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Influencing Engineering Education: One (Aerospace) Industry Perspective*

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The purpose of this paper is to discuss some of the steps that we within the broader technical community (industry, government and academe) can and should take to assure an adequate future supply of well-prepared engineering graduates for the full range of employers who have need for such talent. While presented from an aerospace industry perspective, and thus from that of a 'mature industry' (at least in some major traditional product areas), it is believed that the issues to be addressed have far wider relevance, because the evolution of engineering (and specifically design) practice in the 'airplane business' provides a lens for discerning future trends and requirements for both university and post-employment engineering education programs. Although much has been accomplished in the past decade to enhance engineering education, we, as both educators and practitioners, have much to do to cooperatively create a strong and vivid vision of our future and assure the proper development of a future generation of engineers with the skills and motivation to meet society's needs in our always evolving and ever-volatile enterprise.

INTRODUCTION: A PERSPECTIVE FROM THE PAST

THE PRESENT PAPER is based in part on a series [1–4] begun in 2000 under the general rubric, 'The Demise of Aerospace—We Doubt It.' The series was initiated to counter some of the excesses of a continuing spate of national studies and articles in both the popular and professional presses [e.g. 4–6] that decried the seriously declining state and future of aeronautics (and aerospace in general) in this country, while providing long lists of causes for the putative decline in aeronautics.

Whatever list is constructed, two fundamental underlying factors have been, and remain, causes for serious concern. The first is the fact that we in the aeronautics community (industry, government and academe) have been unable to create a collective vision of our future as compelling and exciting as the one that has driven the past century of our history. The second factor, reciprocal to the first, is the need to aggressively replenish the seriously aging pool of technical talent needed to maintain an industry that still continues to find a multi-billion-dollar annual market for its products and services, and that is fundamentally important in maintaining our security and enabling the further development of our global economy.

An important point to be noted at the outset of this exposition is that, while the focus is ostensibly on 'aerospace' engineering, a company like Boeing, in common with most others in our industry, employs many more electrical, mechanical, manufacturing and computer-related engineering graduates than it does those with explicit *aerospace* engineering degrees. In this sense, the subsequent text relates to our company (and industry) interests in engineering education enhancement and reform in a broad sense.

As pointed out earlier [1–4], the development of aeronautics was a symbiotic co-evolution with the vast change that has been part of the whole industrial revolution taking us from a largely agrarian economy in the 19th century to the world we know today. Through two World Wars, the long-running Cold War, and on into today, aviation has been a key element, both driven by and enabling massive changes in the world as we know it—socially, politically, militarily and economically. Much progress has been made in the art and science of human flight and this may be charted conceptually, as shown in Fig. 1, which was originally created over 20 years ago to explain to Boeing management the reasons why the then-new Boeing 757, after the expenditure of very substantial research and development money, carried no more passengers any farther or faster than its predecessor, the circa 1950s Boeing 707. The conceptual diagram thus created still seems as relevant today as it was then, and shows where we now stand in a 'mature' technology.

Three lines can be drawn on this chart of progress versus time. The first is a *theoretical upper bound* established by the basic laws of physics (and economics). These limits are imposed by factors such as the Second Law of Thermodynamics, the fact that generation of lift with a wing of finite span produces (induced) drag even when 'optimally loaded', etc. The second line represents what *could* be accomplished with the extant technology available to us at a given date *if*

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we had a perfect knowledge and understanding of our art (and no significant economic limits on what we were/are allowed to do). It is shown as a sort of stair-step progression based on significant technological breakthroughs that periodically occur.

The third line on the figure is the measure of *actual* progress made over the course of 100 years of dedicated effort (not forgetting that much of the basic groundwork that led to the Wright brothers' success [which initializes the figure as drawn] had been laid by the advances made by the theoreticians and 'failed' experimentation in previous centuries). This progress has been truly dramatic—particularly in the time period from approximately 1920 through the 1960s. However, as the gaps between theoretical limits, possible achievement and actual realization shrink, the opportunities for further gain in *traditional* measures of performance become increasingly difficult (and expensive) to achieve. This is the hallmark of any 'mature technology,' and is exacerbated by the fact that not only are designers getting smarter over time, but their customers, government regulators and the public are all getting more demanding and sophisticated as well.

In the face of an increasingly lawyer-rich environment, with unending demands for improved safety, reduced noise, increased fuel efficiency, etc., etc., the designers have to run harder and harder to make increasingly small gains. Indeed, if research and development did not continue at a healthy pace, progress would be stagnant or even retrograde at some point under the weight of these external pressures. With regard to the Boeing 757 vis-à-vis the 707, the 757 turned out to be a significantly better airplane than its predecessor in all regards—except speed, range and passenger count. Indeed, had the team developing the 707 been faced with the same circa 1975 design requirements and objectives that the much larger 757 team had to deal with, and were still limited by the circa 1954 knowledge and technology available to them, it is debatable whether the original 707 could ever have flown—and helped change the world as it did.

While Fig. 1 shows a leveling of at least cruise airplane performance over the past two decades, influenced in part by the basic laws of physics and economics, more interesting for our future will be the increasing importance of environmental considerations, and (since the advent of OPEC and its aftermath) the warning of the vulnerability and finiteness of the world's fossil fuel supply. Such constraints on 'faster, higher, farther' have thwarted efforts to develop *economically viable* transports on into the supersonic range. Only the announcement of the short-lived Boeing effort to develop a 'Sonic Cruiser', coupled with the Airbus decision to plunge ahead with their monster A 380, seemed to open the prospect that aeronautical engineers working in the commercial airplane arena need no longer look forward to so dreary a future as was predicted only a few years earlier as we entered the post-Cold War era of 'quicker (to market), better, cheaper.' Thus the question again becomes: is the most exciting prospect on offer, or our inevitable future, simply the further redesigning of the current line of Boeing and Airbus subsonic transports, albeit with more exotic electronics? Given the importance of commercial air transportation (and the aerospace industry as a whole), however, the whole question of what we may mean regarding the supposed maturation of our art must thus be examined and challenged in more general terms.

SO NOW WHAT?

Stories similar to the Boeing 757 can be told within the conceptual framework of Fig. 1 for other classes of traditional aircraft types, both civil and military, and further ruminations may be found in earlier publications [7–11]. The question that arises from such examination is: where do we go from here in the next 100 (or even 20) years

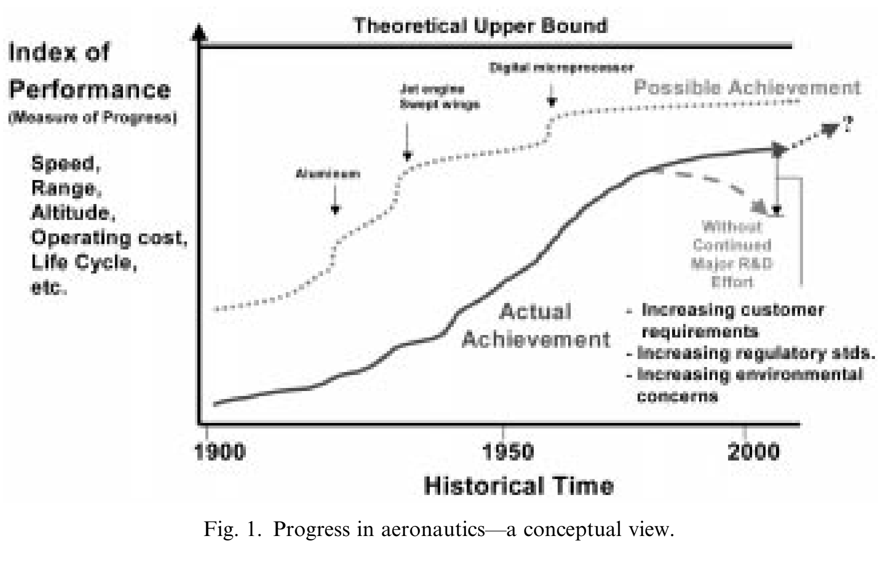

Fig. 1. Progress in aeronautics—a conceptual view.

of an endeavor that has a potential multi-trillion dollar market for its products and services in its first two decades of the 21st century alone? There are at least three possible answers, all of which are likely one way or another, despite (or perhaps because of) the dramatic turn of events on 9/11/01:

- Keep running harder and harder (i.e. doing what we have been doing) for smaller and smaller gains in speed and other traditional performance measures, but with a greatly increased emphasis on safety, security, cost and environmental impact, as long as a market exists for the products thus developed.
- Schedule a breakthrough (e.g. a possible Sonic Cruiser II via large reductions in sonic boom intensity and 'aerospace plane' technology) or an invention (e.g. economically and logistically viable alternatives to fossil fuel propulsion schemes for transport aircraft).
- Start a whole new game—one in which the gap between the possible and the achieved is once again very large, e.g. the whole range of possibilities for uninhabited (combat) air vehicles (UAV/UCAV) which represent a complete fusion of traditional and emergent aerospace vehicle technology with 'information and communications technology.'

Regardless of which path is pursued, there remains much to do in aviation in the coming decades, despite recent events. Many continue to lament the supposed end of 'farther, faster, higher' as the driving force for aeronautical progress, and its replacement with the newer, less exciting call for 'quicker (to market), better, cheaper' [6]. These newer imperatives have been forced on us by a new economic and geopolitical reality, as the competition in all phases of the aviation market has grown increasingly fierce. Such imperatives will not soon disappear, but more likely will simply increase in their complexity.

More recent events have opened new avenues for improving commercial aircraft, at the air transportation system (rather than mere airplane) level, as security becomes a *major* issue to be added to the already existing list of environmental, political, operational and economic pressures to be dealt with. This fact, combined with the advent of new programs such as the A 380 and a need to replace aircraft of 747/757/767 vintage (as but a few of a myriad future possibilities), suggest that a new mantra for further progress may well be: 'faster, higher (farther), cheaper, better, quicker, cleaner, quieter, safer, etc.,' or simply, 'leaner, meaner, greener.' The only constraint is that, while the laws of economics can be bent to some degree, the laws of physics cannot!

