Dreams to Reality:
Bringing “Far out” Back Home to Aerospace Education Through Concept Development

Abstract

Despite the harsh realities of the professional workplace, aerospace engineering still lights up the eyes of many. This paper argues that there is a special place for high-risk, ambitious concept architecture and design in the aerospace curriculum. This is essential because of the special characteristics and aptitudes of aerospace students. Several examples of current “grand projects” are considered, and progress towards them is summarized. Several ideas and proven strategies for nurturing such talents in formal curricula are considered.

Introduction

When asked how to define and differentiate aerospace engineering, the best answer used to be: *“Aerospace engineers turn the dreams of Humanity to reality through science and engineering innovation”*. This is hard to remember in an age when air travel has become less pleasant than a visit to the dentist, working for airlines and aerospace companies seems to be a perpetual scramble to stay aloft in a downdraft, and we are under constant pressure to bring “cost reality” to squelch the enthusiasm of students and “focus on realistic system development” with mind-numbing Trade Studies.

At a session titled “Space: The Next 50 Years” conducted at a famous space operations center a few years ago, the Session Chair opened the proceedings with the grand declaration: “The Next Fifty Years Are Already Here! With the introduction of the (Giant Aerospace Company) Model XXX Version yyy Booster!” Aerospace appears to have lost its edge as a leader of technological development. At the same time, it is the continuing experience of the author that casual conversations with people in all walks of life all over the world, still turn into a sincere “wow!” when they find out that one is an aerospace engineer. The vision of spending one’s time “among the stars” or pursuing grand dreams, is still very much a part of what motivates many of our first-year students. By the time the professor sees the same students again in the 3rd year, there is a completely different look on their faces, a look of being crushed by the weight of the “realities” that we teach so thoroughly in our curricula.

What happened to the grand dreams? This paper takes the position that the dreamer still has a place in aerospace engineering, and lays out examples of projects and course ideas/experiences to tap the potential tied up in those brains. It is very much part of the mission of a university to convey this inspiration to dream, the environment to do so, including the scientific, moral and technical support needed to nurture dreamers into world-changers.

Basis for Argument

1. Aerospace Engineering is the process of turning dreams to reality through science and innovation: The unabashed pursuit of grand designs is a special characteristic of this field, at least in engineering. While all fields have major goals, few manage to convey that everyone has a very important role to play in realizing those grand visions. The pinnacles of aspiration for many aerospace engineers are such things as being an astronaut, or a fighter pilot, or a space mission designer – all considered "dream jobs" with established government agencies or industry. Less appreciated is that many come into aerospace engineering, too shy to really say what motivates them. Their dreams are about building grand designs that solve the outstanding problems of humanity. It is much less about flight than it is about grandeur of ambition, and the quiet confidence that one has the scientific talent to make these visions come true.

2. Government agencies tend to move in tandem: At any given time, the problems of most interest to government aerospace agencies around the world have much in common. This hits home if one watches the presentation of Space Agency heads at the annual International Astronautical Federation Congress. For instance, today every agency claims to be interested in returning to the Moon and then going to Mars. The main rationale appears to be that NASA is doing it and therefore it must be the right thing to do to get money from their own governments. This in turn drives the projects and hiring needs of academia and industry in synchronization, focused on the short term. About 6 years ago, a NASA solicitation specified proposals focused on "Low Earth Orbit and Beyond". A NASA veteran took time to explain this to me: "The Moon does not exist this year" he said patiently when I wondered whether it wasn't "beyond LEO". "LEO = Space Shuttle" and "Beyond = International Space Station".

3. Industrial system optimization often results in a "Race to the Bottom": Although the large companies are led by people with great vision, their day-to-day operations must be run by people well-grounded in reality. Thus, what we hear is about the need for "cost-cutting" rather than long-term investment. Rare exceptions occur, such as in the bio-technology industry a few years ago, where summer interns were told that meeting schedules was important, regardless of costs – reminiscent of the Apollo years. In aerospace companies, airlines and government agencies today, cost-cutting is paramount. Competition by cost-cutting has been described as " a race to the bottom" by dismayed airline employees. Engineers are more careful of what they say in public.

