools never die (unless scrapped and melted), providing replacement parts and reconditioning services for their owners/users represents a crucial service. Bourn and Koch undertook remanufacturing for a wide variety of used tools: gear-related machines, lathes and millers, machining centers, grinders, vertical turret lathes, and more. Another group of Sundstrand exiles formed DeVlieg-Bullard in 1990, with the same mission, to provide rebuilding and parts for machinery from other discontinued lines: “American Tool Works, Blanchard (formerly Cone-Blanchard), Bullard, DeVlieg, Motch, National Acme, Sundstrand, and Universal,” plus in time, New Britain, Omnimill, and Mattison. Eight years later, DeVlieg-Bullard had to file for Chapter 11 bankruptcy; a cash infusion from investors dribbled away and liquidation beckoned. Bourn & Koch purchased the remaining assets, chiefly the rights to make parts and refit machines from these long-running, now-deceased tool companies, adding their lines to its expanding scope. By 2004, B&K also reeled in Fellows Shaper and Jones & Lamson, once-classic machine builders from Vermont’s Precision Valley. The firm is presently developing new tool lines (gear shapers and trunion machines) and will be exhibiting at the China Machine Tool Show, Beijing, April 2009.  

Three major tool firms also emerged from the wreckage of the Eighties, one veteran and two new contenders. Mentioned above, they are Hardinge, Haas Automation and Fadal; we’ll take a closer look at the first two of these contemporary US successes.

184 http://www.fundinguniverse.com/company-histories/Sundstrand-Corporation-Company-History.html (accessed 4 February 2009); Thomas, History of Numerical Control, 337-38; http://www.bourn-koch.com/pages/content/about_us.html (accessed 4 February 2009); http://www.allbusiness.com/primary-metal-manufacturing/foundries/388383-1.html (on Devlieg-Bullard, accessed 4 February 2009). B&K currently states that it holds “an inventory of 600,000 plus parts in our Rockford, IL facility. Parts are stocked and categorized by usage and customer to provide immediate delivery upon request. Each of these parts is manufactured from the original engineering design specifications. As the OEM, we own the original OEM machine specifications, engineering and drawings for the machine tool brands referenced above.” OEM means “original equipment manufacturer.”
Founded in the 1890s, Franklin Hardinge’s Chicago firm started making optical and watch repair and optical tools, then bought a small lathe company just after the turn of the century, added milling machines by 1909, and oil furnace burners in 1920. In the first years of the Great Depression, a New York City firm bought out Hardinge’s machine tool segment and moved operations to Elmira, New York. The new owners acquired another machine builder, added a UK branch in 1939, and prospered through the next three decades’ up and down cycles. In the Seventies, Hardinge introduced CNC lathes and “machining centers, but struggled through the Eighties, as “foreign machine tool manufacturers accounted for more than 66 percent of the US market for horizontal CNC lathes” by 1986. By 1992, more than half the 865 “metal cutting machine tool companies” active ten years earlier had closed. Despite short term Voluntary Restraint Agreements reducing imports (1987-1993), at their expiration non-US builders rapidly covered two-thirds of the market again. Hardinge responded by introducing 21 new machine models, 1993-99, including vertical lathes and machining centers, plus CNC grinders (through acquiring a Swiss specialist) and electrodischarge machines (likewise, but a failure), adding a Shanghai assembly plant for sales in Asia, and thus tripling annual sales ($85 million in 1992, $246 million in 1999) as CNC machining centers became hot properties in machinery markets.185

The new requirement for survival, however, was not just innovation or overseas factories, but rapid turnaround of orders, and global marketing. Rather than building backlogs to work off, Hardinge now manufactures most machines with five days, and

radically reduced its reliance on U.S. sales. In the late 1980s, over 80 percent of production found American buyers; two decades later that proportion was halved, with another 40 percent shipped to Europe and the last 20 percent sold in China and other markets. By 2005, Hardinge had introduced a new ultra-low temperature cutting system (Icefly) which sprayed “a jet of liquid nitrogen cooled to –320 deg F on the insert, increasing tool life up to 250 percent without leaving residue on parts or on the machine.” It also achieved one dimension of the automatic factory, its Super-Precision CNC lathe, which had an “integrated GE Fanuc 200 robot [which] allows unattended machine operation…” Even so, Hardinge remains a small business by global standards, with about 1500 employees and a February 2009 market cap of just $50 million, down three quarters from its 2008 peak. In a sense it represents the aeronautical line of descent, as its principal markets range from defense/aerospace to medical device manufacturing, with some connections to automotive.