PROCESSES AND PEOPLE: THE SOCIAL SIDE OF AEROSPACE

Technological progress is easy to chart for the historian, and to a lesser degree for the prognosticator, via demonstrated performance increases and an assessment of the gap between what has and can be achieved. This can be done based on our current or foreseeable technical and scientific knowledge as constrained by possible political and economic circumstances and developments.

Less easily mapped or predicted is the evolution in the *processes* by which the amazing advances of the past century have been developed, and, more importantly, how these processes will continue to develop in the future. This social aspect and the 'people issues' it contains are of fundamental concern to the future of our enterprise, but are too frequently ignored or treated as a separate, disconnected topic in the aeronautical engineering literature. It continues to be our purpose to treat them here, even if incompletely, as a unity with technology and processes. In reality, technology, processes and people form an inseparable triad in aerospace—in both industry and in academe.

Basic premises

As argued earlier [3, 4], money and people are respectively the blood and soul of any organization that provides goods or services to our society. People, aided (or not) by machines, create, develop and support products and services of value to a customer that can in turn produce a profit and thus provide shareholder value. In this simplistic view, the most important assets of most companies and institutions in our society are their people (their 'intellectual capital') and the cash flow that results from their activities. In this people-centric view of our own industry, it may then be argued that the best technology and processes in the world are useless without the right skilled and motivated people to apply them.

Maintaining and enhancing the excellence of our technical workforce must be a central focus *within the technical community*, in aerospace as in most other industries—now and into our future. As in earlier writings, the author's concern is primarily with the education and motivation of a potential future generation of practitioners, rather than to extol the magnificence of our past for the historical record.

Airplane design today

The large-scale advent and vastly increasing power of the computer and the tools (e.g. CFD—direct analysis and inverse/design, CAD/CAM systems, and multi-disciplinary optimization methods) available to exploit its capabilities, the lessons learned from our friends across the sea (both Asian and European), the end of the Cold War, and the emerging new world economic and political order have combined to cause a transformation in the airplane design process. Terms like 'customer-in,' 'lean manufacturing (and engineering),' 'up the value chain' and 'outsourcing' have become major elements of the new vocabulary of the aerospace industry and many others.

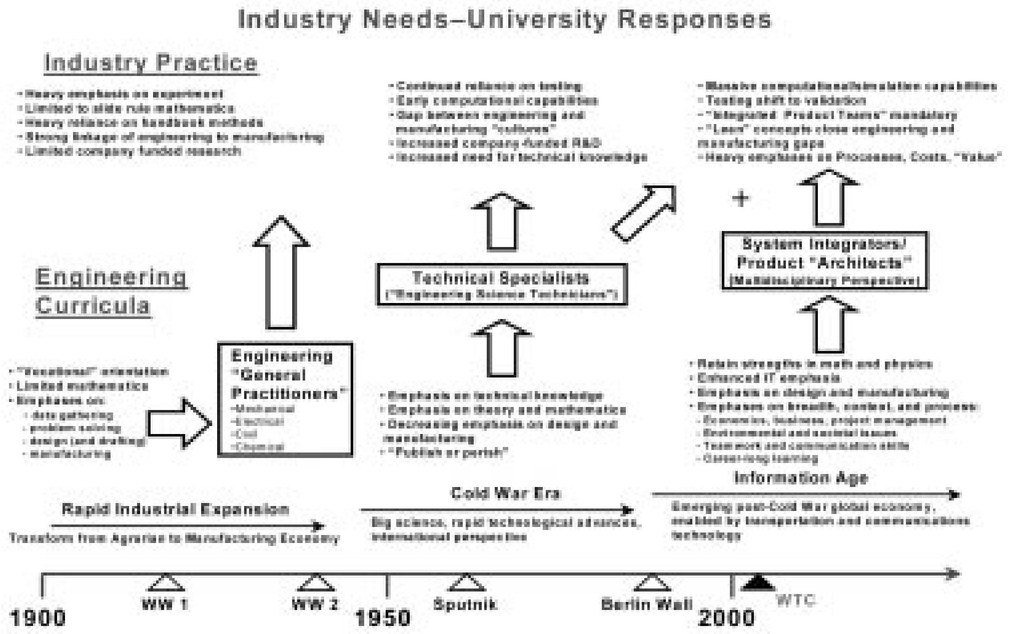

Fig. 2. The education system's response to industry needs.

In the present context, however, perhaps the most significant developments have been the invention of 'integrated product teams (IPTs)' and the more general concept of 'systems engineering'. Recognizing (finally) that separating design from manufacturing (and cost accounting) was a profoundly bad idea, the notion of bringing together interdisciplinary groups of the right people (including customers) and insisting that they work as fully cooperative teams has turned out to work rather well (e.g. the Boeing 777) when done correctly and when the people involved know how to do it. Design has again become a cooperative social activity in the more successful companies in our industry.

In more recent times, it has also become more obvious that the proper approach to design is to adopt a complete and more formalized *system of systems* approach and perspective for a given problem. While the notion of systems is far from new and systems engineering is now an established (if not yet widely accepted professional role among more traditional technical disciplines), the importance of the *system integrator* and *system architect* will continue to become as important to our business as the *configurators* of an airplane have been historically. Recognizing that this is now the case means that dealing with a myriad of related 'people issues' must become a major priority for us all.

FROM CONFIGURATORS TO SYSTEM ARCHITECTS

The development of the technical workforce needed to support our industry in the future, and

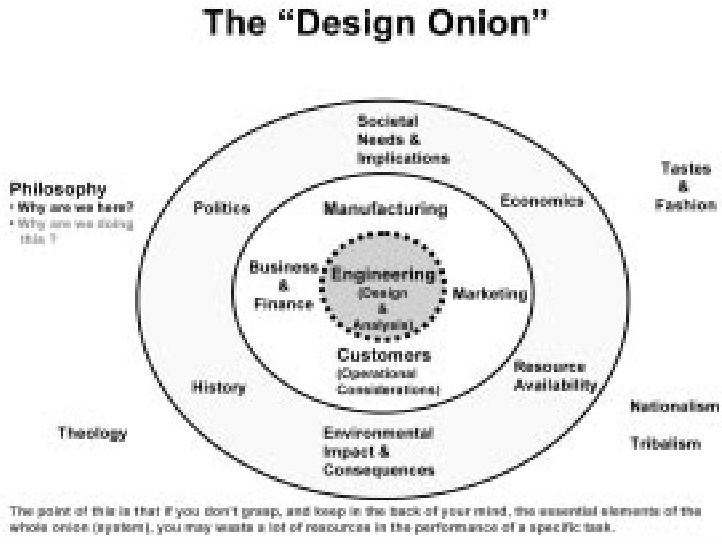

Fig. 3. Engineering is not practiced for its own sake, but is done in context.

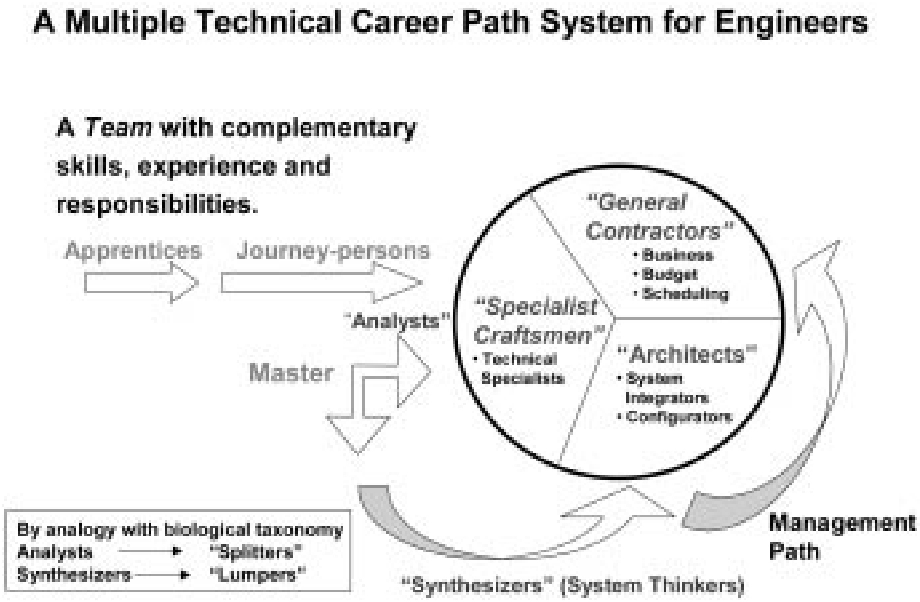

Fig. 4. If one is going to build houses (or airplanes or whatever), one needs three kinds of people.

academe's role in it, is the central concern of this paper. There are a variety of recruiting, hiring and professional development issues that need to be addressed in order to support various enterprise priorities. Some of these issues are new and unique to our times (e.g. the 'globalization' of many of our major companies, the need to deal effectively with an international terrorist threat that now extends to our own shores), and others have plagued industry for decades. Many of these were discussed in our earlier papers [1–4], but one that requires further elaboration is the fundamental question of what engineers will be required to do as our industry and its supporting infrastructure continues to evolve in the coming decades. What skills and attributes will (at least some) successful practitioners need to possess and how will we effectively acquire and develop them—especially in the area of (airplane) design? The suite of figures, Figs 2–10, are intended to address these questions from a predominantly industrial perspective, while additional thoughts on the complementary role academe needs to play (Fig. 2) are included in a later section of the paper.