4. There is no lack of grand challenges today: The human venture into the skies and beyond is still at a very young age, and the opportunities opened up by this endeavor have not even been visualized to any great extent. It is not true that "all the easy problems have been solved" etc. New ways of thinking about problems are opening up, as are new solution approaches.

5. Top-tier aerospace curricula and research institutes must look 40 years ahead and lay out the path to the future. In this global environment, universities are uniquely placed to be different, at least with a small part of their resources. They have the opportunity to inspire people at a young age when they are learning about the business, and show them how to relate long-term goals to immediate priorities in a realistic manner, without losing the long-term vision.

Organization of the Paper

The question asked in this paper thus becomes:
"How can we build a curricular environment where the spirit to dream survives the pressures of the routine workplace and curriculum?"

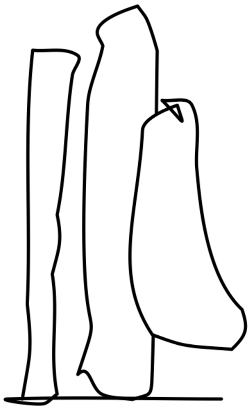

Figure 0: The Squiggle Test

First I look at the unique motivations and learner types encountered in aerospace engineering school. I then summarize what seems to work when trying to guide individual initiative in our environment. Finally, some small efforts at viewing some of the grand challenges, are discussed.

Unique Motivations

Aerospace Engineering is rare among college pursuits, and special among engineering disciplines in that it tolerates and welcomes those who are there "for fun". To a very surprising extent, aerospace engineering students have mental pictures of the field that survive the harsh demands of the everyday courses. To convince yourself of this, please try what I call the "Squiggle Test".

The Squiggle Test: Figure 1 shows a squiggle that I have tried drawing on the board in various aerospace engineering classes that have little to do with Space. Invariably, I draw it, then throw out the casual question: "What is that?" to a class that usually does not respond to most questions. With 100% success as a class-average basis, and some 80% success on an individual basis, the spontaneous reply is "Space Shuttle" followed by quick smiles as they wonder why they said that.

The Jet Fuel Smell Test: A second experiment, which I have been privileged to observe, is the facial expression of students as they are escorted into an aerospace facility. Ancient wind tunnels (such as ours) make our students positively beam. The same observation applies when I have taken a moment to observe students in the middle of very stressful flow measurement experiments in industry or government facilities. These environments resembled scenes from World War 2 movies of submarines under attack, with people concentrate intensely and performing delicate tasks, in 90-degree (or 32-degree) temperatures, after long days of intense and exhausting effort, noise, vibrations, and the small of burned jet fuel.

Learner Types

Some years ago, we studied the Learner Types set out by education psychologists, and developed a classification applicable to our students. This was as follows, and In Table 1, I correlate them with traditional definitions of types of intelligence [1 – 4].

Barnstormer: These people are eager to experiment, learning by trial and error. Too impatient with lengthy "derivations" to obtain elegant solutions, they learn as needed and work intensely on a deadline. They launch bold experiments, and venture into the unknown with little hesitation.

***Rocket Scientist*:**.These people too will venture into the unknown, but want rigorous analysis. They take nothing for granted, and want everything tied to first principles, with uncompromising, rigorous derivations based on the laws of physics. They are usually strong and deeply interested in applied mathematics and physics.

***Astronaut*:**.A third type is best associated with what we know of astronauts. They are very focused and mission-oriented. Far from being the adventurers of popular notions, their real strength is discipline, reliability and excellence in following procedures rigorously with a clear mind even under the most stressful of conditions. They want detailed instructions and training, and lots of worked examples. The superb initiative and lateral thinking associated with legendary rescue missions depend on painstaking training, more than on fortuitous flashes of "brilliance".

Eagle: A separate category must be devoted to those people who must have an eagle's eye view of what they are being taught, before they can focus. Long derivations lose them. This does not make them useless – these are the people who can rise above the details and see the "big picture", and make brilliant connections across vast gulfs between disciplines. They are potentially entrepreneurs. Once convinced, their belief is unshakeable.

