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From Farther, Faster, Higher to Leaner, Meaner, Greener: Further Directions in Aeronautics

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Previous examinations of the historical context and suite of issues surrounding the putative decline in aeronautics are continued. The purpose is twofold and elaborates on several earlier themes. The first purpose is to examine in further detail the coevolution of airplane design practice and aerospace engineering education as an aid to discerning future trends and requirements. The second, and more important, purpose is to discuss some of the steps that can and should be taken within the technical community to reinvigorate aeronautics and airplane design in particular. Whereas aeronautics may indeed be a maturing industry (at least in some major traditional product areas), it still has a future that will be no less significant and potentially dramatic in its second century than it was in its first. There is much to be done by the aeronautics community (government, industry, and academe) to create this strong and vivid vision of this future and to ensure the proper development of a future generation of skilled and motivated practitioners in aeronautics's always evolving and ever-dynamic enterprise.

Introduction

THE present paper is the fourth in a series[1–3] the authors began in 2000 under what has become the general heading "The Demise of Aerospace: We Doubt It." The series was initiated as an attempt to counter some of the excesses of a continuing spate of national studies and articles in both the popular and professional presses[4–6] that decried the seriously declining state and future of aeronautics (and aerospace in general) in this country. As pointed out in our previous work, whatever list of causes for the putative decline in aeronautics may be compiled, two fundamental underlying factors have been and remain causes for serious concern. The first is the fact that we (industry, government and academe) as an aeronautics community have been unable to create a collective vision of our future as compelling and exciting as the one that has driven the past century. The second factor, which is reciprocal to the first, is the need for an aggressive means to replenish and sustain a pool of technical talent needed to maintain and advance an industry that still continues to find a multibillion dollar per year market for its products and services and that is fundamentally important in maintaining our security and enabling the further development of our global economy.

Today's Situation: From the Perspective of the Past

Examination of the history of aeronautics shows that its development has been a symbiotic coevolution with the vast changes of the 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 is charted conceptually in Fig. 1.

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As noted in our earlier paper,[3] Fig. 1 was originally created over 20 years ago as part of an explanation to Boeing management for 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 Boeing 707. The conceptual diagram thus created is generic and still relevant as a means to show where we now stand in our putative mature technology.

As shown notionally in Fig. 1, in a chart of progress (arguably perhaps on a logarithmic scale) vs time, three lines can be drawn. 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 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 in Fig. 1 is the measure of actual progress made over the course of 100 years of dedicated effort (not forgetting that much of the basic ground work that led to the Wright brothers success, which initializes Fig. 1 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 a mature technology and is exacerbated by the fact that not only are designers getting smarter over time, their customers, government regulators, and the public at large are all getting more demanding and sophisticated as well.

In the face of an increasingly litigious environment, with unending demands for improved safety, reduced noise, increased fuel efficiency, etc., 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 (even in an otherwise relatively stable political and economic

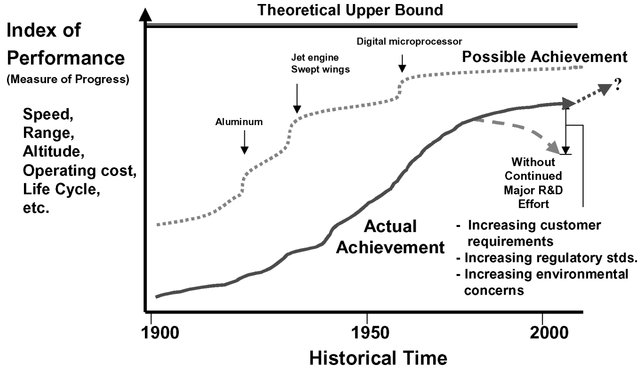

Fig. 1 Progress in aeronautics technology, conceptual view.

Fig. 2 One of many possibilities for future large airplane development[9]: "C-wing" configuration for a possible 600-passenger transport.

world, one in which we no longer seem to live). With regard to the specific case of the Boeing 757 as successor to 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 arguable whether the original 707 or its contemporary DC-8 could ever have flown and helped change the world as they did.

Figure 1 is interesting in that it indicates a maturing (leveling) of at least cruise airplane performance, influenced in part by the basic laws of physics. 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.

With the singular exception of the Airbus decision to go ahead with their A 380, a rather dreary future seemed in prospect as we entered the post-cold-war era of "quicker (to market), better, cheaper." Was the most exciting prospect on offer, or our inevitable future (in the commercial arena at least), simply the further redesigning of the existing lines of Boeing and Airbus subsonic transports (albeit with more exotic electronics and advanced materials)? 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, with specific references here to the development of commercial transport aircraft.

So Now What?

Stories similar to that of 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 an examination is this: Where do we go in the next 100 years of an endeavor that has a potential multitrillion 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 in one way or another, despite (or perhaps because of) the dramatic turn of events on 11 September 2001:

1) Keep running harder and harder, that is, keep 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.

2) Schedule a breakthrough, for example, a possible Concorde 2 via large reductions in sonic boom intensity and development of aerospace plane technology, or an invention, for example, economically and logistically viable alternatives to fossil fuel propulsion schemes for transport aircraft.

3) Start a whole new game, one in which the gap between the possible and the achieved is once again very large, for example, the whole range of possibilities for uncrewed aerial vehicles (UAV)/Uninhabited Combat Air Vehicle (UCAV)-type vehicles, which represent a complete fusion of traditional and emergent aerospace vehicle technology with information and communications technology.

Regardless of which path is pursued, we strongly believe that there is a bright future for aviation in the coming decades, despite recent events. A key to this is to stop bemoaning the past and to apply our collective imaginations to looking forward toward an unknowable, but dynamic future.

Many of our colleagues who grew up in the cold war era continue to lament the supposed end of farther, faster, higher as the driving force for aeronautical progress, and its replacement with the newer, and to many, far less exciting call for quicker (to market), better, cheaper. Our older friends may be partially correct (from their perspective), but the newer imperatives have been forced on us by a new economic and geopolitical reality because 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.

