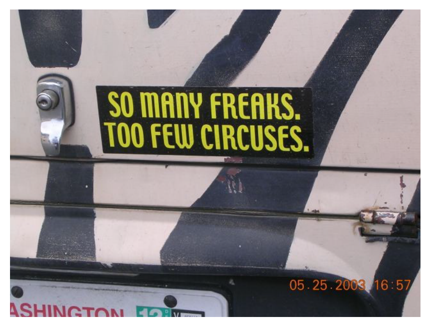
AIAA 2004-1376

Some Systemic Issues in the Development of the Aerospace Industry Technical Workforce of the Future

[Vol. 7 in a series: *The Demise of Aerospace – We Doubt It* or *The Airplane Design Professor as Sheepherder*]

John H. McMasters
The Boeing Company
Seattle, Washington 98124

Russell M. Cummings
Aerospace Engineering Department
California Polytechnic State University
San Luis Obispo, CA 93407



42nd Aerospace Sciences Meeting
5-8 January 2004
Reno, Nevada

Some Systemic Issues in the Development of the Aerospace Industry Technical Workforce of the Future

John H. McMasters*
The Boeing Company
Seattle, WA 98124

Russell M. Cummings†
California Polytechnic State University
San Luis Obispo, CA 93407

Abstract

This paper is a continuation of the authors' previous examinations of a suite of issues surrounding the putative decline in aeronautics in this country. The purpose of this paper is to discuss three specific issues believed to be of particular importance to the future of our industry. The first is the question of how many engineers we may need in our future as we confront the problem of an aging workforce and the globalization of our industry. The second is the question of what skills and abilities these engineers will need to possess as the overall industry continues to evolve. Finally, the need for more systems-oriented, multidisciplinary-skilled talent is addressed. A basic message of the paper carried on from earlier writings is that while aeronautics may indeed be a "maturing industry" (at least in some major traditional product areas), there is much that we can and should do to create a vision of our future as vivid as that which has driven our past as a means to attract and develop the talent needed to assure the future of our enterprise. Without this talent, few of the major technological advances that can be currently foreseen can come to fruition.

* Technical Fellow. Associate Fellow, AIAA.
† Professor, Aerospace Engineering Department. Associate Fellow, AIAA.

Introduction

The present paper is the seventh in a series[1-6] the authors began in 2000 under what has become the general rubric: "The Demise of Aerospace – We Doubt It." The series was initiated as an attempt to counter some of the excesses[7] of a continuing spate of national studies and articles in both the popular and professional presses that has decried the seriously declining state and future of aeronautics (and aerospace in general) in this country.

The principal motivations for all this has been discussed at some length in our earlier writings[3-5] and in connection with this paper, it is based on the simple observation that 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[8] that: *The best* (and most visionary) *technology and processes in the world are useless without the right skilled and motivated people to develop and apply them*.

These "social" and economic aspects of our enterprise are of fundamental concern to our future, but are too frequently ignored or treated as a separated, disconnected topics in the aeronautical engineering literature. In reality, technology, processes and people form an inseparable triad in aerospace. It continues to be our purpose to treat them as a unity with emphasis merely shifting depending on the specific topics to be discussed.

A basic premise of our series of papers[1-6] is 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 chose to be involved in its future. It is fundamentally important to convey this message to our students, for without their talent, our aerospace enterprise can have only a drab and pedestrian future – no matter what future technological fancies[8] we may contrive in our imaginations. While future engineers 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 experienced only vicariously.

While the initial series of our papers[1-4] discussed a broad range of issues and opportunities the authors consider important to the future of our enterprise, this paper returns to a suite of people issues that need to be addressed in order to exploit the topics discussed in two other papers in our 2004 trilogy. A companion paper[5] deals with possible advances in the airplane design process and means to advance this art, while a second in this year's series[6] deals with possible advances in aeronautical technology as viewed in a much broader multi-disciplinary context.

An Aging Workforce

It is now a truism that the aerospace industry is currently suffering from an aging workforce problem that in turn means that we have a suite of major problems to deal with in replenishing the talent base required to assure our future. As globalization continues and increasing amounts of work are either outsourced or mechanized (in the inexorable quest for increased productivity and cost reduction), the entire shape and form of our technical workforce of the future can be expected to change (at least domestically within the United States). This raises the more basic question of: "How many engineers do we actually need in our future? [The parallel question of "What do we need them to do?" will be addressed later in this paper.]

As shown in Fig. 1, one may consider the factors that would tend to create a need for an increase in our national aerospace engineering workforce (noting that this number includes more mechanical, electrical, computer, etc. engineers than it does those with specific "aerospace engineering" degrees) versus those factors which would allow a decrease, it might be logical to project that the two lists are roughly compensatory and that the number we now have is about the same as the number we will need over the next decade or two as a general trend (despite continual fluctuations about the mean as has been true throughout much of our history).

Given the "optimistic" projection shown in Fig. 1, mere cloning of what was (i.e. seeking to replace one-for-one the talent that is retiring or otherwise disappearing) is not the solution to our problem, however. On a pure "change in numbers" sense, the transformation of several of our major companies has already been dramatic (Fig. 2). Far more ominous than the treat of further diminution from retirement, outsourcing and downsizing is the prospect that, as our enabling technology continues to develop, whole classes of jobs may simply disappear as has been the case in other industries across the country. This latter is more threatening to the future employability of many of our co-workers – present and future – than the clear threat of having our work outsourced.