Haas Automation is quite another story. Founded in 1983, it is privately-held and works at the standardized, low-cost, high-volume end of the metalworking machinery market. Like Hardinge, Haas has about 1500 workers, a global presence, and annual sales something shy of a billion dollars. Its flamboyant founder, Gene Haas, who sponsors two Chevrolets on the NASCAR circuit, presently inhabits a half-way house after serving a year in federal prison for tax fraud. Nothing like this has ever happened to Elmira managers.¹⁸⁶ Haas made its mark, not through innovative high-precision work, but by simplification: “adherence to standard products – no specials.” Its lines of vertical and

¹⁸⁶ [http://www.venturacountystar.com/news/2007/nov/06/haas-automation-owner-gets-2-years-in-prison-for/](http://www.venturacountystar.com/news/2007/nov/06/haas-automation-owner-gets-2-years-in-prison-for/) (accessed 6 February 2009); [http://www.tmcnet.com/submit/2009/01/01/3885582.htm](http://www.tmcnet.com/submit/2009/01/01/3885582.htm) (accessed 6 February 2009). The tax fraud evidently was the owner’s tactic for recovering from the government about $10 million he had been forced to pay to another firm for patent infringements, following litigation. After his November 2007 conviction for filing $50 million in false invoices, Haas was compelled to pay $75 million in restitution and fines. Company managers have since “distanced” themselves from his actions and noted that he had not been active in direct management for most of the last decade.
horizontal machining centers, however, feature “modular construction and a high number of common parts” (a technical grandson of Ford’s building blocks), enabling the firm “to offer machines in many models and sizes of both machining centers and lathes while still maintaining economies of scale.”\textsuperscript{187} In 1988, it introduced a CNC milling machine at the IMTS, priced near $50,000; in the succeeding 20 years it sold 85,000 CNC machines and 50,000 lathes, certainly more than any other US builder. Haas early on used its modular strategy to run “unattended” automatic load and unload machines two shifts a day on long runs of standard parts, using humans during the day shift for special jobs and short runs. In consequence its output and sales roughly trebled Hardinge’s production, an automotive-lineage tooling strategy based on Haas’s recognition that “the products that we build are competitive on a performance per dollar basis [whereas] state-of-the-art designs are rarely price competitive.”\textsuperscript{188} Haas avoided seeking the cutting edge, where uncertainties lay.

After this long trek across several generations of machine tool development, it’s time to return to the show, now the IMTS, so as to gauge the reconfigurations which have taken shape over the quarter century since the early 1980s US industry crash. In 1980, the Chicago show, attended by 107,000 visitors, featured 1143 exhibiting firms from 32 nations, occupying 800,000 square feet in the city’s lakeside McCormick Place and spilling over into exhibit areas of the nearby Hilton Hotel. A year later, a global survey determined the top fifteen machine tool builders: eleven were US companies, including the conglomerators who had merged older firms. Fifteen years later another list surfaced, two


US firms remained in the top fifteen, Giddings and Lewis and a conglomerate, Western Atlas. A recent (2006) count showed just one producer: Haas, along with turnaround artists Maxcor, which repackages enterprises. (See Appendix 4 for the three lists and each firm’s sales.) Japan’s Yamazaki Mazak, seventh on the 1981 list, has been the world’s Number One for at least a decade, racking up nearly $2 billion in 2006 sales. Okuma, also a Japanese firm, is also on all three lists, rising from ninth in ’81 to fifth in each of the latter rankings, sales rising above 1.3 billion in 2006. None of 1981’s diversified US conglomerates remains, Bendix is gone, and the rest appear, if at all, as units within leading firms.\textsuperscript{189} Japan had six corporations on each of the later rosters, though its 1-2-3 ranking in 1996 did not persist. Rather, Trumpf and Gildemeister passed Amada and Fanuc in 2006, the latter running ten European plants and having opened a huge one in Shanghai as well (2002). The huge dollar values of 2006 sales (eight firms over $1 billion and three more close to it) indicates that the global market for machine tools has hardly floundered, though these values are in nominal, not real dollars. As 2006 dollars had about half the purchasing power of 1981 dollars, the leading firms have more than compensated for inflation, especially when one compares positions 3 through 13, 1981 and 2006.\textsuperscript{190}