There is no doubt that global air transportation is maturing, and recent events have shown the airline business to be highly vulnerable on several fronts. These events open new avenues for the improvement of 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, a need to replace aircraft of 757/767/A310 vintage, or development of new concepts such as that shown in Fig. 2 (as but a few of the myriad future possibilities) suggest that the new mantra for further progress may well be faster, higher, [farther], cheaper, better, quicker, cleaner, quieter, and safer, etc., or, as the title of this paper suggests, simply leaner, meaner, greener. The only constraint is that whereas the laws of economics can be bent to some degree, the laws of physics cannot.

Processes and Human Issues: Social Side of Aerospace

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

As significant as technological progress reflected in the artifacts designed is the evolution in the processes by which the amazing advances of the past century have been developed, as shown in Fig. 3. More important, how these process tools and methods will continue to develop in our future has become an issue of crucial significance. Ultimately, it is the suite of people issues intrinsic in technology and process advances that is of fundamental concern to the future of our enterprise. Too frequently, however, these human/social/cultural issues are treated as a separated, disconnected topic in the aeronautical

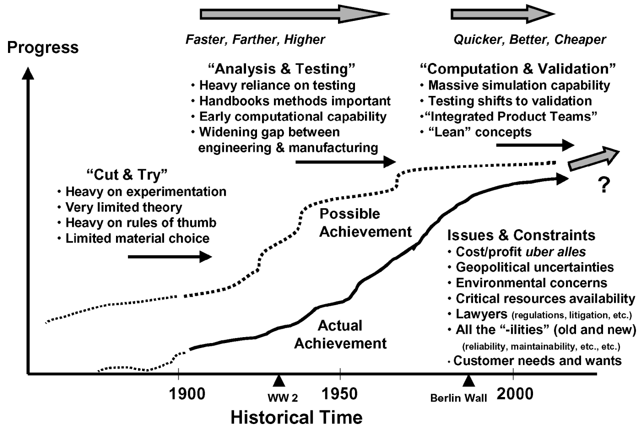

Fig. 3 Progress in airplane design technology and processes.

engineering literature. It continues to be our purpose to treat them here, even if incompletely, as a unity, with the future development of our technical talent pool as a central focus. In reality, technology, processes, and people form an inseparable triad in aerospace.

Basic Premises

As argued at length in an earlier paper,[3] 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 develop and apply them.

Maintaining and enhancing the excellence of our collective technical workforce must be a central focus within the technical community in aerospace, now and into our future. As in our earlier writings, the authors' concern is primarily for 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

As indicated in Fig. 2, the large-scale advent and vastly increasing power of the computer and the tools [for example, computational fluid dynamics (CFD), direct analysis and inverse/design, CAD/CAM systems, multidisciplinary optimization methods] available to exploit their 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 order, have combined to cause a transformation in the airplane design process. Terms such as customer-in, lean manufacturing (and engineering), up the value chain, and outsourcing have become major elements of the new vocabulary of the aerospace industry.

In the context of the present paper, however, perhaps the most significant developments have been the invention of integrated product teams (IPTs) and the more general concept of systems engineering. Given the recognition (finally) that the separation of 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 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 and elsewhere.

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. Although the notion of systems is far from new and systems engineering is now an established (if not yet widely acceptable professional role within 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 (conceptual/preliminary designers) of airplanes have been historically. Recognition 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 is the central concern of this paper. There are a variety of recruiting, hiring, and professional development issues that need to be addressed to support various enterprise priorities. Some of these issues are new and unique to our times, for example, the globalization of many of our major companies and the need to deal with an international terrorist threat that now extends to our own shores effectively, whereas others have plagued the aerospace industry for decades. Many of these were discussed in our earlier papers,[1–3] 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? Figures 4–12 (see Ref. 12) are intended to address these questions from a predominantly industrial perspective, whereas additional thoughts on the complementary role academe needs to play 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 Kármán, A scientist discovers that which exists. An engineer creates that which never was. The purpose in pointing this out is to remind the reader of the obvious fact that engineering (design) is not (engineering) science and, as shown in Fig. 4, neither are professionally practiced for their own sake but always within a broader

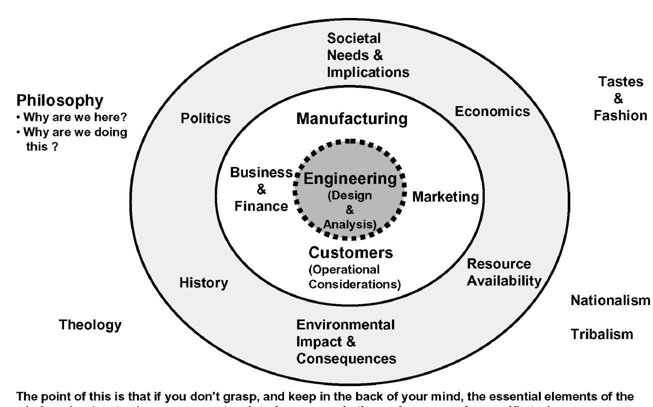

Fig. 4 Engineering is practiced in context: design onion.

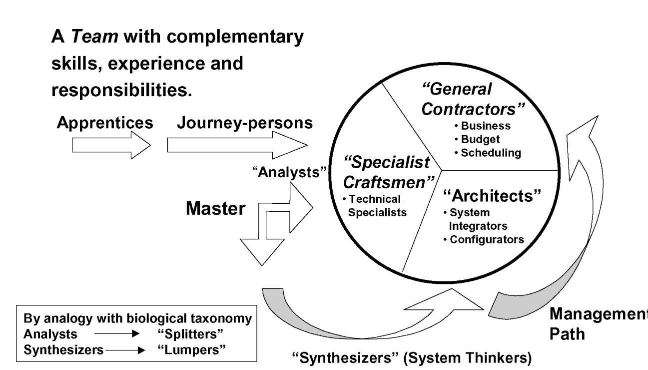

Fig. 5 To build, one needs three kinds of people: Multiple technical career path system for engineers.

context. Even in the engineering-centric sense displayed in Fig. 4, it may further be observed that, as a general rule, to design (and build) just about anything beyond the complexity of a paper clip, there is a requirement as shown in Fig. 5 for at least three classes of individual who may possess one of three levels of skill and experience. Thus, our aerospace industry base has been built over the past century, with a few configurators providing the creative seeds on which a swelling army of technical specialists (engineering scientists and technicians) have performed the myriad analyses and tests required to transform dreams into specific, detailed reality, preferably in high-quality production lots. As this army of engineers and technicians has grown, so has the need for managers swollen, simply to provide some reasonable structure, order, and accountability to a system limited by the ability of ordinary mortals to communicate and cooperate with each other effectively.