For specific companies which have already experienced the trials of post-Cold War downsizing, and a second wave caused more recent by a downturn in the business cycle, the aging workforce problem looks either like that shown in Fig. 2 or, nearly as bad, Fig. 3. Whatever the size of our specific company or agency technical workforces, the age demographic distributions shown in Figs. 2 and 3 are not sustainable, and steps must be taken to attempt to establish the healthier balance shown notionally in Fig. 4 at the earliest possible opportunity. This is nothing less than an issue of healthy, long-term survival for many.

All this is made even more complex by the shifting ethnic demographics of our society, and other factors which must be weighed in establishing the proper mix of skills, talent, diversity, etc. in creating our workforce of the future and is, perhaps the major challenge our enterprise faces in the current decade, in the authors' opinion. How this overall situation might be viewed and addressed in the future (starting yesterday) is the subject of the remainder of this paper.

Thoughts on Creativity and Innovation – A Philosophical Digression

Before discussing the question of what sort of engineering talent we will need in the future, it is first necessary to discuss some basic "philosophical" issues related to the nature of our always "innovative" and highly technical aerospace enterprise, and connect this paper with our earlier writings on engineering and design topics.[3-6]

According to Webster:

Invention – The act of inventing (to produce or devise first, to make up or concoct); A new method, process or device evolved from study and testing.

Innovation – Something that is new or unusual

Design – To think up, invent. To form a plan

Creativity – The art of being inventive or imaginative

We had hoped for more from Webster when we looked up these definitions. They do poor justice to, and do little to clarify, a complex suite of mental processes involved in creating something really new. They also fail to make precise ideas and concepts that are used too loosely, just as we too often use "smart" and "wise" synonymously in general conversation.

We have thought on many occasions about the terms "design" and "invention" in connection with the conception and design of new airplane systems because the distinctions between the two concepts are often miss-used or not well understood by our students in design courses we have taught over many years (and too often by many of our industrial and faculty colleagues). In this connection, the newer buzzword term "innovation" has been far too overused and adds little to a discussion of what talent and skills are needed by our industry in the future.

It is perhaps more useful to think in terms of a sort of hierarchy of creative processes in which invention is at the top, design or innovation (which may require no "invention") in the middle, and devising clever tricks and workarounds to specific problems that may arise (which often involves a degree of "innovation" and sometimes considerable creativity) at the lowest level. Regardless of the taxonomy used, all this is less about technology than about people and how they think. It is a fundamental "people issue".

Invention

Invention is an interesting process and is usually assumed to involve the creation "out of nothing" (other than the basic laws and artifacts of physics and chemistry) of something completely new. This isn't quite accurate in general. Most invention involves nothing more than making highly imaginative connections between sometime wildly dissimilar (but often prosaic) things and concepts that already exist (i.e. there actually is little new under the sun; there are, however, a vast myriad of ways to connect the dots "inventively").

In one of the wiser pieces of literature in my archive,[9] it is noted that the mental processes of invention are very similar to those involved in creating humor. A lot of comedic routines depend on making non-obvious connections between common everyday events. This connection between humor and invention is not trivial, and provides one strategy for encouraging creativity and inventiveness in individuals at all levels of professional experience. Two or three smart people laughing and joking about a problem or situation over a beer can sometimes make amazing (synergistic) and unexpected discoveries when their normal censoring guards are lowered by mirth (and some, but not too much, alcohol). It works and it is not an accident, in our opinion, that some great ideas have had their origins on the backs of bar napkins.

Design and Innovation

Too many people we know and work with seem to have a frail understanding of the similarities and distinctions between "design" (innovative or not) and "invention". While a design is usually "new" for a new product, gadget, or service (depending on the requirements and constraints), it need be neither innovative, nor does it necessarily require invention.

A design is really just a "plan" with all needed supporting drawings, analyses, tests (or sub-plans to get the data), etc. that when made real (built or executed) will produce the desired end result. This definition has some important implications in terms of future engineering practice. Specifically, in the context of currently fashionable Knowledge Management theory, the concept of "knowledge re-use" arises. Think of all the money a company could save in the development of a new "something", by coming up with a design that is merely a repackaging (to better effect) of things we already have in hand or know how to do. This may take considerable creativity and ingenuity (perhaps even some innovation), but no "invention" is required. Why spend money to "reinvent the wheel" if you already have a perfectly good template for one ("pride of authorship" issues aside)? Such a process, fully matured, could in fact be considered highly innovative and looms large in our possible bag of future opportunities.

A second major area of innovation[6] in our future will be to "mine" the knowledge base emerging or already in hand from a widening range of potentially useful technologies and disciplines (some traditional in our business, others not) and synthesize it into new designs for things (products, services, processes, etc.), either traditional or new.

As a sub-set of this process, taking an existing design and replacing an old element or process with a new one is often considered innovative. As our knowledge in specific, mature disciplines (aerodynamics, structures, etc.) run the limits of their practical potential for further discovery or development, the opportunities for perhaps unconventional cross-disciplinary synthesis and synergy becomes the next frontier for further advance. These opportunities are still abundant (even in our traditional product lines), and are further enriched by new developments such as nanotechnology, advances in knowledge in non-traditional areas such as neurophysiology, cognitive psychology, cultural anthropology, etc., and the "system of systems" concepts underlying the study of ecology. Their full exploitation is often limited, however, by the parochialism or "stove pipe mentality" that has developed in each specific mature discipline, together with the "reward and recognition" systems that have been developed to perpetuate and reinforce the boundaries between each.