A useful place to begin this inquiry is to start with some 'first principles' and recall a quote attributed to the late Theodore von Karman: 'A scientist discovers that which exists. An engineer creates that which never was.' The purpose of pointing this out is to remind the reader of the obvious fact that engineering (design) is not (engineering) science, and, as shown in Fig. 3, neither are professionally practiced for their own sake but always within a broader context. Even in the engineering-centric sense displayed in Fig. 3, it may be further observed that, as a general rule,

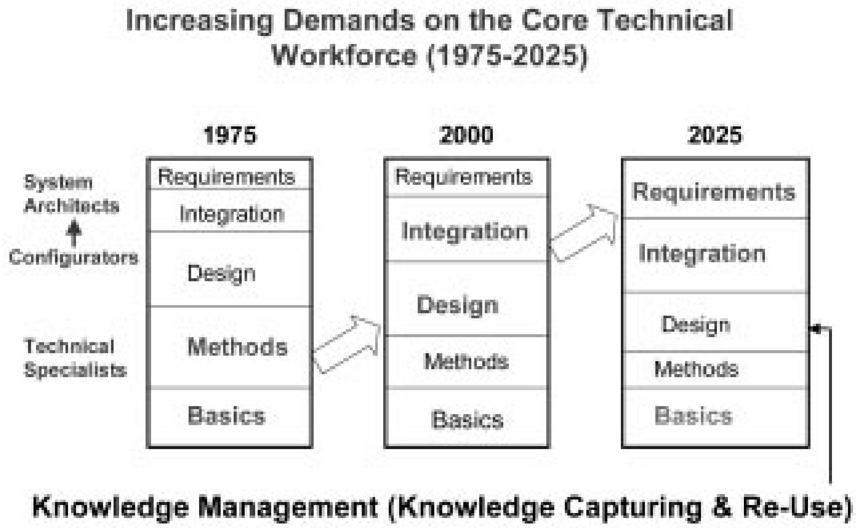

Fig. 5. Changing emphases on engineering work in the coming decades.

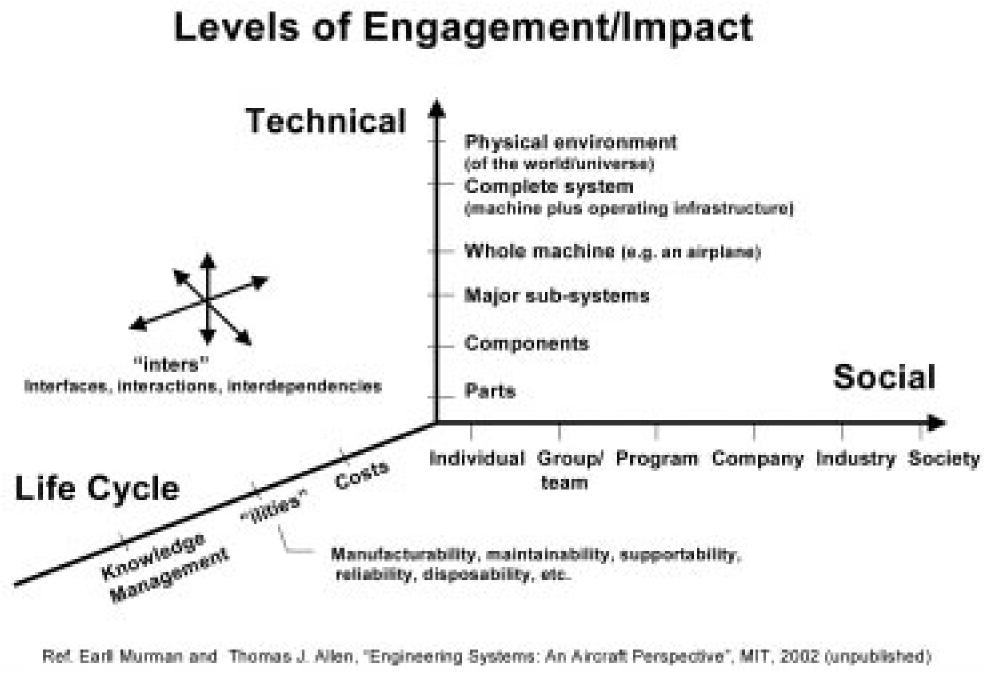

Fig. 6. An (aerospace) engineering systems perspective.

to design (and build) just about anything beyond the complexity of a paper clip, there is a requirement as shown in Fig. 4 for at least three classes of individual who may possess one of three levels of skill and experience.

The industry that has grown in head count, and developed in evolutionary fits and starts over the decades from the late 1930s into the early 1990s, seemed to fly in the face of the late, legendary (via his monumental achievements as head of the Lockheed Martin 'Skunk Works') Clarence L. ('Kelly') Johnson's commonsense dictum: 'If you can't solve it with brain power, you can't solve it with man [*sic*] power.' While we have much to celebrate in our massive achievements during that era, the end of the Cold War (with its imperatives and concomitant wealth of available resources), coupled with the rise of new global commercial competitiveness and a populace with growing demands for 'better, cheaper', we are now confronted with the need to adopt a strict diet of 'Lean' [14] as an over-riding imperative to our continued survival.

Whether we who remain in, or will join, our industry in the coming decades like it or not, the new imperatives of increased productivity and efficiency, coupled with the advent of enabling technology and processes (e.g. the IT and communications

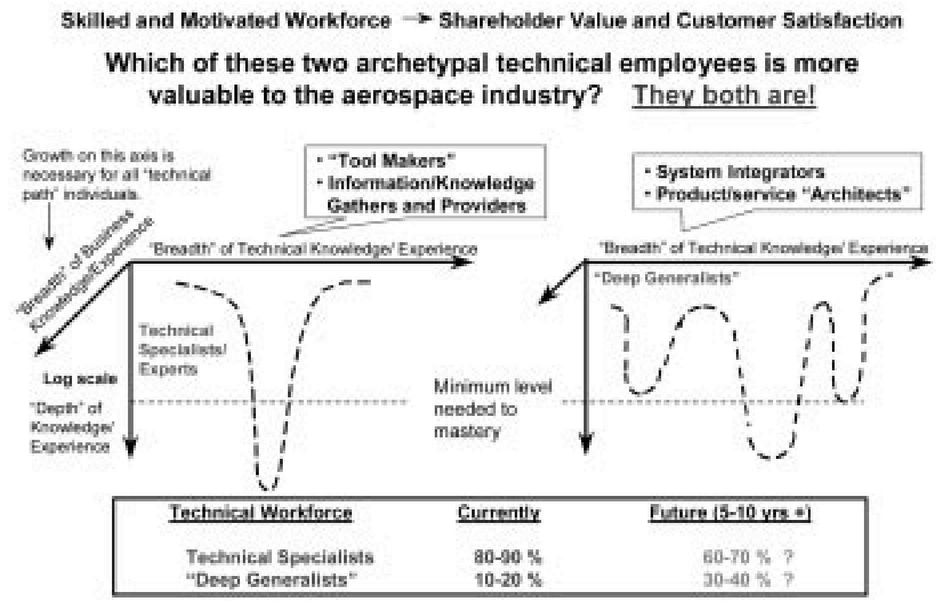

Fig. 7. Engineer archetypes—both are needed in our future.

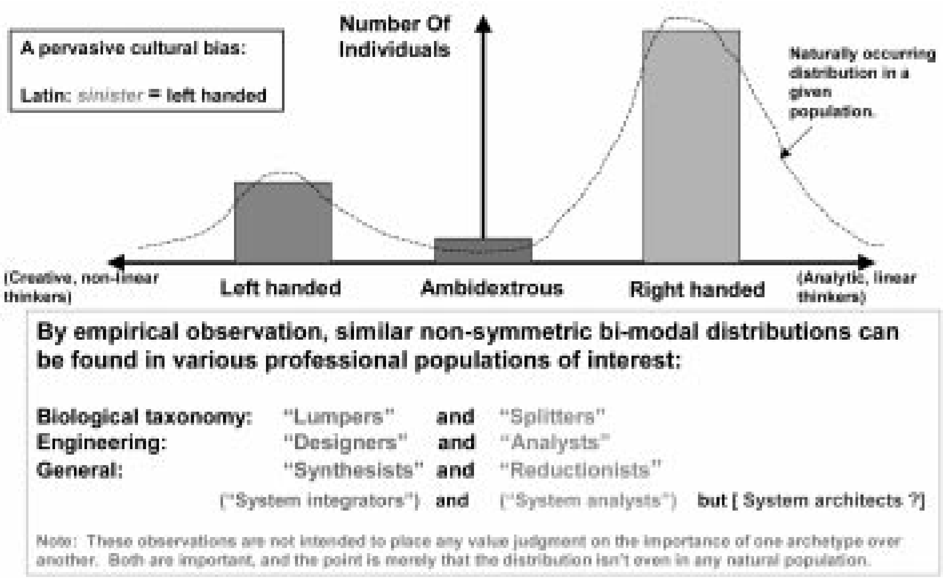

Fig. 8. Observations on the bi-modal, non-symmetric distribution of engineering archetypes.

revolution, Knowledge Management techniques), will change the nature of some major aspects of engineering work. In very general terms, the anticipated evolutionary path these changes may take (at least in the major airframe and supplier companies) is shown in Fig. 5. Coupled with this must be a much stronger emphasis on 'system engineering' (as both system analysts and as system *architects*) and 'system of systems' thinking as typified by the viewpoint shown in Fig. 6. Indeed, a need for a major restructuring or rebalancing of our technical workforces can be foreseen, as shown notionally in Figs 7 and 8.