The industry that has grown 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, great Clarence L. (Kelly) Johnson's common sense dictum: If you can't solve it with brain power, you can't solve it with man[sic] power. Although 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 and cheaper, we are now confronted with the need to adopt a strict diet of lean[13] as an overriding 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, for example, the information technology/communication revolution and 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. 6. 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 viewpoints shown in Figs. 7 and 8. Indeed, a need for a major restructuring or rebalancing of our technical workforces can be foreseen as shown notionally in Fig. 9.

Taken together, Figs. 5, 6, and 9 show that in the future (starting yesterday) the role historically played by the airplane configurator must now be assumed by an increasing number of the deep generalists (Fig. 9) acting as system architects and integrators. Although a natural progression, also note that individuals with real talent as configurator have never seemed to be abundant in the overall engineering population, as suggested in Fig. 10. Those with a high-level ability for design (and by extension system architecture) probably do not exist in equal measure with those who are good analysts (reductionists) in the general population, much as in the case of other professions such as biological taxonomy. This simple, empirical observation (supported by some data from cognitive psychology) 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 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. 11 and 12 and could

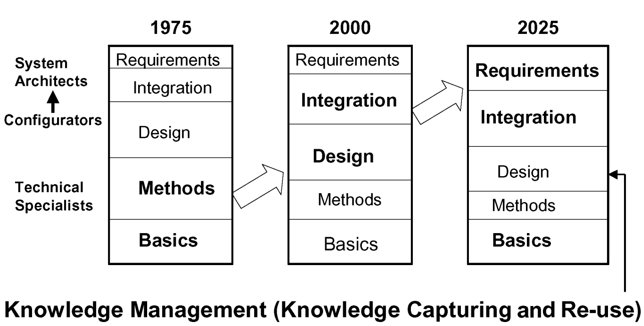

Fig. 6 Changing emphases on engineering work in the coming decades: Increasing demands on the core technical workforce (1975–2025).

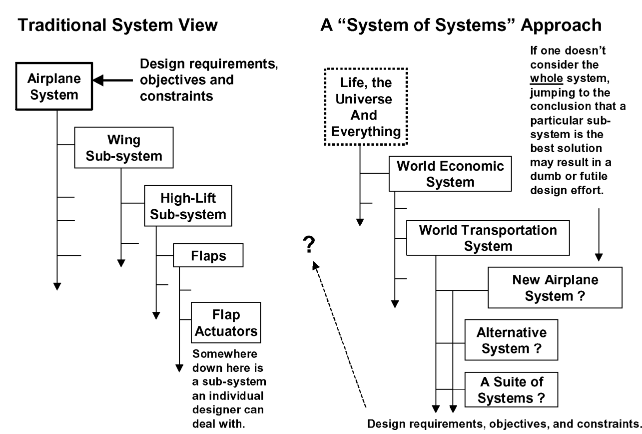

Fig. 8 Changing perspectives in airplane system design, with the specific or implicit objective of improving the air transportation system.

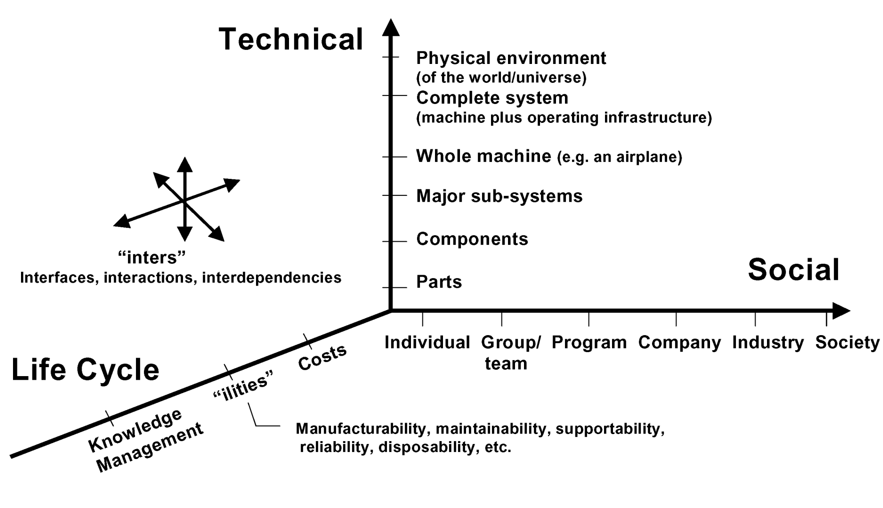

Fig. 7 (Aerospace) engineering systems perspective (Murman, personal comunication): levels of engagement/impact.

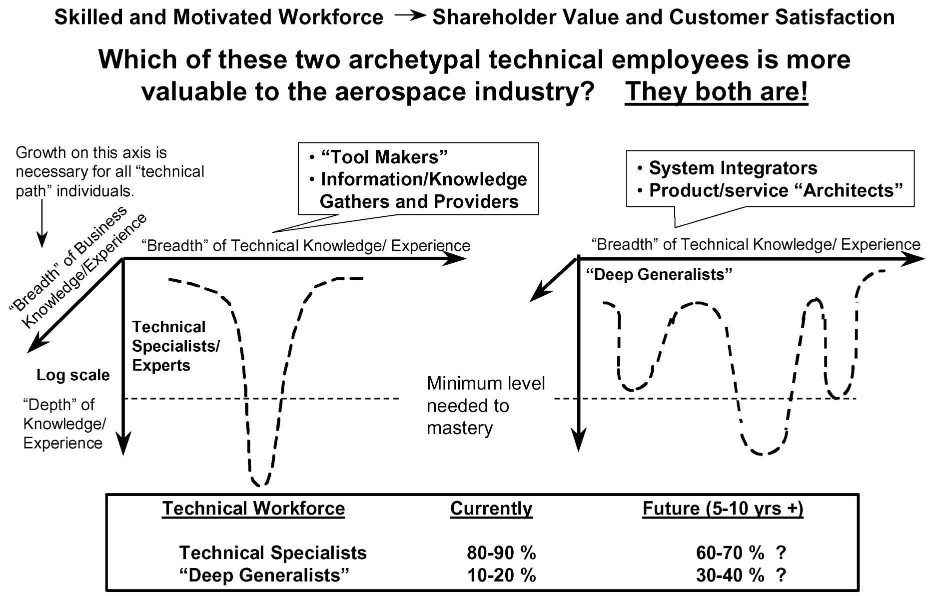

Fig. 9 Engineer archetypes, both are needed in our future.