The aerospace engineering educator's challenge is to cater to all these learning types, but encourage each to acquire the skills of the other types. While we want to nurture the strengths of each student, we would also like them to acquire some of the strengths and skills of their classmates who think and learn differently. This is the strength of learning in a large class, described as "learning through the eyes of classmates"

Table 1: Learner Styles Correlated with Recommended Learning Resources

Learning Style :	Sensory/ sequential (Astronaut)	Global / Intuitive (Eagle)	Global / sensory (Barnstormer)	Intuitive (Rocket Scientist)
Preferred teaching	Sequential Inductive.	Site-maps, overviews.	Perspective. Problem-based.	Rigorous theory; mathematics.
Reasoning	Inductive /Active Processing	Inductive / deductive	Inductive/ deductive	Deductive/Reflective Processing
Resource Types	Point summaries Re-iteration	Glossaries, charts.	Data. Graphs, Examples	Proofs. Original papers.
Input	Auditory	Visual	Kinesthetic	Auditory

The Engineer's Evolving Role: Large System Design and Integration

A major change in outlook over the past 15 years is that teams working on very large problems, across continents, are now commonplace. Large system integration tools have come into the workplace. Conceptually, optimization can include even the "soft" aspects involving social and political realities, that in fact take up a large part of project or system cost and time. Curricula in System Design are obvious avenues for pursuing the design of large systems. At present, the emphasis is on industrial training to use the large computer programs and databases that characterize this discipline. In the curriculum, time may be better spent on the thought processes required. A valid observation regarding System Design is that it buries the concept inventor in a tangle of huge computer codes, and optimization drives towards that for which there is extensive prior experience. In the process, new ideas get rejected, and the system predictably and safely comes up with what a computer would do. Thus, the determined pursuit of grand dreams cannot afford to be tied into System Design and Optimization procedures at an early stage

Success Benchmarks

A well-known example of a successful large-system project is the MIT Lean Aircraft Initiative with its spinoffs. The Human-Powered Aircraft project and the solar-powered aircraft project are also examples of grand challenges pursued over many years to successful demonstration. These projects involved students at several levels, and the graduates from there have gone on to become drivers of other ambitious enterprises.

An avenue for exploring concepts, much preferred by many faculty, is the growing number of annual National Design Competitions. These motivate students, permit teamwork across levels and disciplines, and convey intense experiences of scheduling and formatting. Students often go all-out, and the resulting products are truly impressive. Our school has a stellar record of winning prizes in these competitions. But the focus on “winning prizes” is exactly what I have against such efforts. The effect is to outsource the conceptual selection phase of a major project to student teams, costing the sponsors practically nothing, with great publicity. But 90 to 95% of the effort expended on these projects nationwide is wasted, leaving the students feeling like “losers” and turning them away from such things. The quality of “peer review” and judging leaves much room for thought. As an anecdotal example, the winning entry in a Mars helicopter competition some years ago, had rotor performance designed (for the high Mach number flight needed in the thin atmosphere of Mars) using the much-abused and highly optimistic $C_L = 2\pi\alpha$ corrupted from incompressible thin airfoil theory. That’s not terrible in a student paper, but I do wonder how many good analyses of Martian flight got trashed as “losers” in the process. Engineering professors should reflect on the wisdom of outsourcing student evaluation to the least thoughtful / most managerially-mobile in industry. Another comment that left a deep impression on me years ago came from a senior NASA manager, about the AIAA Student Paper Competition that he had just judged: *“Did you see the winner’s presentation? Wow! He looked JUST LIKE Tom Cruise!”* However, the fact remains that national competitions have a very important place in concept development curricula, as long as they are not taken too seriously.

A resource for cross-disciplinary thinking and daring innovation in the past decade was the NASA Institute of Advanced Concepts[5]. The Institute selected proposals for advanced concepts with new architectures and system designs. The body of work developed by this Institute cut across many disciplines. Concept developers saw the systematic process to go from initial far-out idea to a well-developed level of system design. Many of the reviewers were truly veterans at analyzing radical concepts, starting from the Apollo program days. They were quite secure in their grasp of the laws of physics, and yet had a sufficient breadth of engineering experience to accommodate radical ideas. In my view, this resulted in a peer review process that drew the respect of the proposer. Several of these projects involved students at the graduate and undergraduate levels. The participation level of these students was an eye-opener to anyone who views undergraduate students as passive learners.