Taken together, Figs 4, 5 and 7 show that, in future (starting yesterday), the role historically played by the airplane configurator must now be supplemented and assumed by an increasing number of the 'deep generalists' (Fig. 7) acting as system architects and integrators. While a natural progression, it should also be noted that real configurator talent has never seemed to be abundant in the overall 'engineering' population and a reason for this is suggested in Fig. 8. (and generally supported by the Myers-Briggs data appended in Figs 25–26). Those with a real talent for design (and, by extension, system architecture) apparently do not exist in equal measure in either the general or the engineering populations with those who are good analysts ('reductionists') in the general population, much as in the case of other

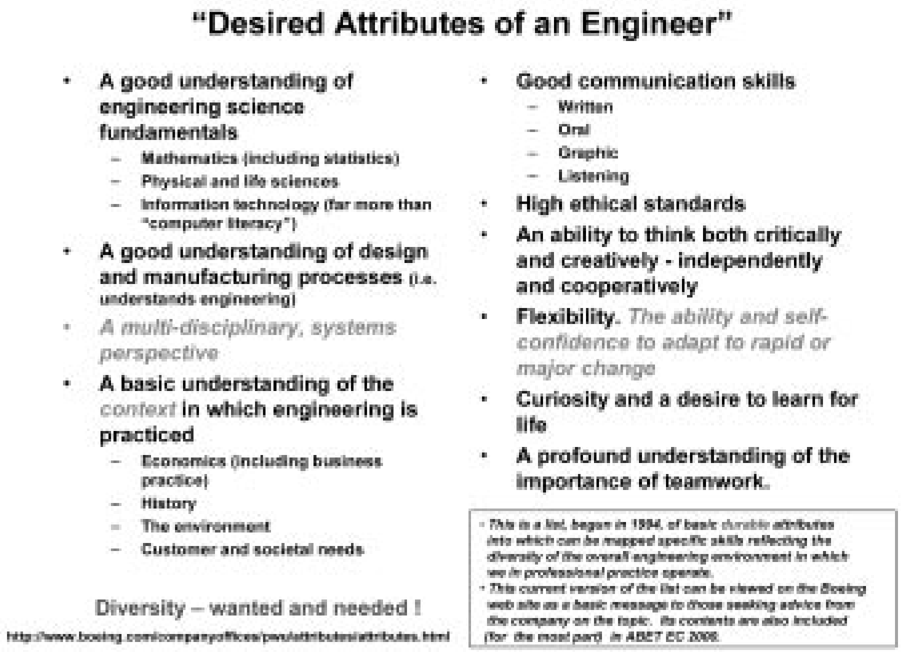

Fig. 9. The time-worn, but durable, Boeing list of engineering attributes.

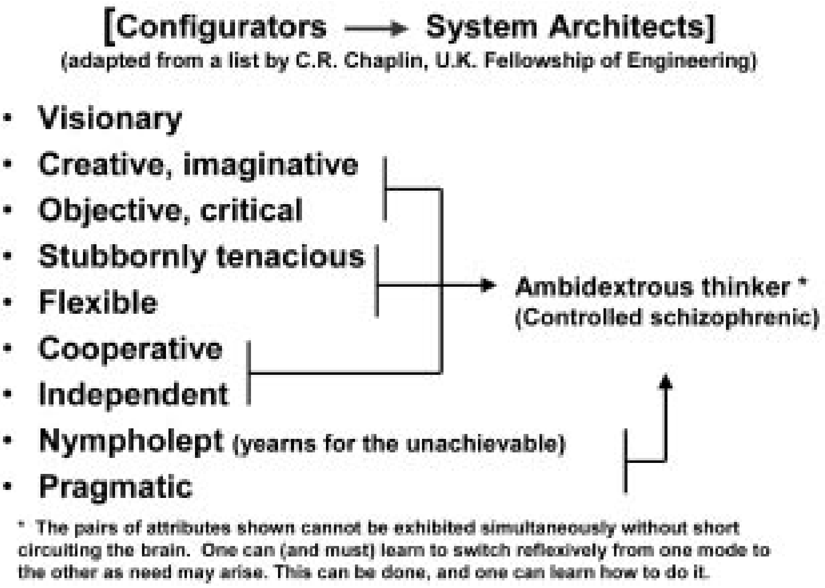

Fig. 10. A precursor and addendum to the Boeing list (cf. ref. 13).

professions such as biological taxonomy. This simple, empirical observation places no value judgment on the worth or merit of one type of individual compared to another, but it does suggest that, if one wishes to create a workforce with a new balance between the two types, very special extra care and attention will have to be paid to finding and developing those in short basic supply. This observation has many significant implications and it should be noted that neither our current college-level education system nor our current industry 'skills management' systems do an adequate job of recognizing, let alone dealing with, the issue. What is wanted is outlined in Figs 9 and 10, and could be supplied with additional effort by a proper interpretation and implementation of the curricular reforms to be discussed in later sections of this paper.

ENHANCING ENGINEERING EDUCATION

It can be foreseen that our industry will need a greatly increased supply of systems engineering talent in the coming decades, and the development of this talent pool must begin while our potential future employees are still in school. Thus, industry, government and academe must work together in

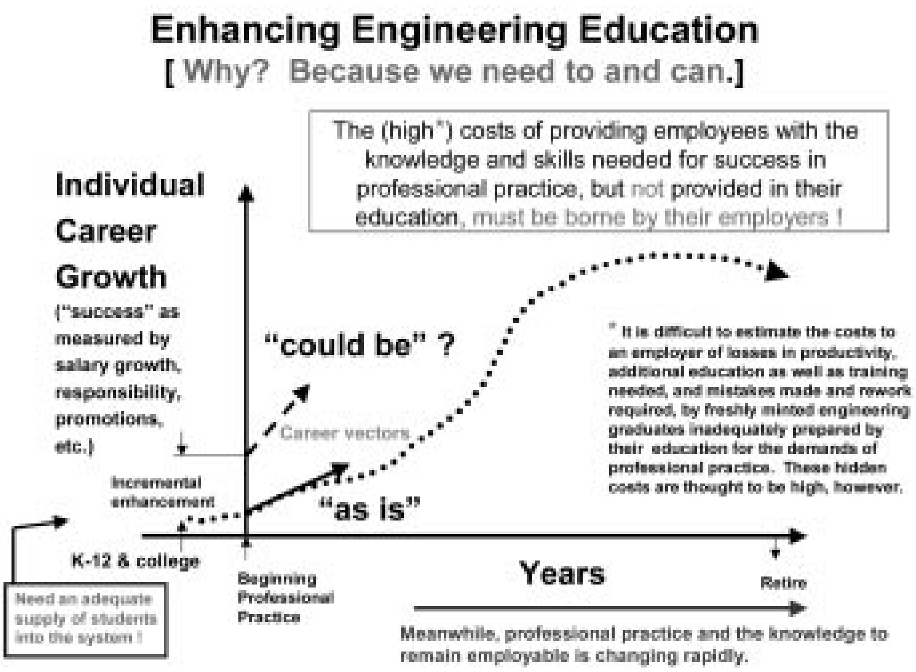

Fig. 11. An industry view on the need to enhance engineering education.

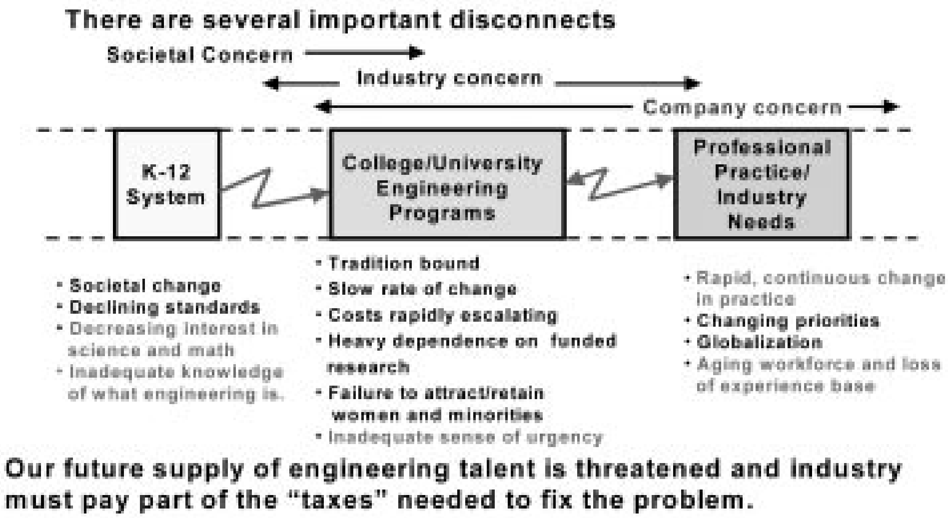

Fig. 12. Our engineering education system is under stress.

complementary ways to assure that our mutual needs are met. This again raises a suite of issues regarding the need to reform or enhance what is currently being offered in our colleges and universities across the country. With regard to the explicit topic of the need to introduce even more design (and system) oriented content into current curricula, Figs 11 though 19 are offered as additional thoughts on the topics discussed in this section of the paper.

For many years, undergraduate engineering education has been based on the implicit (and foolish) assumption that we somehow need to teach students 'everything they might need to know' before they enter professional practice. If a new technological area became important in an engineering discipline, then faculty would add a course on that subject to the curriculum. This 'throw a course at the problem' (reductionist or atomization) mentality continued until engineering programs were saturated with courses, within engineering, math & science, and the liberal arts. We need to do a much better job of determining how to educate students to operate in a modern engineering environment, rather than merely thinking about what specific skills they may need to gain their initial job assignments, or as preparation for graduate school in research. We need to demonstrate to students that engineering is practiced within a much broader societal context, and that

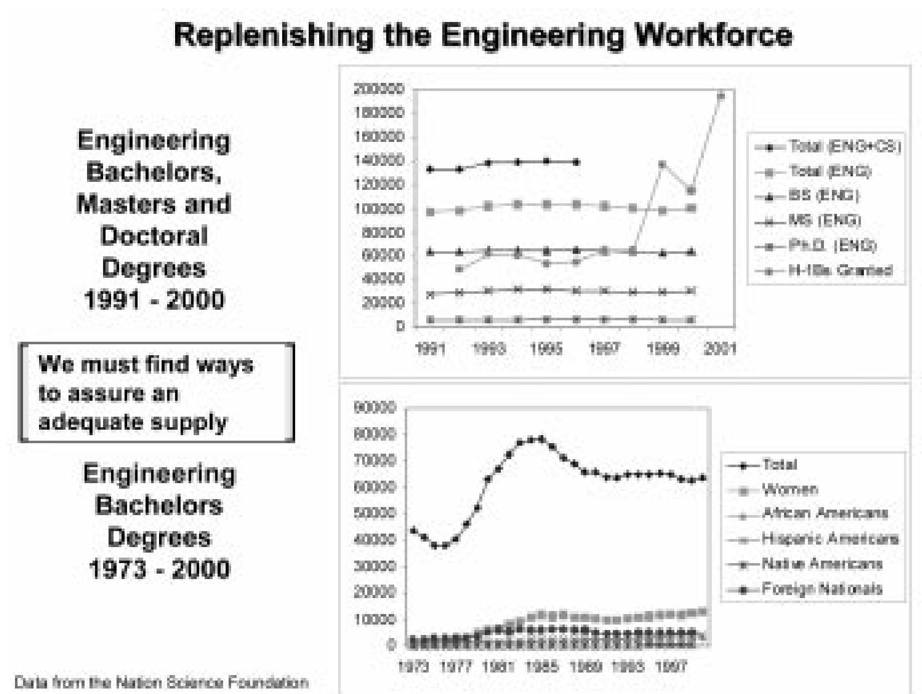

Fig. 13. The supply of engineering graduates may be inadequate unless steps are taken to attract and retain students.