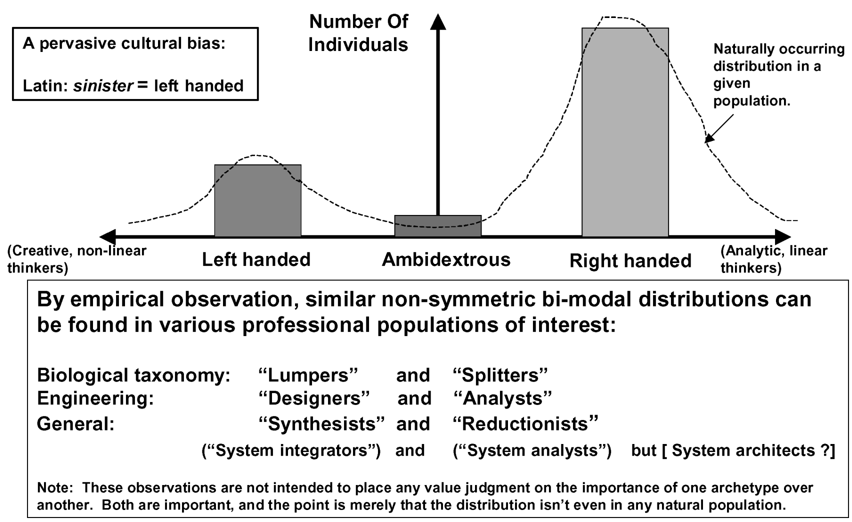

Fig. 10 Observations on the bimodal, nonsymmetric population distribution in engineering and others technical professions.

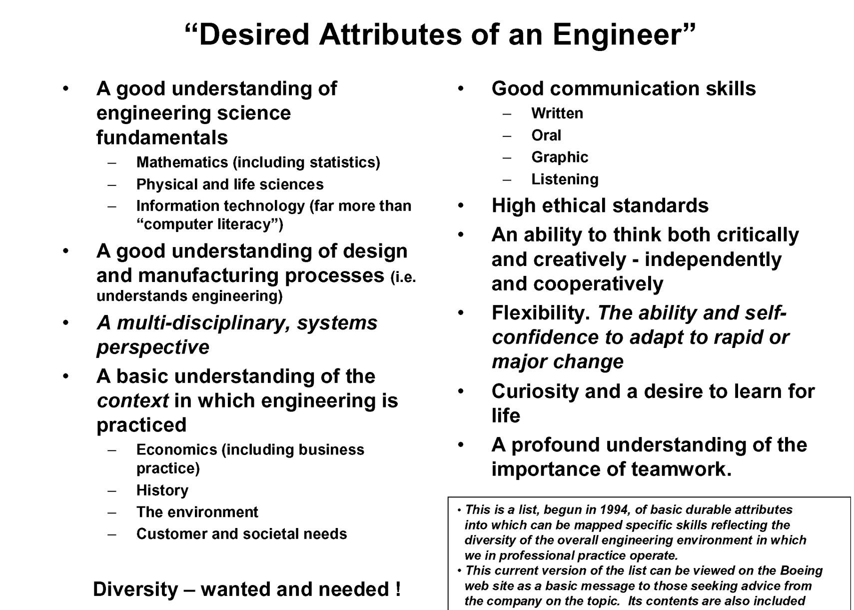

Fig. 11 Time-worn, but durable Boeing list of engineering attributes.

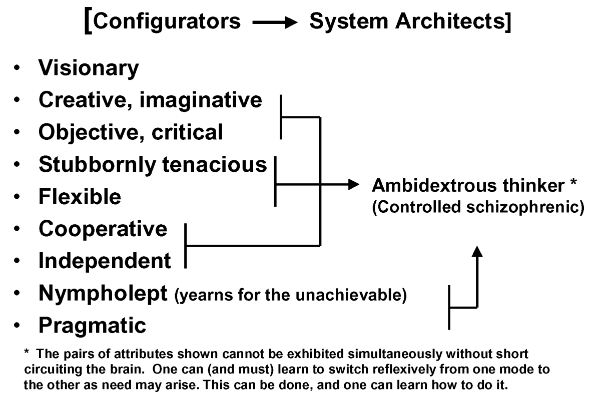

Fig. 12 Precursor and addendum to the Boeing list (cf. Fig. 11 and Ref. 12).

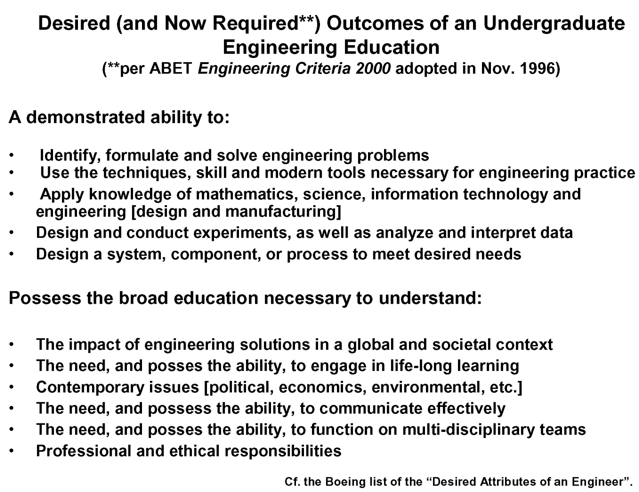

Fig. 13 ABET Engineering Criteria 2000 student learning objectives.

be supplied with additional cooperative effort between industry and academe by a proper interpretation and implementation of student learning centered curricula specified by ABET Engineering Criteria 2000, shown in Fig. 13.