In 1992, the MBTBA, which owned the Chicago Shows, completed a two phase re-labeling transition, becoming the Association for Manufacturing Technologies, having renamed the Show in 1990. Eight years later, 280 non-US firms exhibited at the IMTS, from 24 countries, led by Germany (55), Taiwan (42), Canada (38), and Italy (32).

`Recently, the IMTS expanded to 1300 exhibitors from 40 countries, but ever fewer US

\textsuperscript{189} Western Atlas was an conglomerate based on oil-field drilling equipment; it acquired Landis Tool and was itself taken over by Baker Hughes, another conglomerate in 1998.

\textsuperscript{190} Using the CPI, $100 in 1981 was worth $221 in 2006.

enterprises. In controls, for example, at the 2006 show, Fanuc devices ran 523 of the 949 active CNC machines on display; under a quarter of these were GE Fanuc. Siemens had a hundred and Haas 58, numbers tailing off after that. Visitors could observe the latest trends: ultra-high-speed machining (15-21,000 rpm spindle speeds), high-volume modular manufacturing systems (flexible alternatives to the transfer line), “lights-out manufac

191 Yet for all the festivities, IMTS was no longer THE place to be; other exhibition options abounded – Eastech, Westech, Hannover, Shanghai, several just as huge as the Chicago operation, or nearly so.192 The center had not held; global networks now substituted for American dominion in the “machines that make machines.”

Nor was there any longer meaningful content to the concept, machine tool industry. The US association had twice stretched its boundaries in the postwar to recognize emergent processes, tool categories, and enterprises, but contemporary tools are on one hand diversely electronic and on another elaborately convergent (machining centers and cells that mill, bore, grind, and polish/hone), even as the magnets for automation and precision/flexibility remained powerful, not in Detroit and Southern California, but worldwide. Perhaps it’s worthwhile thinking about “industry studies” as being one of Ulrich Beck’s “zombie categories,” terms that are dead, but still walking, eclipsed by the passage of time and the persistent reconfigurations of capital and technology. Finding another


conceptual container for this work, which has become more about materials processing than metalworking, and its multiplying arrays of devices,¹⁹³ would be an intriguing task.

One way of commencing this reconceptualization might be to ask whether “production history” could be organized around processing as a ubiquitous dimension of industrial practice, and processing technologies links to classes of inputs. Processing stands midway between other central actions in cycles of production: extraction, movement (to, through, and after processing), packaging/storage, use (consumption or operation), repair, and disposal/recycling. Just as there are technologies associated with all central actions (pumps/pipelines, trucks, and railroads for movement, for example), so too are their varieties of processing technologies which could be investigated without being limited to “industries” or the dreaded US Standard Industrial Code system.¹⁹⁴ Thus we might consider subclasses of processing technologies as first, those associated with processing materials from agriculture/fisheries and from forestry/mining, as baseline feeders, then second, as associated with transforming materials in process – liquids and gases, bulk solids (metals, glass, clays), refined solids (bar stock for milling, lumber, plywood, plastics for extrusion, molding, etc.) and third, associated with processing information - oral, visual, imprinted, or electronically conserved. Even if this trial balloon pops on cursory review, the notion of


¹⁹⁴ Reliance on SIC classes, in which computer and information technologies were scattered at the four digit level obscured the advances in (and some argue the productivity contributions of) these sectors for several decades until the measures were reconstructed. (See Chris Thompson, “Some Problems with R&D/SE&I-based definitions of high-technology industry,” Area 20(1988): 265-77.
devising more supple containers for research on technological transformations seems appealing and perhaps timely.