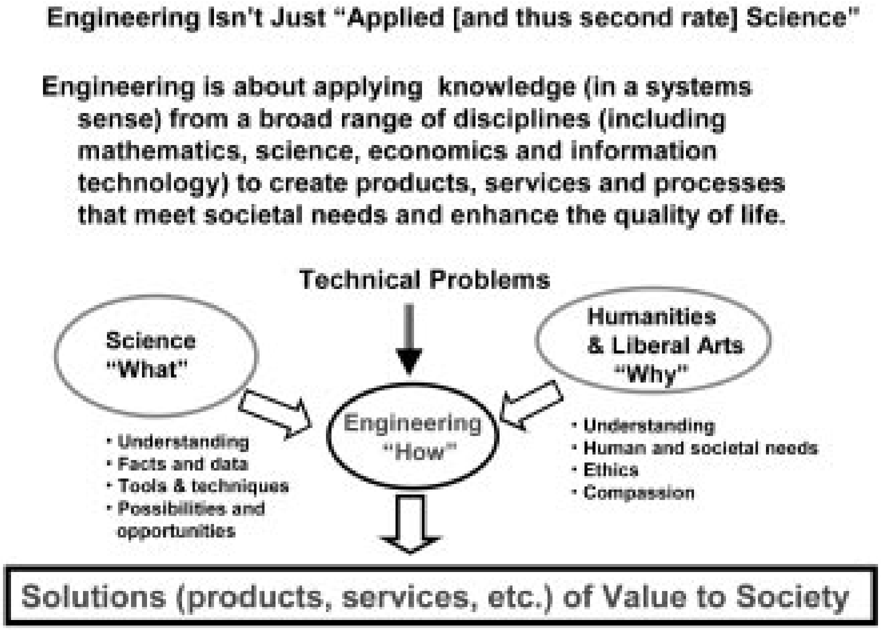

Fig. 14. A fundamental view of what (aerospace) engineering in the new century is really about.

engineering is not an end in itself. We need to teach students how to learn, and how to make learning a life-long pleasure.

Quality vs. quantity undergraduate engineering education

How can this be accomplished with the ever-growing constraints on higher education? We believe that solving this problem will require a new way of thinking about engineering education. Instead of creating a course to meet a need, we need to develop in the students a fundamental understanding of the *unity* of the fundamental tools and concepts needed for engineering practice (rather than providing them with a vast bag of tricks for solving selected problems). These basic fundamentals include (cf. Figs 9 and 10):

- Mathematics
- Information technology
- Science, including the 'engineering sciences'
- Design and manufacturing
- Economics and business practices

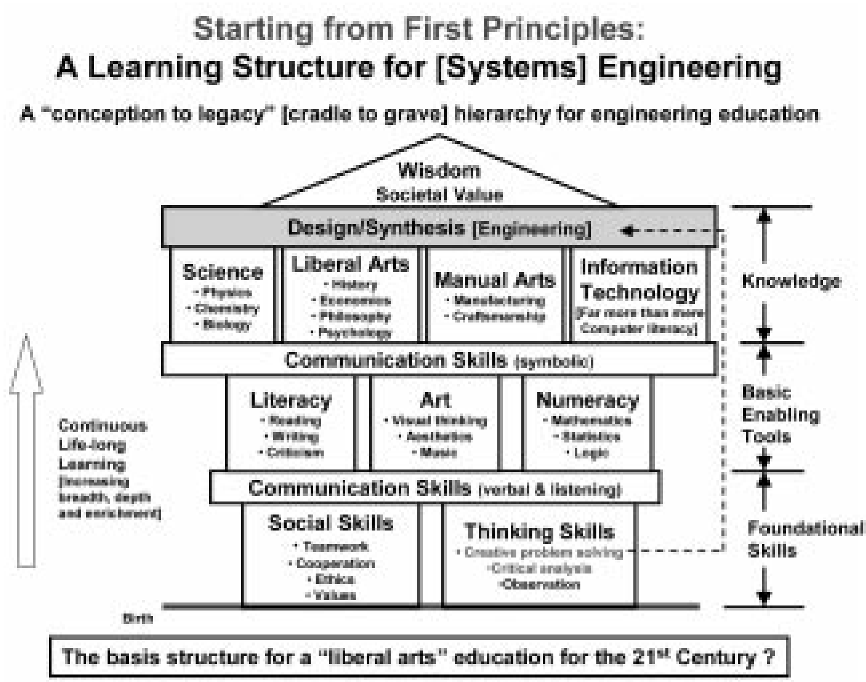

Fig. 15. Elements of a comprehensive 'engineering' education.

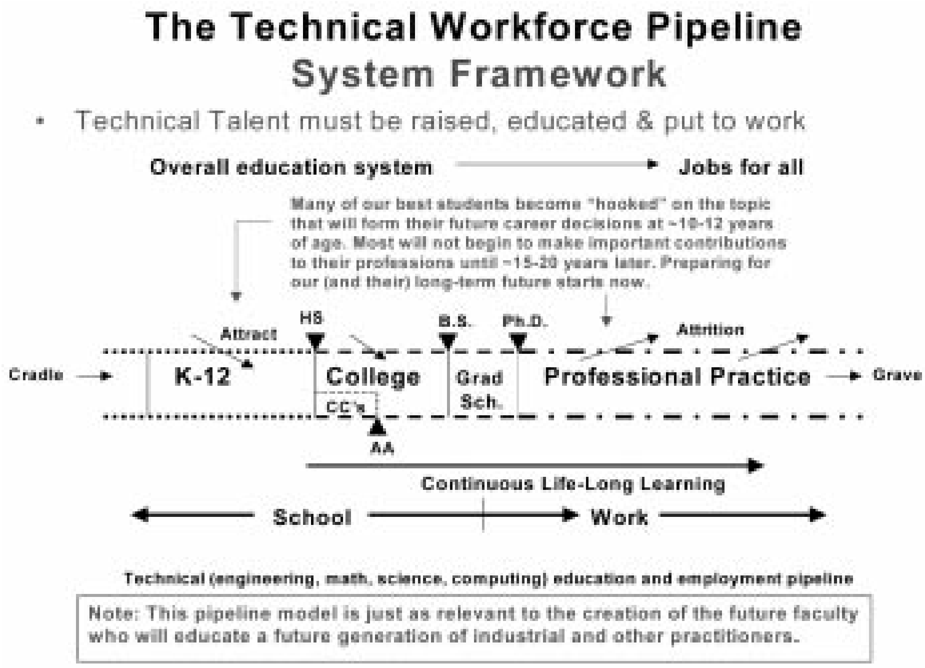

Fig. 16. A longer-range view of the engineer supply pipeline.

- Communications and teamwork (rather than mere 'group work') skills

Of utmost importance, we need to emphasize 'design (system) thinking', where students learn creative thinking and open-ended problem-solving, but always within the context of design's close connection with manufacturing (i.e. 'If you can't build it, you can't use or sell it') and customer/societal needs. This must also be done in such a way that students learn how to get information and how to deal effectively with *too much* of it (i.e. emphasize *critical thinking* and evaluation skills), hopefully in an environment that emphasizes teamwork and communication skills. Students must learn the 'Why' and 'What' of theory, and how these basics are then applied in practice. The further refinements on 'How' in applications can then be gained by experience, and subsequent training and continuing education provided by

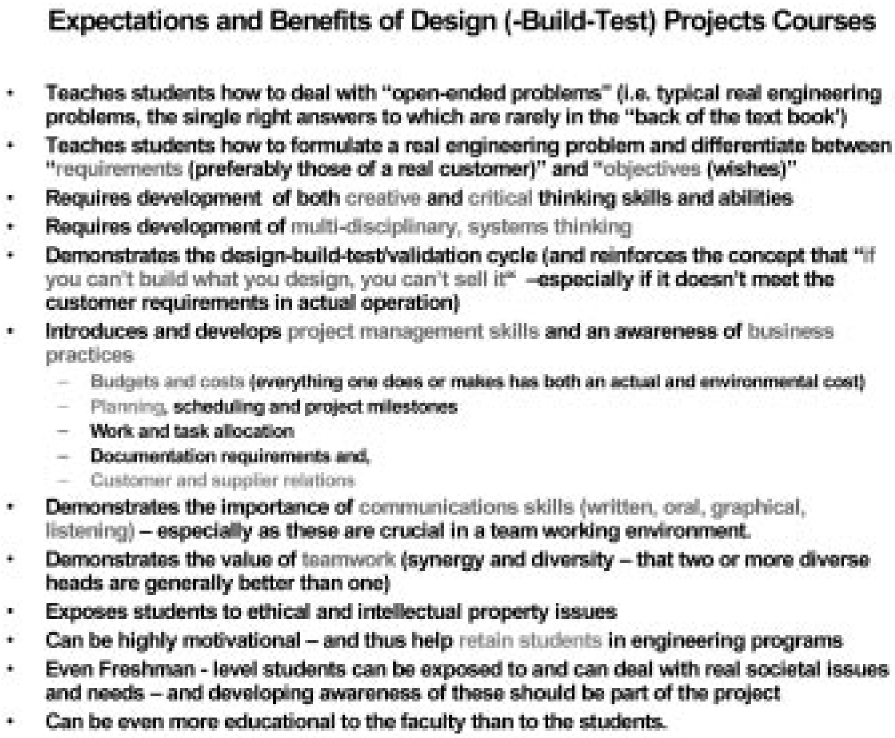

Fig. 17. The value of design (-build-test) projects.