Making the transition from a workforce development system that encourages our engineers to mature in accord with a single discipline "technical specialist" mind set, to one that places high value on those (not necessarily all) with a fully developed multi-disciplinary systems perspective and concomitant expertise (in depth), is a fundamental "people issue" for the aerospace industry.

"Innovation, for the sake of innovation can be a great waste of time (and money)."

Rule #2 (from the as yet to be written)
Airplane Configurator's Handbook

Engineers of the Future

Creating a strategy for future technical workforce development is roughly analogous to the problem of adhering to the requirements of ABET Engineering Criteria 2000 in creating an educational program. It involves defining what the mission or business goals of the particular agency or company are to be, and then assessing which core competencies and processes are needed to meet the defined goals and objectives – and thus the number and types of people required to execute the plan. This is best done by starting from some "first principles" and for purposes of this discussion, Figs. 5-7 are taken from an earlier paper.[4] Figure 5 is an attempt to define the basic types and skill levels of people needed for most companies and organizations in our enterprise. Figure 6 then elaborates on the two basic engineer archetypes required – making clear that choosing one versus the other is not an either/or dilemma. Both are needed, the main trick being to get the balance right, and a current "best estimate" is suggested in the figure.

Figure 6 is an attempt to estimate, in generic terms, the type of work a predominance of our people will be required to do as our businesses continue to evolve, more work is automated, etc. In at least the larger prime and major sub-contractor companies, more and more technical work will become system integration and requirements development activities. There is still a need for the "specialist", but in our current estimate, "systems engineering" is one of the major, clear growth career areas within our industry, and this is one that is probably as robust as any against the ill fortunes of outsourcing. Other more traditional specialties within the standard aerospace technical disciplines may wax or wane, while new ones develop, but as far as any reasonable crystal ball allows us to see into our future, design and systems integration are not likely to diminish in significance.

The Need For System Engineers

The authors' argued the need for more systems engineering talent at some length in an earlier paper[4] and that discussion need not be repeated. Several points do need to be reemphasized or clarified, however. A problem with the current use of the term "system engineer" is that it means too many things to too many people, and it has different connotations to those who work primarily with a government or defense related customer base, versus those who work primarily in the civil/commercial product world. In the latter context, the term system engineer still has the meaning of one who develops a hydraulic, flight control, or computer system, and this is far from what is intended in this discussion. For specificity, the following Boeing definition is offered as representative of what is wanted in more generic terms.

Systems Engineering (SE) – An interdisciplinary collaborative approach to derive, evolve, and verify a life cycle balanced system solution that satisfies customer expectations and meets public acceptability. Systems Engineering is a generic problem-solving process that provides the mechanisms for identifying and evolving the product and process definitions of a system.

Systems engineers tend to come in one of three basic flavors:

System Analysts – Individuals who can decompose a complex system in a well ordered, disciplined fashion to allow necessary component tasks to be performed

System Architects - Individuals who can transform a set of requirements and constraints into a well-defined system that meets customer needs

System Integrators - Individuals who can integrate the work of various groups dealing with sub-elements of a large system so that the sum of the parts produces the desired result

As pointed out in our earlier papers, system talent (especially those who serve as "system architects") is relatively rare in the general engineering population (Fig. 8) and special care is needed to cultivate and develop it in student and apprentice-level engineers. While Fig.8 was originally presented as a "heuristic" based on the authors' personal experience, but otherwise unsupported by any data, we have since discovered the Myers-Briggs Type Indicator (Fig. 9) as a good way to understand and map what we think of as "intellectual (and social interaction) diversity. It also has a database associated with it (Fig. 10), that does support Fig. 8 and also shows some interesting gender differences along the way. Here it must be pointed out forcefully that Myers-Briggs, is not a strength, talent or IQ test. It merely shows an individual's preferences for certain patterns of thought and social action in an ideal setting. *All people can and do act out of type, when need arises.* Further, no value judgment is made regarding the value of one Myers-Briggs type relative to another.

From this discussion one concludes that "systems thinking" is a skill to be developed and cultivated in those who have the necessary (if latent) capability for it as shown in Fig. 11. Among the ways this can be done, the following are important needs:

– An identification process of those individuals who have a reasonable probability of being "good at it" [e.g. based on Myers-Briggs]. This includes considering an individual's:

- Breadth as well as depth of knowledge and experience
- Curiosity and eagerness to learn new things
- Interest in concepts, meaning and context
- Flexibility

– A strategically oriented job rotation program (well beyond a particular discipline or specific technical area) as shown in Fig. 12.

– Targeted continuing education and training as needed to provide in-depth foundational rigor and exposure to fundamentals not provided in work assignments

– Targeted work assignments that provide a practicum for dealing with "system problems" of increasing complexity

– Mentoring (lots of mentoring!)

– Special assignments as opportunities arise that provide a non-traditional breadth of knowledge or perspective – or which simply stimulate "systems thinking"

– Exposures to important new technologies such as multi-disciplinary optimization (which can be more powerful as learning devices than as mere working tools) – operating like "video games."[5]

The desired outcome of all this is to produce a substantial cadre of "well rounded engineers" as shown in Fig. 13, that can form the basis of a highly flexible and effective technical workforce.

Some Concluding Comments

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, but design and systems thinking likely will remain a core capability in any imaginable future aerospace industry in the future. As shown (again) in Fig. 14, aerospace engineering remains the single *institutionalized* multi-disciplinary, large-scale systems-oriented program in our current engineering education system. As our need increases for "systems of systems thinkers" across a broad range of professions, 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 assuring a continued supply for both our own industry needs and in many others as well.