Conclusion

In August 1998, looking back at postwar machine tool history, American Machinist judged that:

the two distinguishing characteristics of the last 60 years that have been most responsible for shaping the industry have been the globalization of marketing and the emergence of microelectronics. Most successful manufacturers have had to carve a marketing niche for themselves in the context of a sophisticated, worldwide marketplace… By the late 1960s, a "one world, one market" philosophy was becoming more common. Many companies, in an effort to "fish where the fish are biting," established international operations to serve local users. In an effort to expand product and technology offerings, manufacturers frequently entered into strategic partnerships which might include marketing agreements, equity investments, joint ventures, acquisitions, and technology exchanges.195

This retrospective discussion did not focus on the US machine tool sector, but rather on global processes of innovation and reconfiguration. Nor did it note that when the “one world, one market” approach arose, few US firms internationalized. To be sure, at the end of the 20th century, automotive and aerospace imperatives still pushed tool builders to exceed current technical limits, but now these pressures were networked and omnidirectional, not flowing outward from Detroit and the Pentagon. Materials continued to evolve and the repertory of techniques, firms, and institutional influences continued to cycle.196


196 As a sign of American eclipse, many of the trade and technical journals I relied on for the period from the 30s through the 60s are gone (Magazine of Wall Street, Materials in Design Engineering, Factory Management and Maintenance, among others). American Machinist is now a monthly, not a weekly and Tool Engineering has been renamed Manufacturing Engineering.
Viewed from a national perspective, the decay of the US industry is clearly a tragedy; Joe Michaels has captured a sensibility pervasive among veterans in the trade:

The US Machine Tool Industry was an old-time heavy slugger going up against an endless tag team of new style fighters who came into the ring from all sides and never stopped jabbing and dancing. The jabs… were countless and came in from all angles… Despite this the US Machine Tool Industry never took a single shot KO that knocked it off its feet or through the ropes. It took a few years on the ropes… before it slid to the canvas in the last year or so. Like [the industry,] the US-made machine tools were truly heavyweight sluggers – built to go the distance and then some. The new generation of [professional] boxers are mostly imports who are fairly lightweight and rely on rapid light punching… I don’t know if the new fighters could go the distance the old sluggers did. So it is with the new generation of imported machine tools – lightweights that can’t stand flatfooted and slug it out or go the distance the old US-made machine tools continue to go.197

Michaels’ metaphors do double duty here, conceptualizing international competitors as brisk and relentless, buzzing round the dazed heads of tough, but old, less agile US firms. Secondly, imported machines are here similarly positioned as lightweight and non-durable, unlike their tough, heavyweight US predecessors. Both points are well taken, it seems to me, as is his observation that the trade experienced a second crash around the turn of the century, falling to seventh place globally by 2006. With few exceptions (e.g., CMM), US machine tool enterprises failed the tests of rapid technological change – they were slow to adapt to flows of challenges and of innovations, at least slower than not just Japanese, but German, and later Chinese and Korean firms. Moreover, they also stood by when global markets soared. As Stan Modic put it recently:

There are many reasons why the U.S. industry slipped in its world ranking; a major one was that the industry, to a large extent, missed the globalization boat that really started in the 1970s. At the time, the builders were fat and profitable, serving the giant U.S. market. Why bother with the harder-to-sell foreign markets? It’s not that they didn't have adequate warning. I recall Jim Grey, executive director of the National Machine Tool Builders' Association ...used every opportunity to convince his members to explore foreign markets. To his frustration, most ignored his

warning even as competitively priced imports started to gain acceptance in the lucrative U.S. market.¹⁹⁸