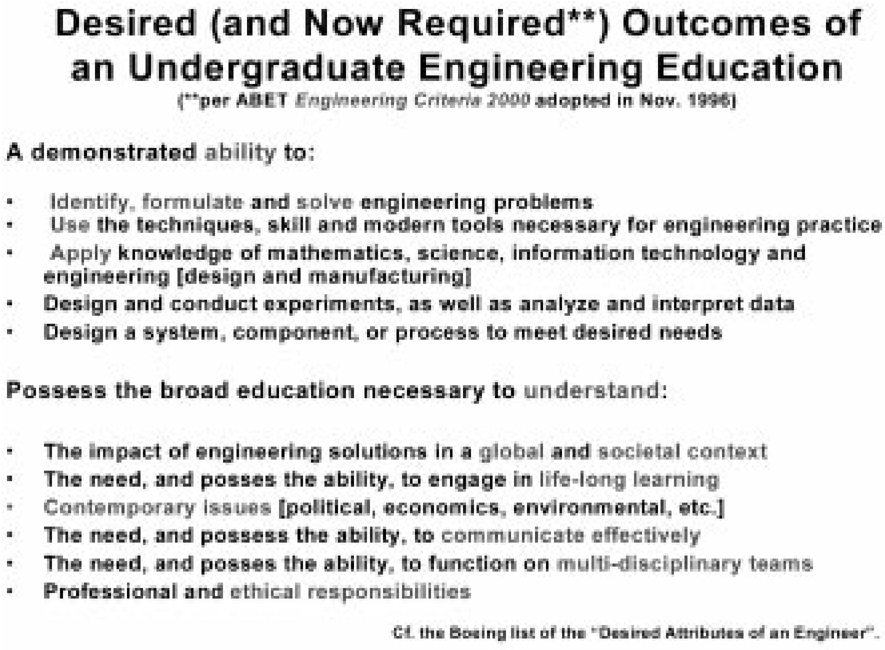

Fig. 18. The ABET engineering criteria 2000 requirements.

their employers in close cooperation with academe and our various professional societies.

Desired elements of a model engineering education program: a high level view

In order to achieve the goals of producing modern engineers of real value to our industry and our society, we need curricula with real content rather than mere course listings that strike a proper balance between fundamentals (math, engineering sciences, IT, etc.) and provision of in-depth experience in skills and issues important to professional practice. This requires that programs be fully compliant with the spirit *and* intent of ABET EC 2000, as informed by employer *strategic* (rather than short-term) needs and concerns. We need to provide students with a solid foundation for subsequent graduate study, professional practice and continued career-long learning in an environment where career change may become the norm for job security and employability. This can be accomplished by building on our traditional strengths in graduate education, but not by viewing graduate education via research programs as the sole

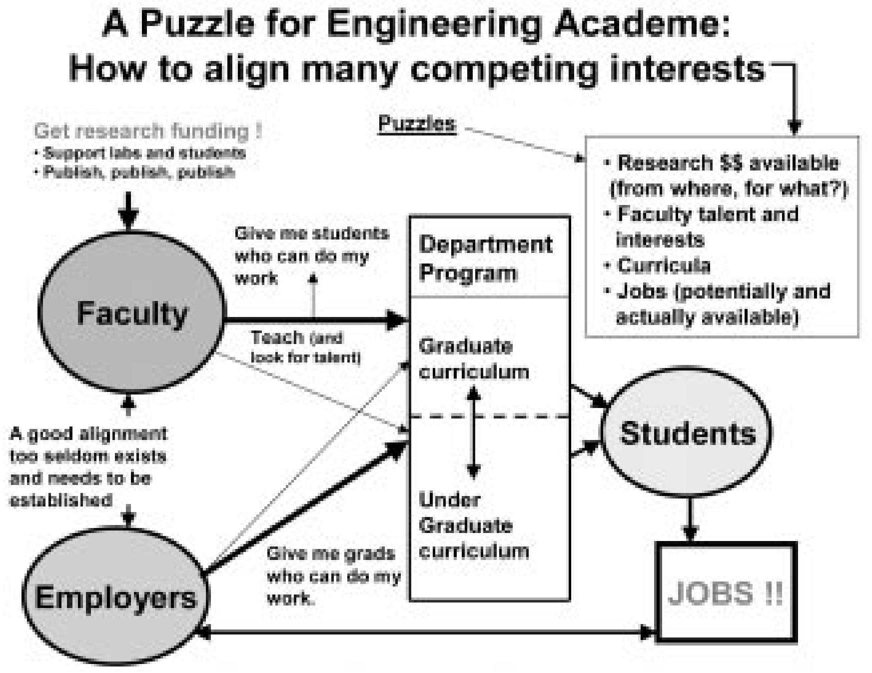

Fig. 19. Competing demands from competing interests.

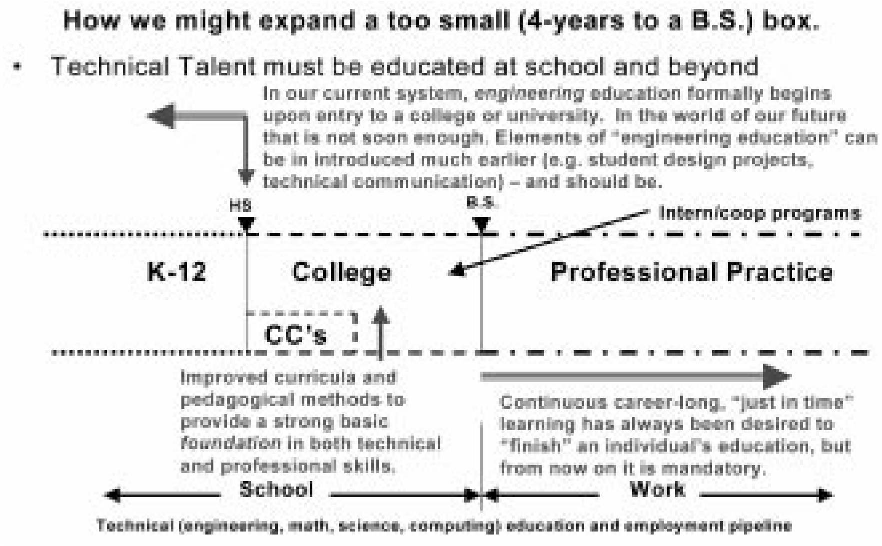

Fig. 20. Some ways to fit more education into too small a box.

purpose of the university. Also, an even stronger emphasis on *design-build-test* project experience from the freshman year through graduation (at whatever degree level) would greatly enhance the quality of engineering education, and help to create engineers with the ability to solve real problems for which the answers are seldom among the even numbered ones in the back of a textbook.

What does this mean to the faculty at universities? Well, probably even more work for one thing, with little prospect of near-term reward. Changing the goals and rewards for faculty may be more difficult than changing the curriculum they teach, but a focused effort needs to be made that is both practical and realistic. A similar effort is needed to attract a diverse, dedicated, well-qualified faculty who have strong teaching ability, as well as a desire to perform meaningful research. This faculty of the future should have industry and professional practice experience, so that they are 'literate' in this, as were many faculty members prior to World War II and into the 1950s. Perhaps most difficult of all is to create a culture and climate where faculty are willing and able to function as a team. In this way they will serve as true role models for their students—as a group of engineering educators who are true exemplars of life-long learning and team-based problem-solving.

The basic puzzle for engineering academe

The preceding discussion suggests that engineering academe faces as many challenges today as does industry as a whole. At root, however, it must

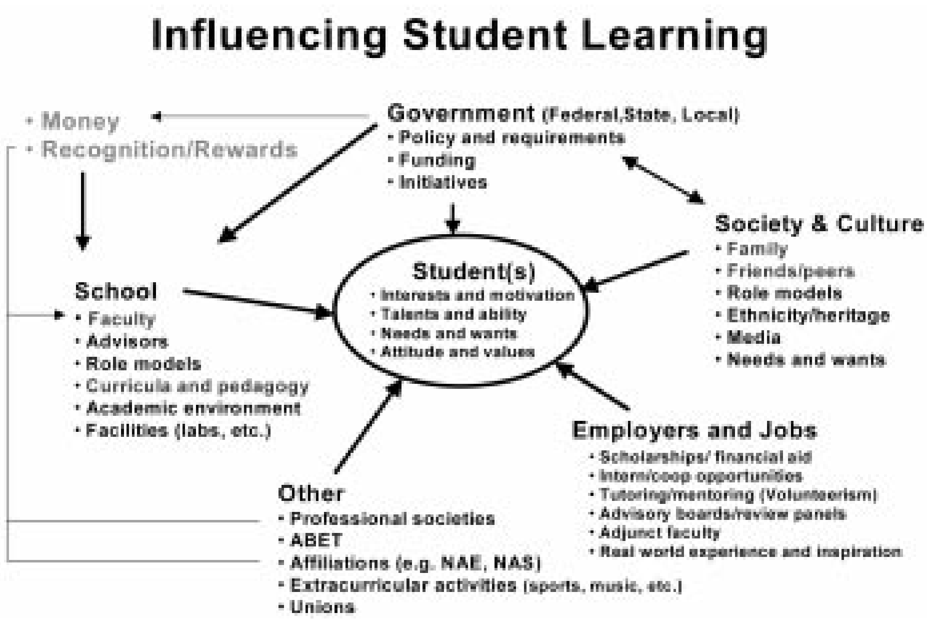

Fig. 21. A 'student-centric' view of education.