Proven Approaches to Challenge, Enthuse and (hopefully) Inspire

1. ***Open-ended assignments in courses***. In the mid 1980s this appeared to be rare in undergraduate programs, but today there is well-developed terminology for it. There is less agreement with the idea of using homework and tests as part of the learning process rather than as training (learning to do tests) or testing. This requires strong committed support from colleagues and the administration to educate students whose expectations are dulled by practices in high school and large freshman-sophomore classes. The opportunity to encourage thinking far outweighs the negatives. There is no reason to expect less from aerospace students than from Olympic / professional sport stars in rigorous learning, experimenting, eliminating errors, and using initiative.

2. ***Undergraduate Research Assistants and Special Problems Research Projects.*** These should never be "make-work" or "opportunities for students to experience the world of research". Instead, students should be encouraged as future leaders, to take initiative and responsibility as fast as safety and common sense will permit. A good way to jump-start inexperienced undergraduates is to make them the project team leaders responsible for progress, and tell them that graduate students are tasked with helping them do what they needed to do, rather than to tell them what to do. This usually ignites initiative. It does require excellent graduate students, and deep individual attention to each student from the advisor. I now have 15 undergrads working in my research group, following the tradition of some 130 others, most of whom signed up *after* going through my sophomore aerodynamics course, validating Item 1 above. Laboratories are excellent places to convey physical insight, while teaching organization. documentation and observance of procedures. Ambitious goals, insistence on progress reports and attendance, and evidence of continuous thinking, are vital to success.

3. ***Design-Centered Introduction To Aerospace Engineering***[6]: In 1997, faced with high attrition in first and second year classes, the School asked me to implement what I had grandly declared possible in the middle of some heated argument years ago: invert the role of "capstone design" and teach the first part, conceptual design, to entering freshmen in their first weeks in college. The student is exposed to considering customers, defining requirements, setting out a "mission profile", benchmarking, and initial sizing. They see how an idea gets translated to the initial description of a system, with mass, power etc. before the shape is ever drawn. The process leads quickly to bounded uncertainty and logical calculations of system characteristics. This is tremendously empowering, and removes the largest mental block in engineering education, by conveying the "common-sense" aspect. Eight weeks into college, students have "designed a vehicle", checked how it will perform, and validated their results against historical data. They are now *insiders!* They discover the skills for exploring across disciplines and the confidence to talk to others about technical objectives. Unfortunately, there was no way to get instructors in other courses in the first two years to build on this. By the time the same students get to the third year, their drive and lateral-thinking initiative appear to be suppressed, instead expecting cookbook-level instructions, narrowly-defined assignments, and tests straight from homework. Of the Learner Types, we may be developing Rocket Scientists and Astronauts, but they are missing what they could learn from the Barnstormers and the Eagles, whom our system does not appear to accommodate. Many are lost to engineering.

Towards Formal Curricula in Concept Development

The question opened is how to replicate these lessons, and find more ways to nurture students with these talents. Surely the faculty to serve as mentors are already present. A tentative proposal towards incorporating advanced concept development in formal curricula is given below. Table 2 summarizes the proposed curricular elements.

The proposed sequence of three Special Problem Research experiences, each with a faculty advisor guiding an ambitious concept development program, is intended to provide the support needed to retain the gains in the first-semester Design-centered introduction. The formal proposal at the end of the junior year imposes urgency and direction. This proposal must be approved by at least one faculty member. Currently in our school, students qualify for an Honors Program, with selection based on grade point average. Those selected must choose a faculty advisor, and complete two semesters of research Special Problems including at least one presentation on research. Experience with this system is positive, but experience outside the Honors program show that we have several students (see the Learner Types) who may excel at developing original concepts, long before their learning skills "click" by GPA measures.