Acknowledgements and a Disclaimer

The authors owe a substantial debt to many individuals who have contributed thoughts or inspirations used in this paper. While too many to list exhaustively, several must be acknowledged for their singular importance. These include: Robert E. Spitzer, The Boeing Company; Michael S. Francis, DARPA; and our old friend,[3] "Dr. Sliderule" (wherever, and whoever, he may be). This paper remains an ongoing work in progress and reflects the authors' own opinions that may not necessarily reflect the views or positions of their respective employers. We made this all up, and remain solely responsible for its contents.

References

1. McMasters, J.H. and Cummings, R.M., "Airplane Design – Past, Present and Future," AIAA 2001-0535, Jan. 2001 [also published in the *Journal of Aircraft*, Vol. 39, No. 1, Jan.-Feb. 2002, pp. 10-17].
2. McMasters, J.H. and Cummings, R.M., "The Demise of Aerospace – We Doubt It," *Flight Journal*, Aug. 2001, pp. 97-8.
3. McMasters, J.H. and Cummings, R.M., "Airplane Design as a Social Activity: Emerging Trends in the Aerospace Industry," AIAA Paper 2002-0516, Jan. 2002.
4. McMasters, J.H. and Cummings, R.M., "From *Farther, Faster, Higher* to *Leaner, Meaner, Greener* – Future Directions in Airplane Design in the New Century," AIAA Paper 2003-0553, Jan. 2003 [accepted for publication in the *Journal of Aircraft*, 2004].
5. McMasters, J.H. and Cummings, R.M., "Rethinking the Airplane Design Process – An Early 21st Century Perspective," AIAA Paper 2004-0693, Jan. 2004.
6. McMasters, J.H., "Airplane Design and the Biomechanics of Flight – A More Completely Multidisciplinary Perspective", AIAA Paper 2004-0532, Jan. 2004.
7. Dr. Sliderule [Anonymous], "The Demise of Aerospace", *Flight Journal*, Dec. 1999, p. 122, 121.
8. "The Future of Flight (special issue)," *Popular Science*, Nov. 2003, p.64.
9. Chaplin, C.R., "Creativity in Engineering Design – the Educational Function," U.K Fellowship of Engineering Report No. FE 4, Nov. 1989.

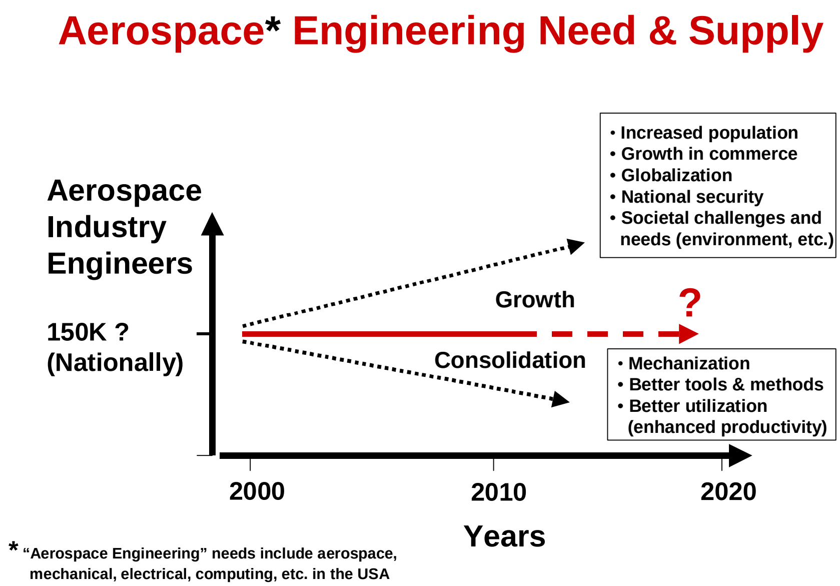


Figure 1. How Many Aerospace Engineers Do We Need?