Adaptation to change provides insights into actors’ culture(s). US machine tool builders had long anchored their industrial culture in traditions of husbanding orders and backlogs, orienting innovations to the Shows’ five-year cycles, courting close relations with clients (in consequence, doing a fair measure of custom work), holding cash reserves for the inevitable down-cycles, and conserving their self-images as world-beaters (in consequence, lacking interest in exhibiting at foreign tool shows or in creating international marketing arms, or overseas production facilities). The Tool Show’s shift from five year to two year intervals (1972) evidenced the NMBTA’s recognition that the leisurely pace of tool development had accelerated and diversified – the year non-US exhibits arrived on site, as well. Yet these changes came midway in a long series of machine tool sell-offs, cash-outs, and mergers, as owners, partners, and heirs no longer sought to push the technological envelope. This often happens in family businesses, and such moves generally clear the way for new entrepreneurs to pick up technical or market challenges and re-invigorate the trade. The surprise this time was that on one side, acquiring teams sought revenue streams not innovations, and that, on another, the new competitors came from California (Haas, Fadal) and from overseas, with the external cohorts far more assertive than most locals. Japanese tool innovators created lightweight, non-durable, and hence, cheaper tools, in part because they recognized that the rapidly shifting technological contexts (not just in electronics) entailed that, as one commentator noted, “Even a ten year old machine is pretty much in the dark ages.”¹⁹⁹ Many US builders kept fabricating heavyweights, adding NC or dial-up feeds, but not revisiting their core design assumptions


¹⁹⁹ “HMC Reduces Precision Machining Time,” 124.
in a fashion that acknowledged the relationship between accelerated innovation and reduced tool life, hence vacating the need for 40-year-use principles.

One way to conceptualize this relative stasis may come from Gramsci via David Harvey. In assessing “uneven geographical development,” a key element in globalization, Harvey noted recently that Gramsci distinguished between “common sense” and “good sense.” The first is a “conception of the world… uncritically absorbed by the various social and cultural environments in which the moral individuality of the average man is developed.” “Common sense” may enclose the conservative, confident culture of US machine tool makers, which as Gramsci noted “holds together a specific social group.” Yet such a perspective not unusually comes into conflict with “good sense”: the consciousness “which is implicit in [an actor’s] activity and which in reality unites him with his fellow workers in the practical transformation of the real world.” In machine tools, I’d suggest, the latter worked to facilitate embracing novelty, managing creative but routinized redesigns, integrating new features into conventional base machines, while observing gradually-building threats from the triple substitutions: materials, processes, and new firms.

Tension between the two “senses” can engender a certain “passivity” which undermines critical thinking about both unacknowledged assumptions (theoretically) and long term challenges, trajectories, and complexities (empirically).200 It is this fracture that reflective posts on Practical Machinist.com underscore.

Yet viewed globally, the US machine tool industry’s erosion hardly merits more than passing notice. West German output passed US tool production in 1971 and led the global rankings throughout the Seventies. US tool builders again reached the top rung in

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1980, peaking at $6 billion, holding a quarter of the world market (est. $23B), ceding leadership to Japan by 1983. In 1995 and 2000, US builders generated less than $5 billion (third place), as world sales reached $37 billion in both years. Yet by 2007, global tool production had nearly doubled (to $70B), with the US contributing $3.6B, just over 5 percent, a striking loss of market share in a secularly-expanding market. As the mid-20th century high era and the later descent of US machine tool building unfolded amid global technological, economic, and political processes, thinking about how this saga interacts with ways of conceptualizing globalization may be useful. Leading theorists have devoted considerable energy to delineating and critiquing globalization (Giddens, Castells, Bauman, Jameson, Held, and others). This conference’s project is seeking, as well, to build a “Global History of Production.” So how best can we connect elements within this ubiquitous, contentious concept to the mutations of our US machine tool narrative (or vice versa – I’m currently agnostic about the direction of flow)?

Manfred Steger’s chapbook in the Oxford “Very Short Introduction” series provides a venue to attempt a link-up. Steger, having outlined key propositions in recent arguments, argues that “new forms of technology are one of the hallmarks of contemporary globalization. Indeed technological progress of the magnitude we have seen in the last three decades is a good indicator for the occurrence of profound social transformations.” Yet he, like most commentators on this process, considers consumption, finance, politics and culture far more richly than production, much less the machinery for production. In this relative neglect lies an opportunity.

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If we think about Steger’s notion that “At its core globalization is about shifting forms of human contact,”\textsuperscript{203} the machine tool case immediately comes alive. In depression and war, US tool makers saw foreigner builders and tool users as enemies or distant customers, then after 1945, as possible clients, visitors to exhibitions who looked and scribbled more than they purchased. In time these foreigners, some of whom as visitors had been taking engineering notes for possible use in domestic manufacturing, surfaced as arms-length competitors (in the Coliseum), then as serious rivals on the Show’s site, starting in 1972. From being fringe exhibitors, however, they quickly shifted to being central, even dominant presences at the Shows, now that the American Century had gone bust.