Developing Airplane Design Talent the New Old-Fashioned Way

Although it can be foreseen that our industry will need a greatly increased supply of systems engineering talent in the coming decades, the development of this talent pool must begin while our future employees are still in school. In the meantime, we have an educational system seriously under stress (Fig. 14) and major issues regarding our future supply of talent (Fig. 15). Thus, industry, government, and academe must work together in 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, this section of our paper is included to offer some thoughts on this subject.

Quality vs Quantity Undergraduate Engineering Education

Premise: It is impossible to teach a student everything he or she needs to know as preparation for a professional career in a 4- or 5- (or 10-) year university program.

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 or other fashionable topic area became important in an engineering discipline, then faculty would add a course on that subject to the curriculum.

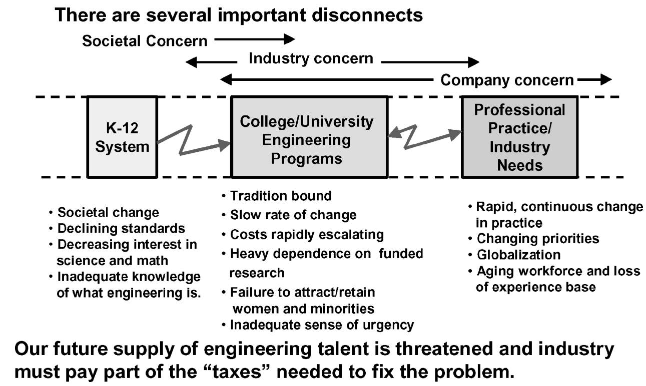

Fig. 14 Our engineering education system; our technical workforce is under stress.

This throw a course at the problem (reductionist or atomization) mentality continued until engineering programs were saturated with courses, within engineering, mathematics science, and the humanities and 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 engineering is not an end in itself. We need to teach students how to learn and how to make learning a lifelong pleasure.

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 in a more holistic and logical sense. 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 a vast bag of tricks for solving selected problems). These basic fundamentals include not only the traditional mathematics science, and information technology core, but also include 1) design and manufacturing, 2) economics and business practices, 3) 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 and customer/societal needs, that is, If you can't build it, you can't use or sell it. 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, that is, 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, subsequent training, and continuing education provided by their employers in close cooperation with academe.

Desired Elements of a Model Engineering Education Program: High-Level View

To achieve the important goals of producing modern engineers of real value to our industry and our society, we need curricula with content that is compliant with the spirit (outcomes based, student-centered, and continuous quality improvement) and intent of ABET EC 2000 (Fig. 13), 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 predominant purpose of the university. Also, an even stronger emphasis on design–build–test project experience[14] from the freshman year through graduation (at

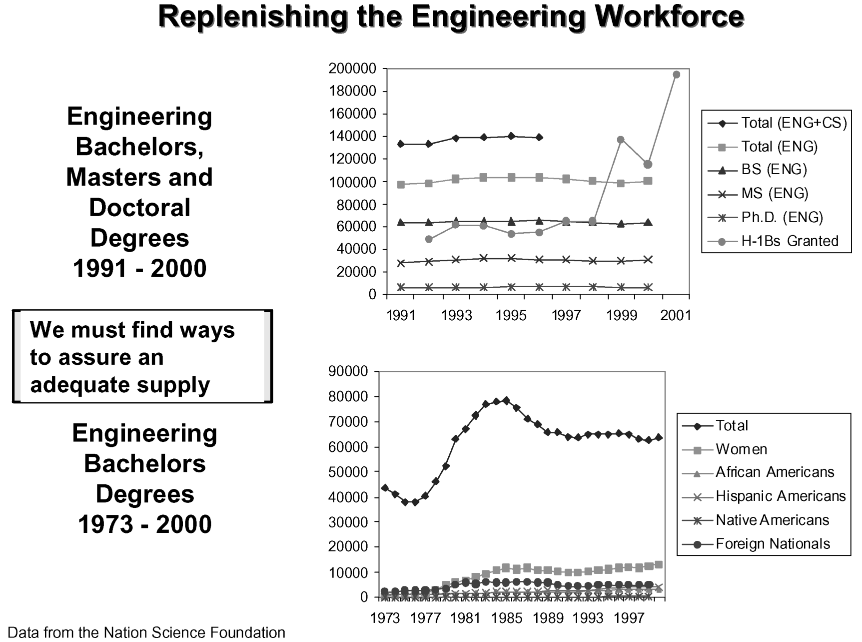

Fig. 15 Supply of engineering graduates may be inadequate to meet our future needs unless steps are taken to attract and retain students.

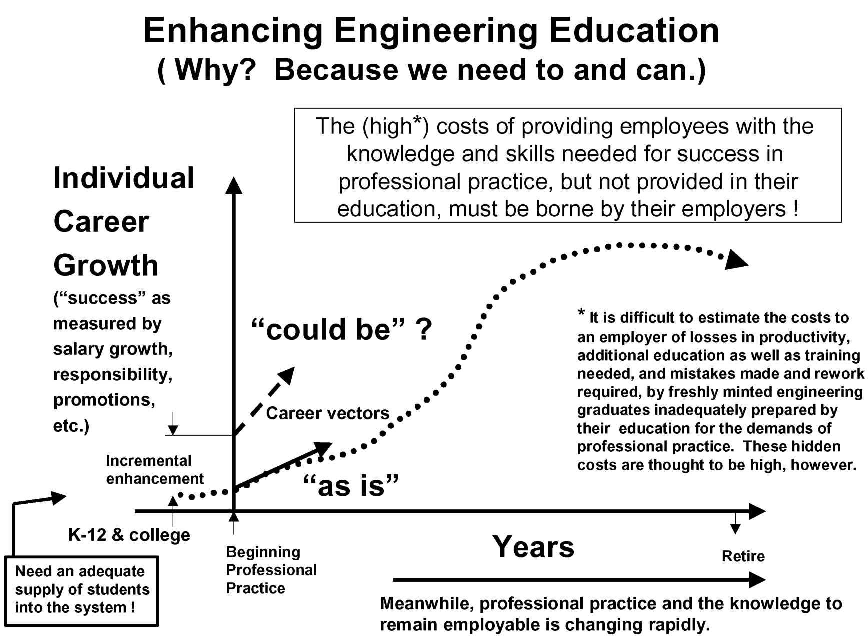

Fig. 16 Industry view on the need to enhance engineering education.