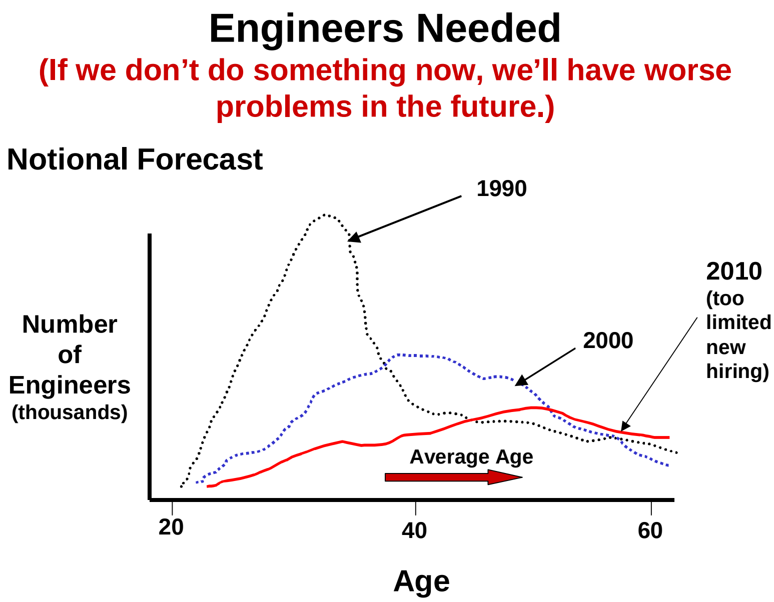


Figure 2. An Aging Workforce

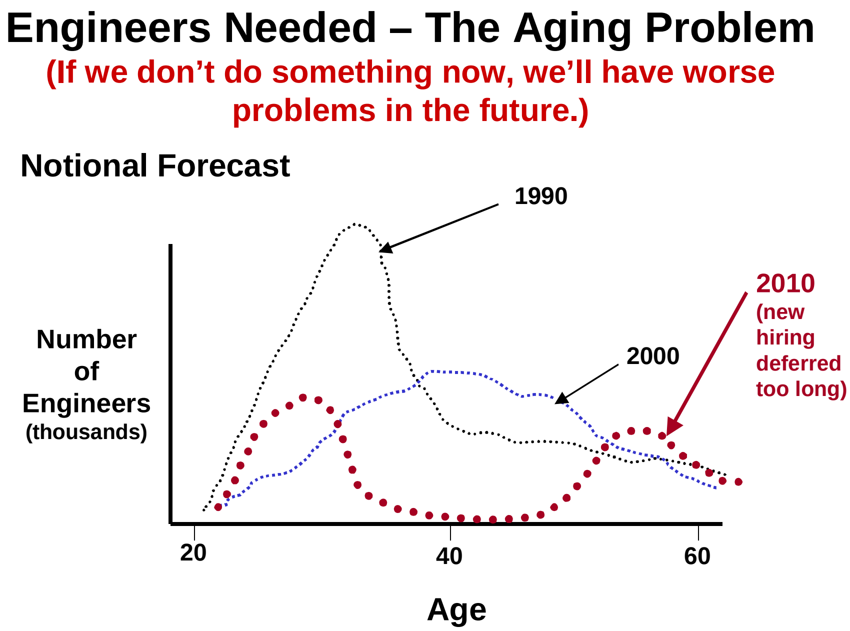


Figure 3. The Consequence of Deferring New Hiring Too Long

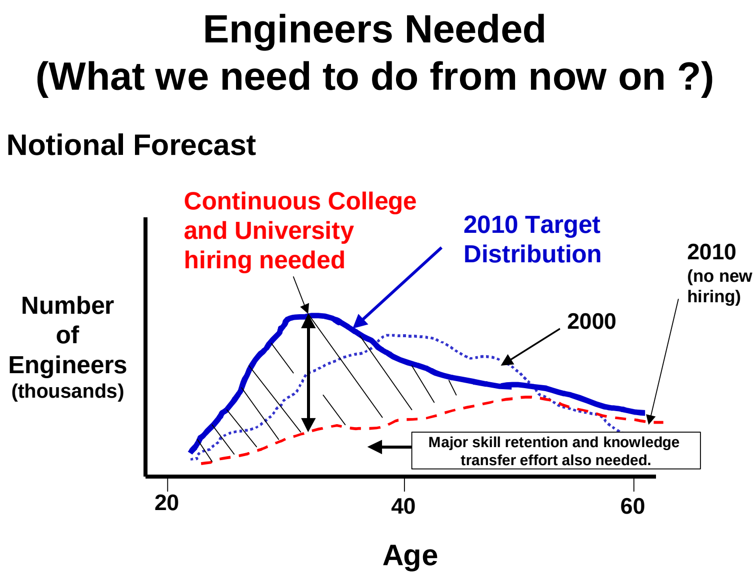


Figure 4. Achieving a Healthy Balance

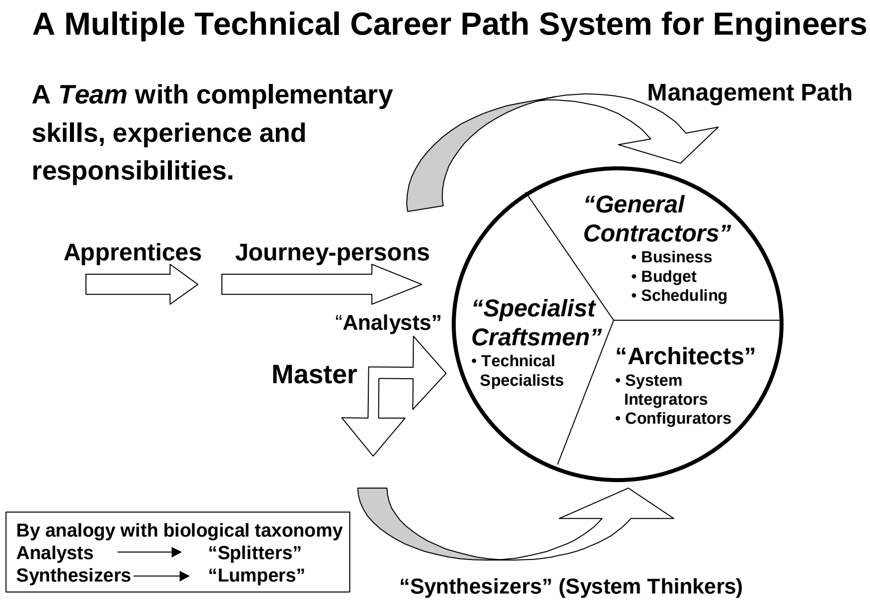
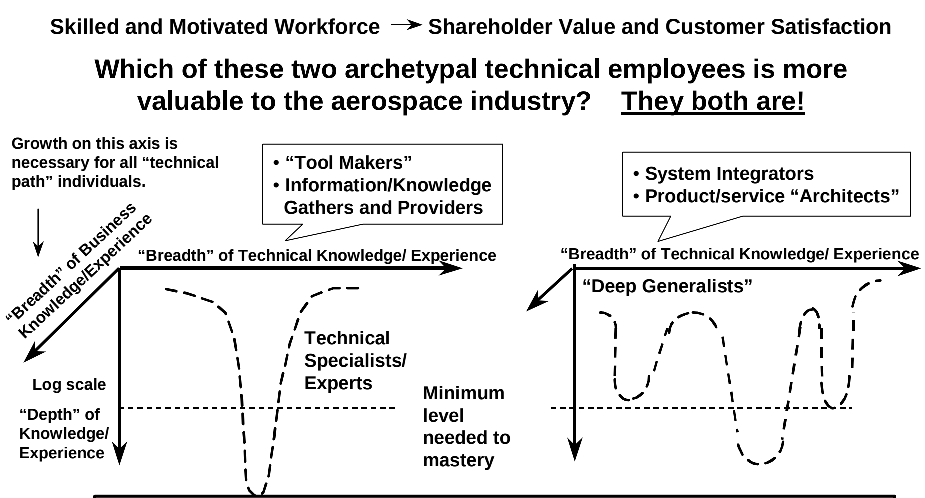