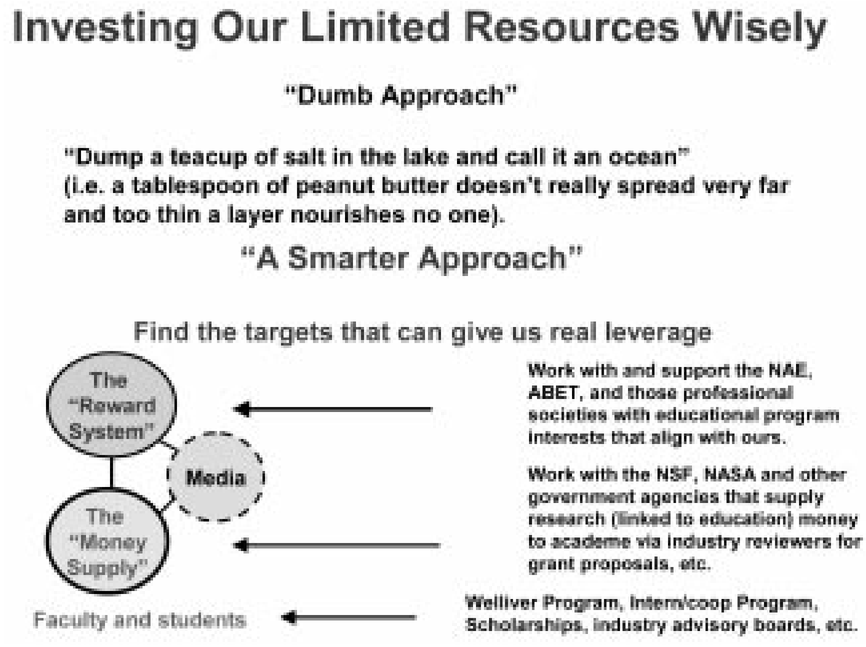

Fig. 22. Key leverage points in influencing engineering education.

be recognized that, despite all criticism, we still retain arguably the finest graduate education system in the world and that any attempts to reform or enhance undergraduate programs must be done in a way that does not damage the quality of what we now have. In making this observation, it must be recognized that research remains the life-blood of much of the current system. We have much to do in this arena as well, to assure the future health of our industry.

Effective mechanisms must be put in place to integrate knowledge transfer (teaching, etc.) with research and community service:

- Vertically, between graduate and undergraduate programs
- Horizontally, across department, college and discipline boundaries

How all this is to be done is left as an exercise for the 'student' and may be recognized by engineering faculty as just a major system of systems design problem.

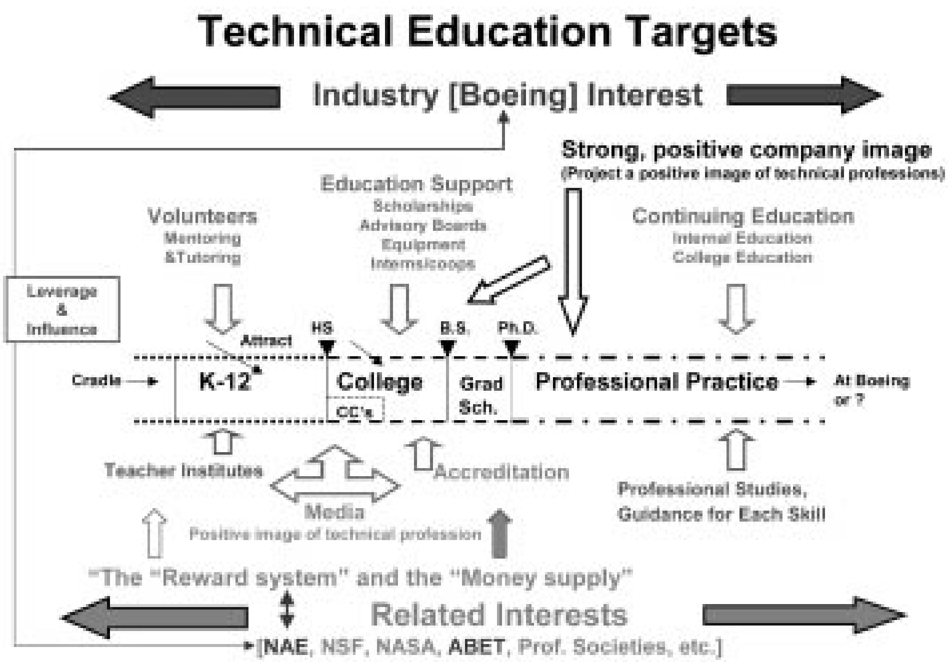

Fig. 23. Influencing engineering education—an industry (Boeing) view.

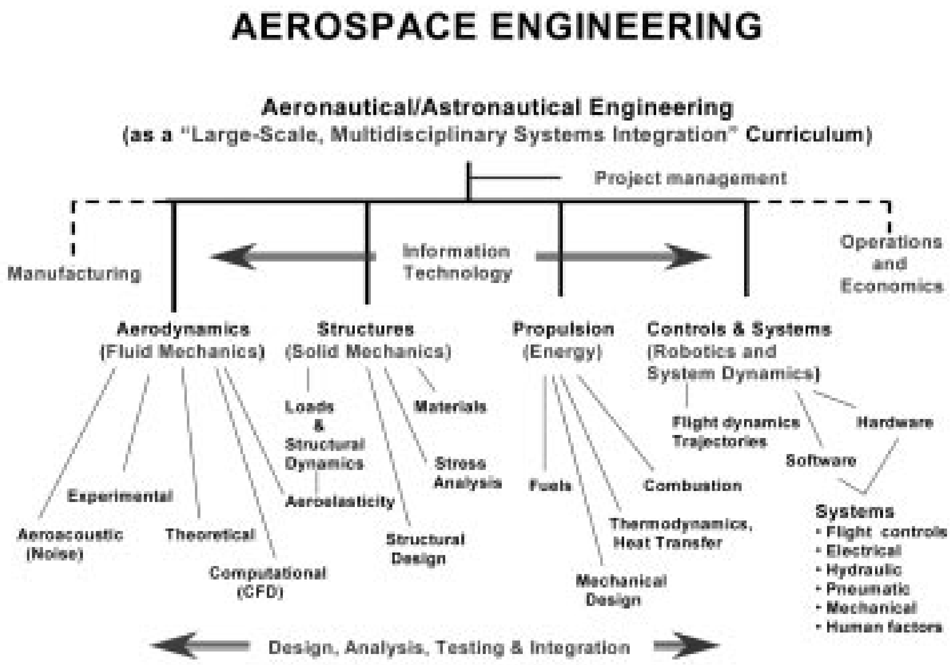

Fig. 24. A general 'aerospace' engineering education.

INFLUENCING ENGINEERING EDUCATION REFORM

While much progress has been made in the past decade (e.g. the adoption and initial implementation of ABET Engineering Criteria 2000 as an outcomes-based, continuous improvement method of accreditation), many acknowledge a need for further significant reforms in engineering education in this country. There remain some formidable roadblocks to this process, and they are far from limited to academe itself. Among those that can be clearly identified are:

- The 'faculty reward system' (more than just tenure)
  - Driven by research and associated prestige
  - What incentives to devote effort to undergraduate teaching?
- The industry 'reward system'
  - Driven by near-term needs for business (and career) success

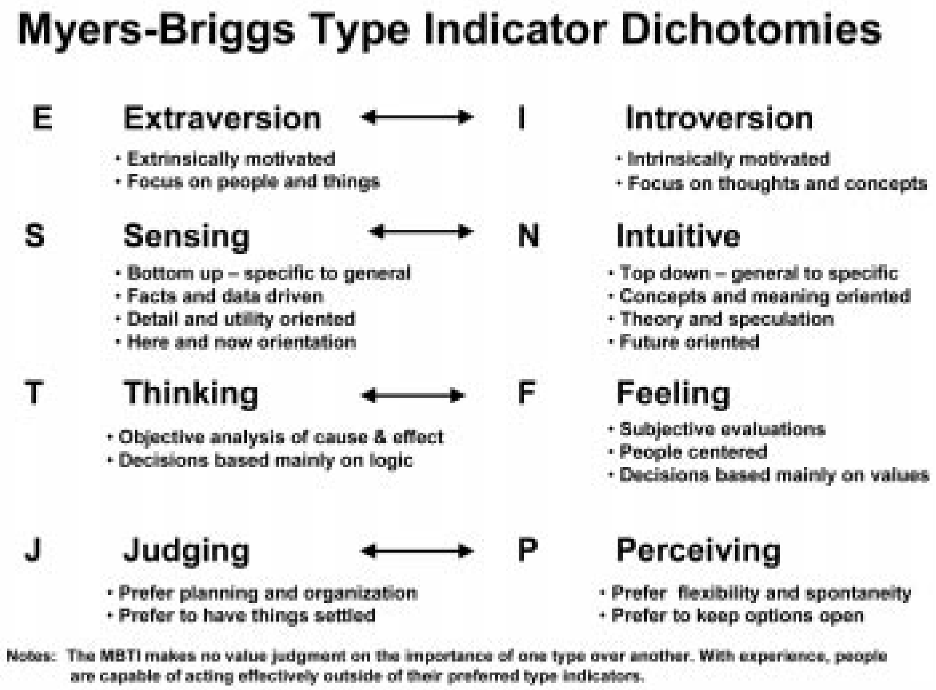

Fig. 25. The basic Myers-Briggs categorizations of 'type preferences'.

Myers-Briggs Type Indicator National Sample Data

	Sensing Types (73.3%) [M: 71.7%, F: 74.8 %]		Intuitive Types (26.7%) [M: 28.3%, F: 25.2 %]		
	ISTJ 11.6% [M: 16.4%, F: 6.9%]	ISFJ 13.8% [M: 8.0%, F: 19.4%]	INFJ 1.5% [M: 1.3%, F: 1.6%]	INTJ 2.1% [M: 3.3%, F: 0.85%]	Introverts (50.7%) [M: 54.1%, F: 47.5%]
	ISTP 5.4% [M: 8.5%, F: 2.4%]	ISFP 8.8% [M: 7.6%, F: 9.9%]	INFP 4.4% [M: 4.1%, F: 4.6%]	INTP 3.3% [M: 4.8%, F: 1.8%]	
	ESTP 4.3%	ESFP 8.5%	ENFP 8.1%	ENTP 3.2%	Extraverts (49.3%) [M: 45.9%, F: 52.5%]
	ESTJ 8.7%	ESFJ 12.3%	ENFJ 2.5%	ENTJ 1.8%	

(National Sample, [**Male: N = 1,478; Female: N = 1,531**] combined male and female: N=3,009)

Fig. 26. A national database supporting Fig. 8.