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 for near-term reward. Changing the goals and rewards for faculty may be more difficult than changing the curriculum they teach. This effort needs to be made, however, in parallel with efforts 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 at least literate in this, as were many faculty members during the days of the engineering practitioner before World War II. Industry must be an active partner in this effort, as argued in Fig. 16.

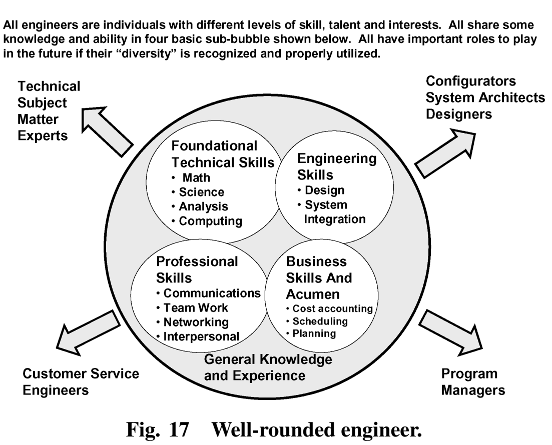

Fig. 17 Well-rounded engineer.

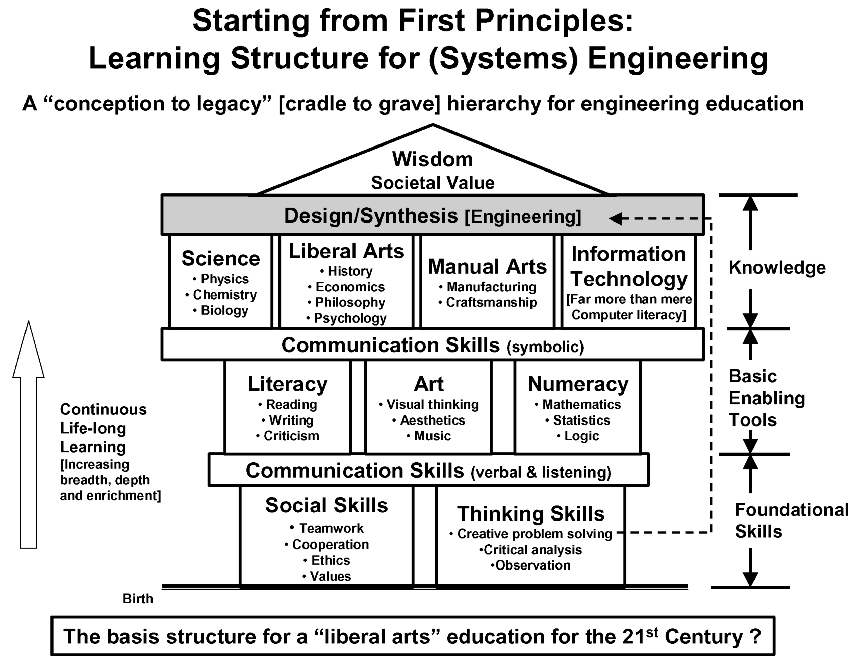

Fig. 18 Elements of comprehensive structure for engineeringeducation.

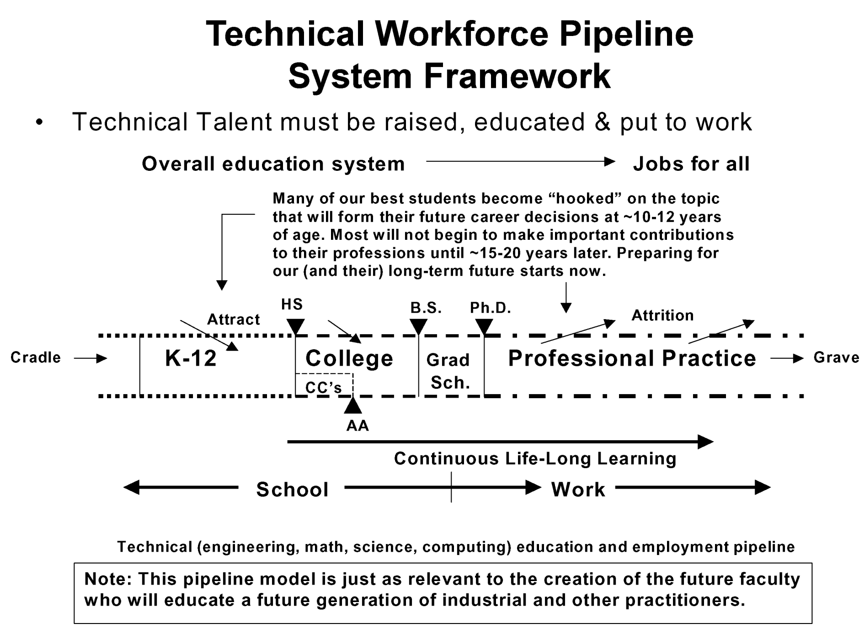

Fig. 19 Strategic view of the engineer supply pipeline.

Perhaps most difficult of all is to create a culture and climate where faculty are willing and able to function as a team. In doing so they will serve as important role models for their students' formative years, as a group of engineers who are true exemplars of lifelong learning and team-based problem solving.

Basic Puzzle for Engineering Academe

The preceding discussion suggests that engineering academe faces as many challenges today as does our industry as a whole. At root, however, it must 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. When this observation is made, it must be recognized that research remains the lifeblood of much of the current system. We have much to do in this arena as well, to assure the future health of our industry.

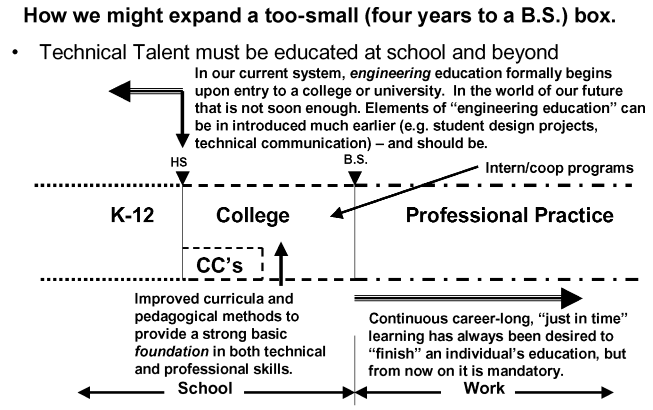

Fig. 20 Some ways to fit more education into too small a box.