Figure 5. Engineers Needed – What Kinds and Flavors.



Technical Workforce	Currently	Future (5-10 yrs +)
Technical Specialists	80-90 %	60-70 % ?
"Deep Generalists"	10-20 %	30-40 % ?

Figure 6. The Archetypical Engineer – We Need Both.

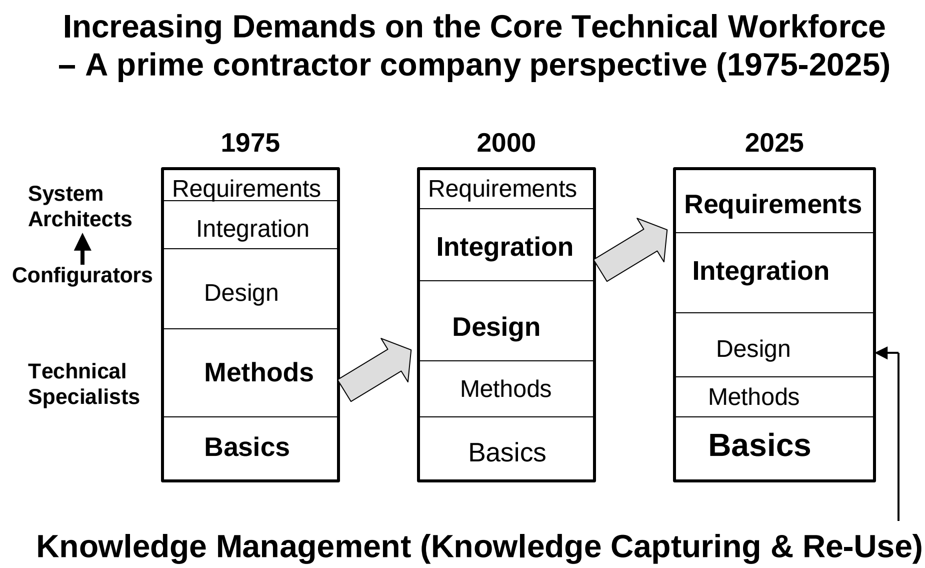


Figure 7. Up the Value Chain in Engineering Work.

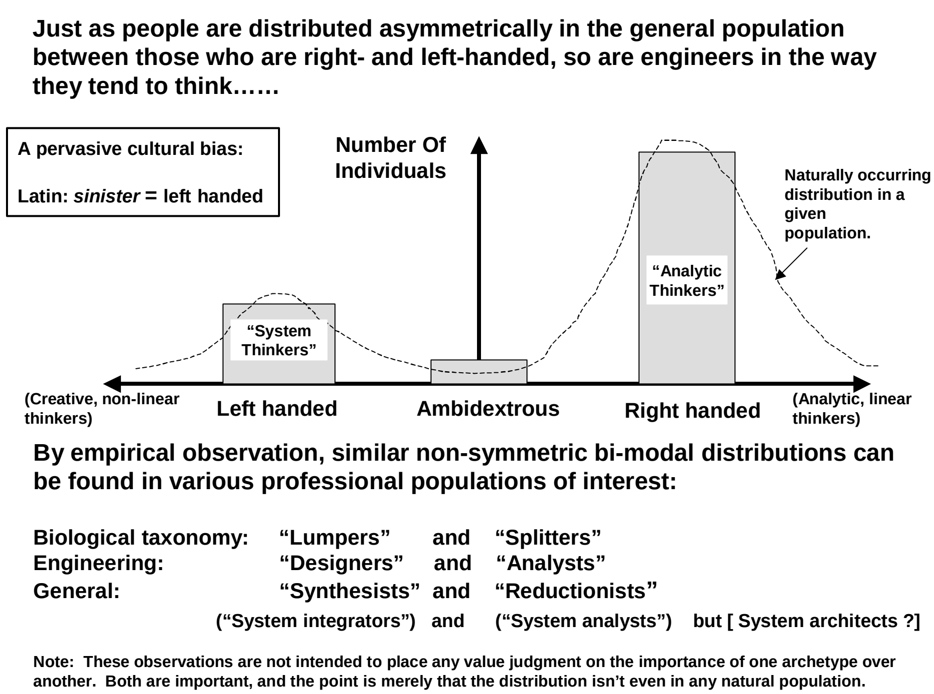


Figure 8. We Have a Basic Supply Problem.