- What career incentives to devote effort to 'university relations'?
- General lack of communication and shared common vision
  - A lot of 'runners out for a pass', with a too-limited vision of our future
  - Ignorance of industry needs from a university perspective
  - Little understanding of faculty needs and constraints in industry
  - Industry and university timescales for change or action are very different—which thus causes major gaps between expectations and realization

Despite these and other challenges, there is much that can be done with the always too limited resources available to us. Some elements are indicated in Figs 19–23.

Some of this can be accomplished at the local or specific program/departmental level in a given college or university. If one seeks real systemic change, however, a much more pervasive assault is required and this must be based on some basic principles. These include:

- A 'system of systems', student learning-centered approach and perspective must be adopted.
- It must finally be recognized that reform cannot be accomplished 'unilaterally'—it must involve a combined, fully cooperative effort by a suite of stakeholders, including academe itself, government and industry.
- Culture change, as many have advocated, takes generations to accomplish; behavior change can be accomplished more rapidly if one works with (to the degree possible) rather than against the existing culture and its reward systems—as appropriately modified by invoking the simple principle of enlightened self-interest. In the end, we really are all in this together and we will

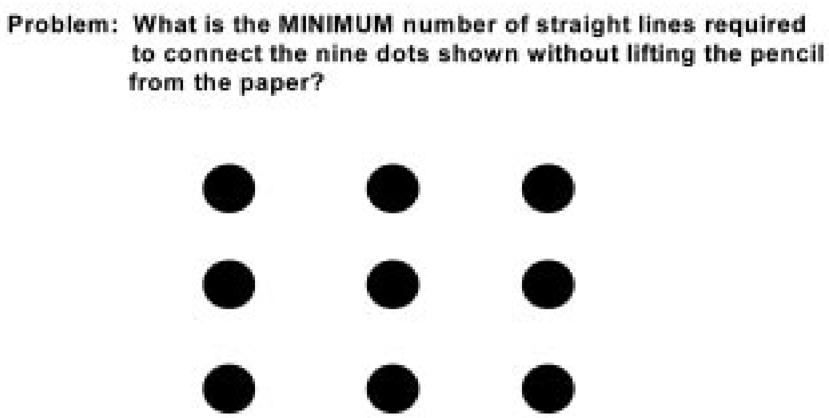

Fig. 27. An abstract paradigm for dealing with old problems in new ways.

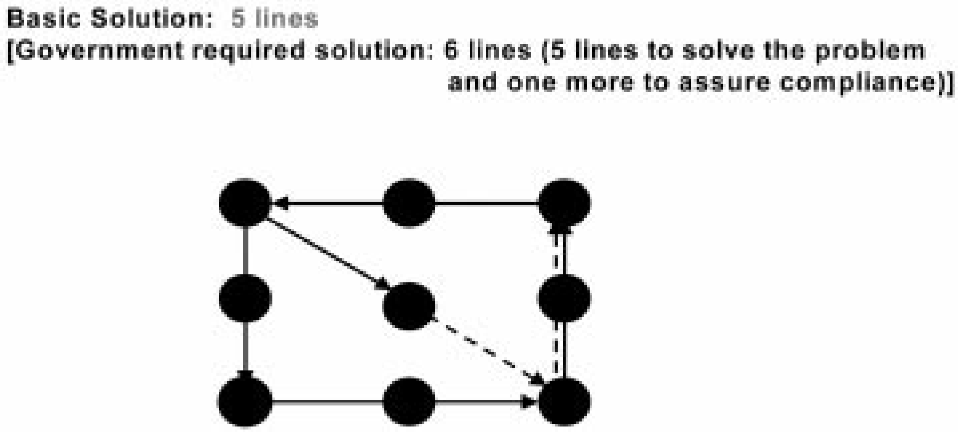

Fig. 28. The traditional 'within the box' solution.

succeed or fail to the degree we choose to find common cause.

SOME CONCLUSIONS

This paper and our earlier series [1–4] have been primarily concerned with advancing the argument that airplane design, in common with most modern engineering practice, must be fundamentally viewed as a social activity wherein technology, processes and people must be treated as a unified whole—from a true 'systems perspective'. Many issues have been raised and thoughts and suggestions have been presented about how these might be viewed and dealt with in the future in order to assure the continued prosperity of our enterprise. These need not be recapitulated, but three final conclusions need to be reinforced as a summary of what has been written.

The aerospace industry (in common with many other industrial sectors in our economy) continues to change in massive ways, and probably can be expected to remain volatile and dynamic through the rest of its foreseeable history. The events of 9/11/01 and their aftermath, while horrifying, are only one of the more vivid incidents that have rocked our complacency and reordered our priorities since the beginning of our industry. In a longer-term view, many of the conclusions in our earlier work may still be considered valid. An important conclusion of that work was that, while the aerospace industry of tomorrow may be very different than it was in the Cold War era in which many of us matured professionally, it is incorrect to assert that it will be any less exciting and challenging to those who will choose to be involved in its future. While those future practitioners should be fully cognizant of our past, it is they who will invent our future, and the value judgment regarding the nature and quality of the jobs they will perform should be left to them to decide—not unduly colored by the prejudices and nostalgia of practitioners from an earlier era they cannot have experienced.

The aerospace industry, both nationally and globally, can be expected to prosper over the long haul, barring a complete collapse of the world economy. While space exploration and astronautics has an obvious future, there is no reason to predict that aeronautics has a future any the less bright—despite too many recent predictions to the contrary. Airplanes are not a 'done deal', with nothing of substance to look

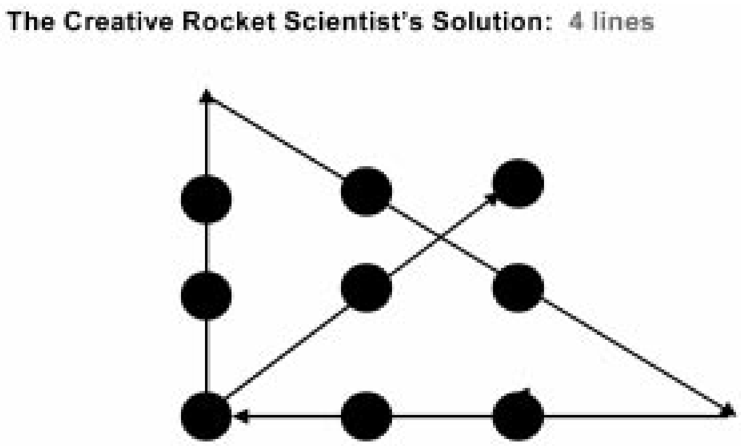

Fig. 29. The conventional 'out of the box' solution.

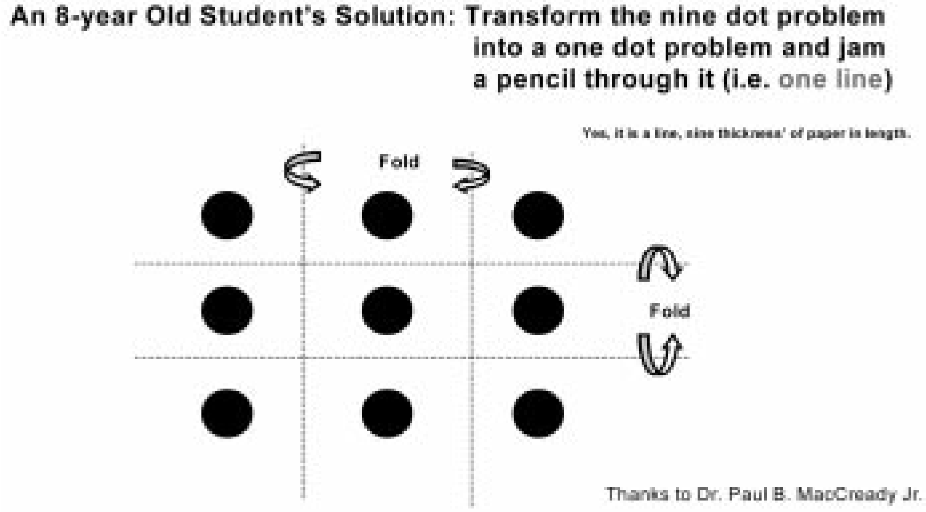

Fig. 30. An even better solution to the problem.

forward to in future developments beyond mere refinements of well-established recipes. At least three broad categories of future airplane development opportunity can be readily identified:

- Continued development of a national and global air transportation system as an intrinsic and fundamental part of maintaining our national security and enabling the full development of a global economy. Much of what airplanes enable simply cannot be provided by virtual means (e.g. via the internet or any of its potential future developments).
- Prospects for flight in hostile environments—from O'Hare or Detroit to Afghanistan to Mars and beyond. This covers a myriad of opportunities and issues both civil (e.g. operations in any weather or extremes in hot and cold, etc.) and military (UAVs again, etc.). In this latter connection, it may be observed that flight at extreme conditions (altitude or temperature) in the earth's atmosphere using 'robot airplanes' is little different than the problem to be solved in flight in other planetary environments.
- The convergence of aeronautics and astronautics in developing 'flight vehicles' that provide affordable access to space. The 'aerospace plane' problem has been the subject of decades of study and needs to be 'solved.'

Finally, as shown in Fig. 24, aerospace engineering remains the single *institutionalized* multi-disciplinary, large-scale systems-oriented program in our engineering education system. As our need increases for 'systems of systems thinkers', we can expect to need more, not less, 'aerospace engineering' graduates in our national future. Departments that offer such programs (in the more generic sense intended) should learn to market their graduates as such, as an aid to assuring a continued supply for both our own industry needs and in many others as well.

We all (industry, government and academe) as an *aerospace community* have much to do to assure our future security and prosperity. Individually, we face often seemingly insurmountable challenges, but collectively we can succeed if we have the will and imagination to do so.

'I don't know why people are frightened by new ideas. It's the old ones that frighten me.'
John Cage, American Composer

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