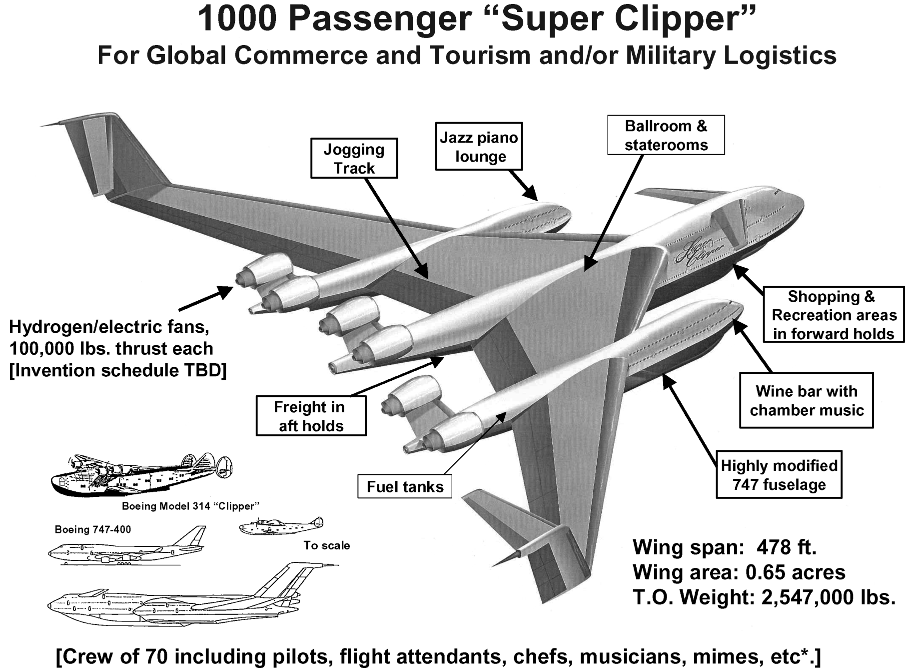

Fig. 21 Possible flight of fancy in our future,[9] if we have the technical talent pool needed to transform dreams into reality.

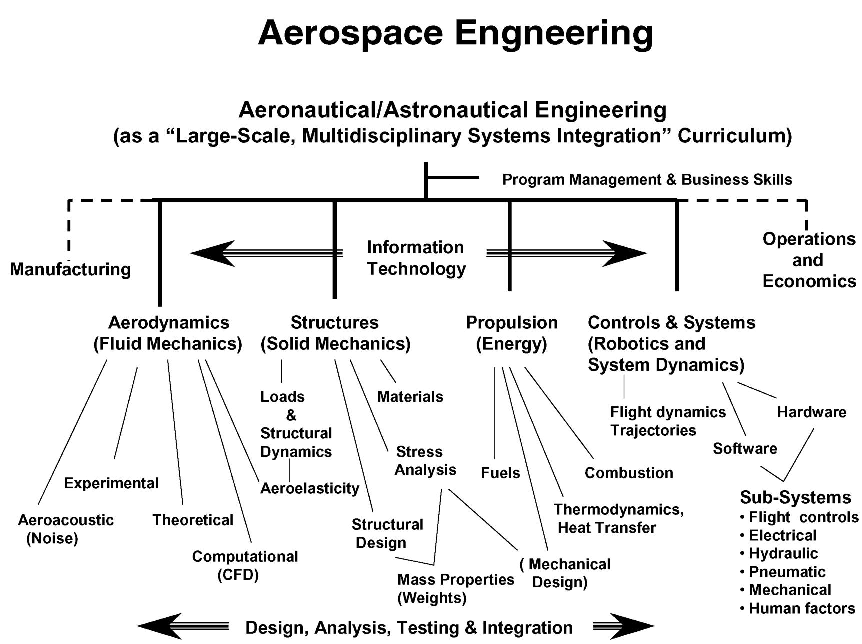

Fig. 22 Way to view the curriculum content of a properly integrated aerospace (system) engineering program.

At a minimum, effective mechanisms must be put in place within academe to integrate knowledge transfer (teaching, mentoring, etc.) with research and community service, both 1) vertically between graduate and undergraduate programs and 2) horizontally across department, college, and discipline boundaries. How all of 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. Figures 17–24 are offered as additional thoughts on the topics discussed in this section of the paper.

Thoughts on Vision in Aeronautics

Given the turmoil in aerospace over the past decade and (when our series[1–3] began) appallingly low employee morale in some areas as typified in our recent exchange[2,5] with one of our vociferously malcontented colleagues, it is clear that one of our foremost challenges is to deal with the vision issue.

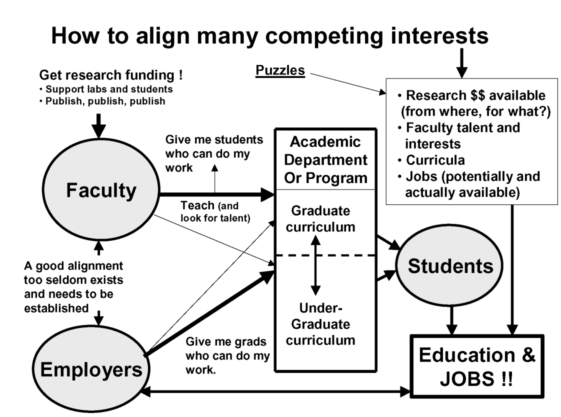

Fig. 23 Puzzle for engineering academe (and all of us in aerospace).