Myers-Briggs Type Indicator Dichotomies

E — Extraversion ⟷ I — Introversion

- Extrinsically motivated
- Focus on people and things

- Focus on thoughts and concepts
- Intrinsically motivated

S — Sensing ⟷ N — Intuitive

- Bottom up – specific to general
- Facts and data driven
- Detail and utility oriented
- Here and now orientation

- Top down – general to specific
- Concepts and meaning oriented
- Theory and speculation
- Future oriented

T — Thinking ⟷ F — Feeling

- Objective analysis of cause & effect
- Decisions based mainly on logic

- Subjective evaluations
- People centered
- Decisions based mainly on values

J — Judging ⟷ P — Perceiving

- Prefer planning and organization
- Prefer to have things settled

- Prefer flexibility and spontaneity
- Prefer to keep options open

Note: It is important to recognize that the Myers-Briggs construct places no value judgment on the importance of one personality type over another. People can (and frequently do) act outside a given type preference as need arises.

Figure 9. Myers-Briggs Dichotimises.

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%	

Types predominantly attracted to engineering and science are:

ISTJ
INTJ
INTP
[ENTJ]

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

Figure 10. Myer-Briggs National Data Sample.

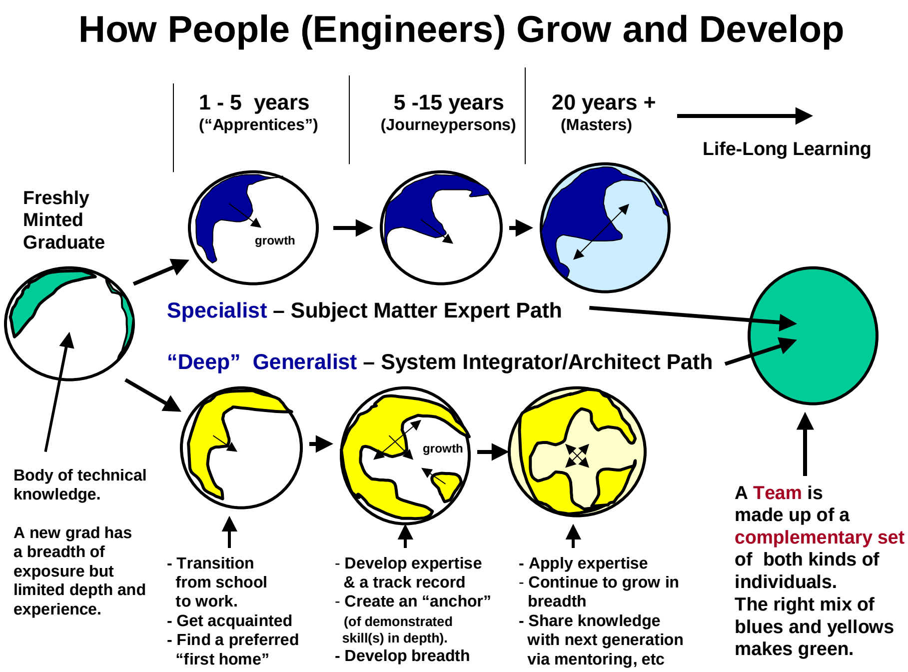


Figure 11. The Long-Term Development of Engineers.

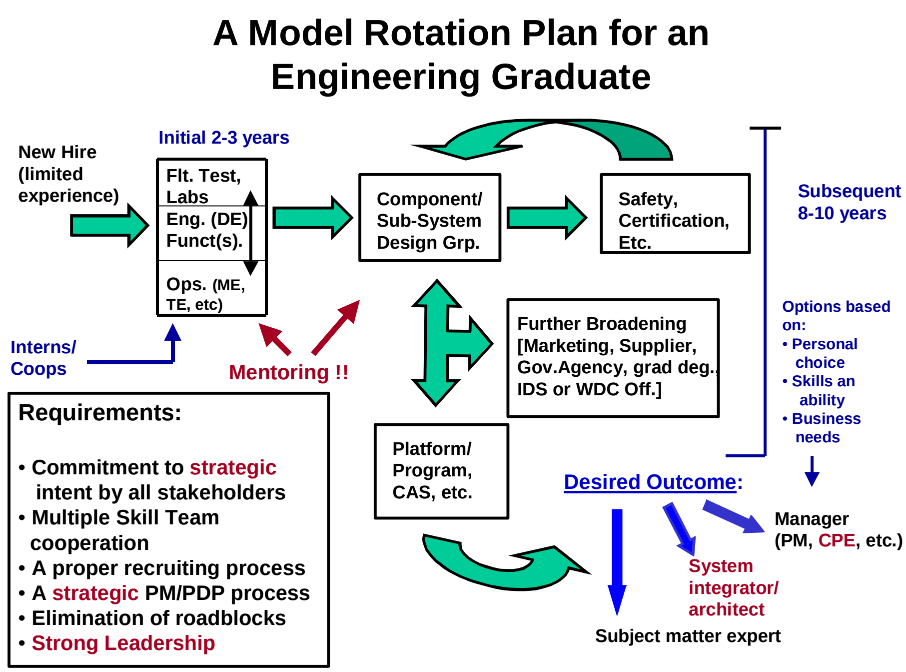


Figure 12. Job Rotation As an Effective Means of Skill Development.