The curricular proposal closes the loop with a 2-semester concept development project, modeled on NIAC criteria, that occupies the senior year. *Success of the concept is not nearly as important as thorough, honest evaluation, and exploration of the options opened up*. The peer review lessons from NIAC show the vast difference between review by young industry engineers, many of whom would flunk a PhD Qualifying Exam in their area of expertise, but puffed up with "Here's How We Do It In the Real World" attitudes, and review by veterans experienced at looking out where no one has ventured before. At the beginning of the program, this should be in addition to the formal Capstone Design. My belief is that in the long run, both types of experiences are valuable, but perhaps the Capstone Design folks will get converted by the excitement and opportunities in applying their skills to bold concepts rather than training for today's industry. Concept development will equip students for both industry and graduate school.

Some concepts being explored by my group are shown in Table 3. The first two have been described in papers including undergraduate co-authors[7-9]. The first (space economy planning) has been developed through several years of participation in NASA-sponsored space business planning exercises, interacting with teams from business and advertising schools. The third item, Micro-Renewable Energy Systems, is being developed through a new course under the International Plan at our institution. The five students who dared to sign up for this completely new area, are pursuing five different projects, each in a team of two. Five abstracts to an Undergraduate Research Symposium promise unique contributions. These projects relate Space ISRU (in situ resource utilization) technologies to the mass marketplace of kitchen stoves and robotic lawnmowers run on methane from the grass they cut in previous weeks, as examples.

The fourth item is an offshoot of my experience in Boeing's Welliver Summer Faculty program in 2004. The next big challenge in US airliner development is to make the business case for supersonic airliners, using the tremendous changes that have occurred in the Eastern hemisphere in the past two decades. The item last is a grand dream to achieve truly distributed fuel generation, and break through to a hydrogen economy, freed from fuel monopolies.

Table 2: Ingredients of a formal curricular sequence on concept development

Item	Description
Design-Centered Freshman Introduction	2 – to 3 credit freshman/ sophomore course.
9 hours of Special Problem research experiences, including 6 in advanced concepts	Spread through three semesters, freshman through junior year.
Formal proposal for concept development	At end of junior year
2-semester Concept Development project	Senior year, modeled on a NIAC Phase 1 effort

Table 3: Examples of exploratory Projects

Project	**Comments**
• Global Space Business planning.	With International Studies and Economics
• Evolutionary approach to Space Solar Power: Beamed-energy marketplace.	Power grids, beaming, Global Warming, renewable energy and orbital mechanics
• Micro- Renewable Power Generation	New course under International Education
• Revisiting prospects for Supersonic Transport in the altered global realities	Economics, route-mapping, demographics, aerodynamics, acoustics and engine technology.
• Village-Level Hydrogen Economy	Collaboration with international entities

Being the instructor in a learning experience on such concept development, brings a whole new set of learning challenges. The concept of "textbook" has to be re-thought, since the resources are scattered all over the internet, and many of the insights about the marketplace can only be found through interaction with people far removed from aerospace engineering. The ideas to be conveyed come from many diverse fields. While some lectures are needed at the outset, I find that the learning becomes much more intense as students delve into their projects, and the course format becomes much more of a roundtable conference with everyone participating in the discussion. If this experience expands to courses with much larger numbers of students, the challenge of monitoring each student's progress and maintaining academic standards, will pose fresh questions for which I shall have to learn and report on the answers in future years.

Conclusions & Recommendations

The theme of the author's approach is based on the following points:

1. Aerospace engineering is still about pursing dreams that most people laugh off, and turning them into reality through rigorous application of science and engineering.
2. Aerospace Engineering still lights up the eyes of some very special people.
3. "Breakout" thinkers will always seek other directions than the "fashion"
4. Advances in the science of System Engineering should enable rather than hinder this process.
5. Lessons from project experiences provide guidance on curriculum design for initiative, cross-disciplinary learning, skill-sets and career choices.
6. There is no shortage of grand dreams for AEs to pursue.
7. The knowledge base of aerospace engineering is relevant to developing concepts, seemingly far outside the aerospace realm.

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