From a different angle, forms of human contact also changed on the international side. Post-war US firms started by filling welcome overseas orders fueled in part by Marshall Plan funds, but generally disdained exhibiting abroad in the Fifties, establishing external sales units, etc. By the 1980s, as AM described (above), with America’s tool industry crumbling, surviving and new firms commenced scrambling for cross-national licensing, joint ventures and the like, only to find that this was being done all round, among German, Japanese, Italian, and later Chinese and Korean tool builders, linking among themselves and taking lead roles in establishing contracts for sales and production outposts in the US. The reconfiguration of production from a nation-based to a network-based dynamic evidently built dramatic synergies that doubled global tool sales, 2000-07 (They are certain to collapse in the current crisis, which will demonstrate whether keeping reserves for bad times has persisted, perhaps learning from the conglomeration period.).

\textsuperscript{203} Steger, Globalization, 8.
Insofar as globalization involves “movement toward greater interdependence and integration,” or “the creation of new and multiplication of existing social networks,” materials processing technology makers exemplify these elements world-wide. As globalization also features “expansion and stretching of social relations,” or “intensification and acceleration of social exchanges,” yes, again. The multiplication of expositions, the extension of both production and sales units to distant places (serving regional users), growing numbers of global associations for standards, data-gathering, and information sharing, a vast array of publications in many languages (print and on-line) and the rich variety of internet contact sites, all testify that globalization has positive vectors, a swelling flow of innovations, information, testing and assessment, - enriching the trade considered as a whole. Practical Machinist.com, with over a million posts and tens of thousands of threads since 2002, captures the value-adding network effects that opening up worldwide discourse generates (yes, English only on this site, but there are dozens of others, some with non-English forums). 204

David Held has provided an inclusive and helpful definition of a process too often captured ideologically by neoliberal promoters:

Globalization may be thought of as a process (or set of processes) which embodies a transformation in the spatial organization of relations and transactions – assessed in terms of their extensity, intensity, velocity and impact – generating transcontinental and interregional flows and networks of activity, interaction, and the exercise of power.205

Bringing the exercise of power into view reminds us that globalization is an “uneven process.” So how do we engage the asymmetries that emerge from its deployment? Harvey has noted that there’s “nothing new about uneven geographical development within

204 Ibid., 9-12.
205 Held, quoted in ibid., 10.
capitalism.” Capitalism is about producing inequalities, not resolving them; so perhaps we could begin by thinking about how to conceptualize various strata of unevenness, at least as these related to machine building, spatially, culturally, politically, and economically, over the last six decades. The largest framework for asymmetries would surely be American hegemony in the quarter century after World War Two, cemented economically by the Bretton Woods agreements and the institutions which ensued. This dominion broke initially with Nixon’s default on the gold standard in the early 1970s and fully with neo-liberals triumphant maneuvering following Reagan’s 1980 election. Unevenness also was created and reconfigured at other levels across these years: for one, access to new tools, new materials and technologies, and cutting edge information (shaped by national security, international relations, and currency and credit concerns, or by local rules and resources, etc.) and for another, entrepreneurial initiatives (encouraged or constrained by government support, science, technology and vocational training, industrial cultures, or capital markets). Sorting out these patterns stands as a research task worth undertaking, as is feeding back empirical findings into re-conceptualizing technical and market development processes.

At least one thing is clear about machine tools and globalization: there was no race to the bottom, as seems to have happened in a number of consumer goods sectors.\textsuperscript{206} Rather, as tools have to perform superbly under demanding conditions, demands that have escalated each decade, we find instead, if not a race to the top, at least a struggle for tool quality and efficacy in highly differentiated situations, generating material, technical, 

\textsuperscript{206} Some firms and machinists claimed “cheap tools” from low wage countries were ruining US firms, but such sentiments failed to recognize that high-quality tools from Germany and Japan, built to be succeeded by more advanced models, and hence less expensive than heavy, durable US tools, shifted the game. Machine tools are not T-shirts or toasters; the geography of their transnationalization is directly connected to their contexts of use and expectations for performance.
spatial, enterprise, and user reconfigurations that continue. As yet, in my view, we know far too little about differing dynamics across processing contexts (from tools to trousers), creating room for detailed and determined, comparative, historical research in production and technological deployments. That work lies ahead.