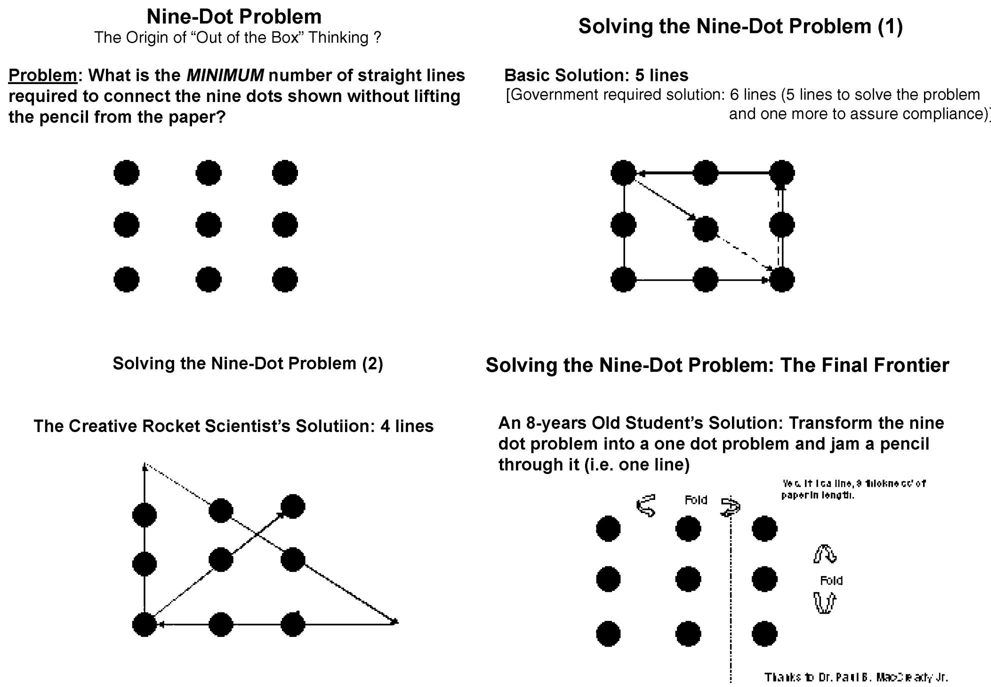

Fig. 24 Famous nine-dot problem, a paradigm for paradigm shifting.

From our perspective (as working-level members of the engineering community), we can see several things that contribute to the "we are a dying business" problem that have not been adequately addressed by our leaders (and our fellow colleagues themselves). First, and foremost, has been the message given to all of us over the past several years, from our CEOs on down, that the world is changing dramatically, and we have a continuing industry-wide business crisis that demands that we all devote our full attention to process improvements emphasizing cost and cycle time reductions with concomitant productivity increases. Whereas this may be true, it is not a message that resonates sufficiently strongly with a substantial portion of our technical workforce. It has suggested to us that all of the "cool stuff" that engaged us in the past is no longer important and that technology really does not matter much any longer. All of us must now change gears and concentrate on the "boring stuff" that will keep Wall Street and, thus, our investors (and at least some of our customers) happy, whereas globalization is merely code for domestic job loss. All of this is at best simplistic, with a strong whiff of nostalgia as some of our leaders have correctly pointed out. It still creates the perception that our now mature industry has become about as exciting to work for as the bus or refrigerator manufacturing industry.

In marshaling our forces to address the challenges we face in our immediate future, the central thing that needs to be done is to send our technical workforce a message that they can relate to rather than a mere exhortation to do the necessary right things. Specifically, we need to do the following:

1) We need to create a product (and important service) focused vision of our future as compelling as that which has driven our past. Regardless of whatever else we are trying to do as businesses, the core of that business will remain designing and building the neatest products (airplanes) there are, ones that remain both exciting and useful to our customers and our society. There is a very large difference between being a mature industry and a dying industry. The technical challenges in our future may well have a different focus, for example, reduced cost, but the same level of creativity, imagination, and innovation as was required in the past still will be required in our future. Creativity and imagination are items not easily outsourced.

2) We need to create a very simple focus for our people. A fundamental and overarching objective might be to emphasize pride. Once upon a time, being an aeronautical engineer was a badge of pride, and it still is to some of us as a positive aspect of our nostalgia.

3) We need to build a robust people-focused infrastructure at both the national and local (company, agency) levels that effectively serves our future needs. Building this infrastructure will take some time, but if it is done in concert with the necessary messages to our people to motivate them to persevere, we really can do much to assure the future health and vibrancy of our enterprise.

Looking back at the history of our aerospace enterprise from the perspective of a long career in it, one sees that much of our post-World War II progress was driven by cold war imperatives with the gut-wrenching prospect of nuclear holocaust as a fundamental consequence of failure. Global competitiveness simply does not have the same sort of immediacy, even if the consequence of failure by a company to meet new challenges may be rather devastating to those who have spent their careers in it. Our real challenge is to find the messages, a vision, that can motivate us into our future. Our products, real or fanciful, (Fig. 21) remain a primary hook for this.

Conclusions

This paper and our earlier series[1–3] have been primarily concerned with the advancement 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 system (of systems) perspective. Many issues have been raised and many thoughts and suggestions have been made about how these might be viewed and dealt with in the future 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 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 11 September 2001 and their aftermath, albeit 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[1–3] may still be considered valid. An important conclusion of that work was that, whereas 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 chose to be involved in its future. Although 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 can have only vicariously experienced.

The aerospace industry, like our stock markets, both nationally and globally, can be expected to prosper over the long haul, barring a complete collapse of the world economy. Whereas space exploration and astronautics has an obvious future, for example, to make the dreams of science fiction some form of reality, there is no reason to predict that aeronautics has a future any less bright, though more down to Earth, despite too many recent predictions to the contrary. Airplanes are not a done deal with nothing of substance to look 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:

1) 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, for example, via the internet or any potential future "holodeck" developments.

2) Prospects for flight in hostile environments, from O'Hare to Afghanistan to Mars and beyond, cover a myriad of opportunities and issues both civil, for example, operations in any weather or extremes in hot and cold, etc., and military (UAVs again enriched by consideration of biological flight systems,[7,8] etc.). In this latter connection, it may be observed that flight at extreme conditions (altitude or temperature) in the Earth's atmosphere by robot airplanes is little different than the problem to be solved in flight in other planetary environments.

3) 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. 22, aerospace engineering (in the broader sense indicated) remains the single institutionalized multidisciplinary, 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 should learn to market their graduates as such, as an aid to ensuring a continued supply for both our own industry needs and for many others as well.

We all (industry, government, and academe) as an aerospace community have much to do to ensure our future security and prosperity. Individually, we face often seemingly insurmountable challenges, as shown in Fig. 23, but collectively we can succeed if we have the will and imagination to do so. To quote the U.S. composer, John Cage, "[We] don't know why people are frightened by new ideas. It's the old ones that frighten [us]."

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