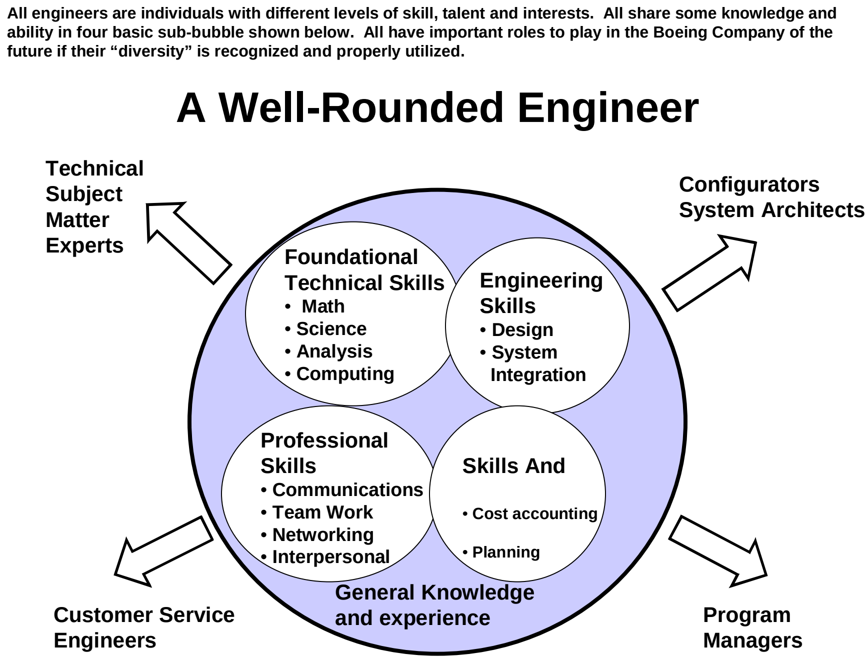


Figure 13. Opportunities for Well-Rounded Engineers.

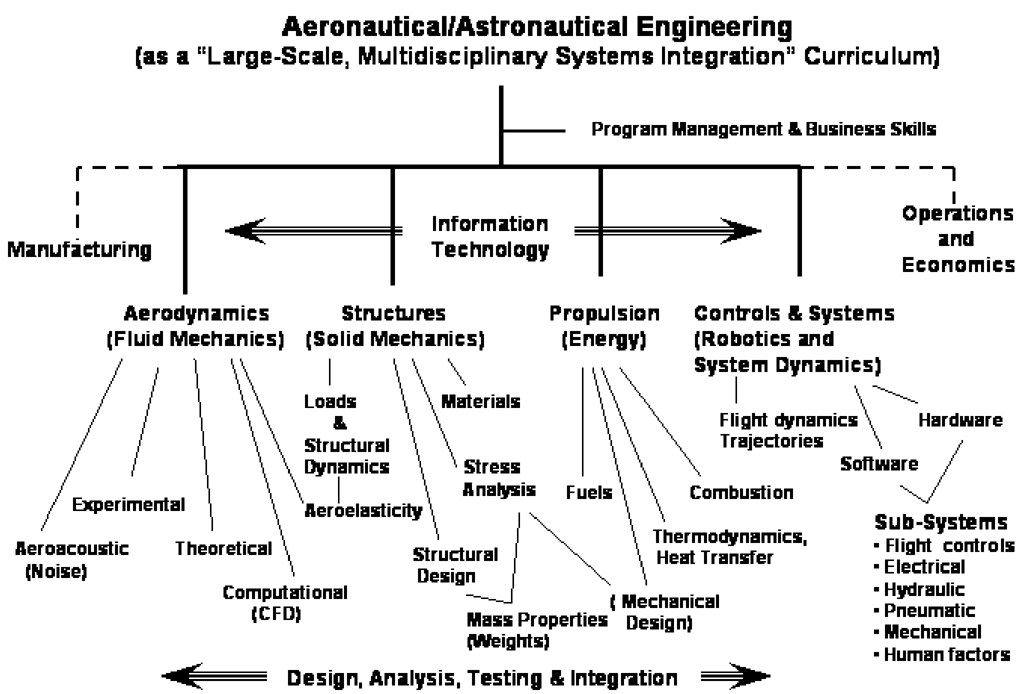


Figure 14. A Generalized View of Aerospace Engineering Education.

Boeing List of "Desired Attributes of an Engineer"

- A good understanding of engineering science fundamentals
  - Mathematics (including statistics)
  - Physical and life sciences
  - Information technology (far more than "computer literacy")
- A good understanding of design and manufacturing processes (i.e. understands engineering)
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
  - Economics (including business practice)
  - History
  - The environment
  - Customer and societal needs

Diversity – wanted and needed !

http://www.boeing.com/companyoffices/pwu/attributes/attributes.html

- Good communication skills
  - Written
  - Oral
  - Graphic
  - Listening
- High ethical standards
- An ability to think both critically and creatively - independently and cooperatively
- Flexibility. The ability and self-confidence to adapt to rapid or major change
- Curiosity and a desire to learn for life
- A profound understanding of the importance of teamwork.

• This is a list, begun in 1994, of basic durable attributes into which can be mapped specific skills reflecting the diversity of the overall engineering environment in which we in professional practice operate.
• This current version of the list can be viewed on the Boeing web site as a basic message to those seeking advice from the company on the topic. Its contents are also included (for the most part) in ABET EC 2000.

Attributes of a Good Designer

[Configurators → System Architects]

(adapted from a list by C.R. Chaplin, U.K. Fellowship of Engineering)

- Visionary
- Creative, imaginative
- Objective, critical
- Stubbornly tenacious
- Flexible
- Cooperative
- Independent
- Nympholept (yearns for the unachievable)
- Pragmatic

→ Ambidextrous thinker *
(Controlled schizophrenic)

* The pairs of attributes shown cannot be exhibited simultaneously without short circuiting the brain. One can (and must) learn to switch reflexively from one mode to the other as need may arise. This can be done, and one can learn how to do it.