[Appendices 1 – 4 on following pages.]
Appendix I: Machining to Millionths

The text that follows is taken from an August 2007 online discussion at the “Practical Machinist” website, which is rich with comments and advice shared among machinists (at least some of which are shopmen in engineering schools), business owners, and retirees. For those having some familiarity with tool operations, it’s a treat to visit. Here is what seems to me to be a key post, with both empirical and theoretical notes on “machining to millionths.” Note that “toastydeath” interchanges “precision” and “accuracy” in ways that seem to me to be fairly common in the trade.

toastydeath 08-02-2007, 10:13 AM
[Quoting an inquiry] Guys...thanks for your replies...I’m learning more as I use this site. But I still ask...if we can machine to a millionth of an inch for NASA...why must we hand scrape a way? Is it a matter of practical cost?? If one were to program a CNC machine, like the Bridgeport Company for example, wouldn't the resulting product not need hand fitting? I don't understand why with this state of the art tech.....a way still has to be hand fitted.

[Here’s toastydeath’s try at answering this question; all emphases added.]
First, you have to understand that there is no machine process that is as geometrically accurate over a long distance as either hand scraping or hand lapping, because both involve local correction of errors as they develop, which requires considerable logic and forethought to correct on a case-by-case basis. The automated process cannot do this. Gages of all kinds are lapped both manual machines and by hand, because no machine can figure out what needs to be done next to bring the gage in.

Where does the precision way grinder and the diamond turning machine obtain precision from? Most people do not understand that, when they're talking about a "precision" machine process, that the precision has to originate from a set of surfaces somewhere that does not exist yet and must be created for that machine. The machine is not made to tolerance, it is made by a process called "to fit." That is, the parts are matched together, without any particular requirement for dimensional accuracy. They are only geometrically constrained, with the workers allowed to do literally whatever is necessary to give the machine that geometric accuracy. This gives you a good way grinder that can produce ready-to use machine ways for more inexpensive machines. Production way machine, ready to use, but the machines it produces will not be as accurate or be anywhere near as long-lived as the way grinder itself is.

Most machines accurate [to] millionths and under are absolutely full of hand-work. After the general way form is established by high precision grinders, the gentlemen of precision scrape the ways, lap the ways, and whatever else is necessary in order to give the greatest advantage possible to the error correction and compensation systems that will be installed on top of that surface.

The natural question that arises here is usually "well, after you make one, why don't you simply re-create the machine components on the precision machines?" It turns out to be a very simple set of reasons: One, most of these machines are not able to work the superalloys used in critical machine components even in machines made of granite and
ceramics; Two, these machines produce a lot of scrap anytime you try to work with them - rather than a static machine error correction, they involve dynamic "correction tapes" for error correction that must be continually altered for the part being machined to bring it to the limit of accuracy, and this can scrap two or three parts per good part; Three, these machines take LONGER to produce a part than hand scraping and lapping does. Now, a caveat. The people who do hand scraping and hand lapping are, for the most part, unaware of or inexperienced in the use of the ultra-precision tools and devices necessary to make a machine way accurate to a verified few millionths of an inch, over a considerable travel for that accuracy. The theory is also lacking. Theoretical and practical knowledge in controlling temperature and other sources of error become paramount for the person actually doing the work.


Appendix 2 : Metals and Alloys chart: The “Flow” Under Controlled Materials Plan”
[17(January 1943): 6]
Appendix 1: World War Two’s Largest US Machine Tool Firms (1942)

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Location</th>
<th>Year started</th>
<th>Employees Dec 42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cincinnati Milling Machine Co.</td>
<td>Cincinnati, OH</td>
<td>1880</td>
<td>6902</td>
</tr>
<tr>
<td>Brown and Sharpe Co.</td>
<td>Providence, RI</td>
<td>1868</td>
<td>6193</td>
</tr>
<tr>
<td>Bullard Co.</td>
<td>Bridgeport, CT</td>
<td>1880</td>
<td>5538</td>
</tr>
<tr>
<td>Warner and Swasey Co.</td>
<td>Cleveland, OH</td>
<td>1880</td>
<td>5027</td>
</tr>
<tr>
<td>National Acme Co.</td>
<td>Cleveland, OH</td>
<td>1895</td>
<td>4166</td>
</tr>
<tr>
<td>Kearney and Trecker Co.</td>
<td>Milwaukee, WI</td>
<td>1898</td>
<td>4105</td>
</tr>
<tr>
<td>Van Norman Machine Tool Co.</td>
<td>Springfield, MA</td>
<td>1888</td>
<td>2779</td>
</tr>
<tr>
<td>Gisholt Machine Co.</td>
<td>Madison, WI</td>
<td>1889</td>
<td>2690</td>
</tr>
<tr>
<td>Monarch Machine Tool Co.</td>
<td>Sidney, OH</td>
<td>1909</td>
<td>2491</td>
</tr>
<tr>
<td>Heald Machine Co.</td>
<td>Worcester, MA</td>
<td>1890</td>
<td>2311</td>
</tr>
<tr>
<td>Norton Co.</td>
<td>Worcester, MA</td>
<td>1885</td>
<td>2291</td>
</tr>
<tr>
<td>Gleason Works</td>
<td>Rochester, NY</td>
<td>1865</td>
<td>2128</td>
</tr>
<tr>
<td>New Britain Machine Co.</td>
<td>New Britain, CT</td>
<td>1895</td>
<td>1955</td>
</tr>
<tr>
<td>Pratt and Whitney Co. (tools only)</td>
<td>Hartford, CT</td>
<td>1869</td>
<td>1914</td>
</tr>
<tr>
<td>Jones &amp; Lamson Machine Co.</td>
<td>Springfield, VT</td>
<td>1898</td>
<td>1775</td>
</tr>
<tr>
<td>Cone Automatic Machine Co.</td>
<td>Windsor, VT</td>
<td>1916</td>
<td>1774</td>
</tr>
<tr>
<td>Fellows Gear Shaper Co.</td>
<td>Springfield, VT</td>
<td>1898</td>
<td>1755</td>
</tr>
<tr>
<td>Hendy Machine Co.</td>
<td>Torrington, CT</td>
<td>1870</td>
<td>1504</td>
</tr>
<tr>
<td>Ex-Cell-O Corp.</td>
<td>Detroit, MI</td>
<td>1919</td>
<td>1464</td>
</tr>
<tr>
<td>General Machinery Corp.</td>
<td>Hamilton, OH</td>
<td>1871</td>
<td>1416</td>
</tr>
<tr>
<td>American Tool Works Co.</td>
<td>Cincinnati OH</td>
<td>1898</td>
<td>1391</td>
</tr>
<tr>
<td>Landis Tool Co.</td>
<td>Waynesboro, PA</td>
<td>1889</td>
<td>1258</td>
</tr>
<tr>
<td>Bryant Chucking Grinder Co.</td>
<td>Springfield, VT</td>
<td>1903</td>
<td>1119</td>
</tr>
<tr>
<td>Lodge and Shipley Machine Tool</td>
<td>Cincinnati OH</td>
<td>1892</td>
<td>1069</td>
</tr>
<tr>
<td>Landis Machine Co.</td>
<td>Waynesboro, PA</td>
<td>1903</td>
<td>1017</td>
</tr>
</tbody>
</table>

Appendix 4 --

Top Fifteen Machine Tool Firms Worldwide: (sales in millions, US dollars)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1. Milacron (646)</td>
<td>Yamazaki Mazak [J] (1188)</td>
<td>Yamazaki Mazak [J] (1818)</td>
</tr>
<tr>
<td>7. Yamazaki Mazak (313)</td>
<td>Giddings &amp; Lewis (700)</td>
<td>Jtekt [J] (1240)</td>
</tr>
</tbody>
</table>

J – Japan, C – China, Sw – Switzerland, G – Germany, I–Italy, K – Korea

* - majority of sales from controls (info for 96 only).