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The Enterprise of Aerospace Research and Vehicle Design

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This paper presents a panoramic view of the numerous considerations which comprise the successful application of aerospace research to advance air vehicle design. The university–industry symbiosis is rationalized with mechanisms provided to integrate university research with industry design solutions. The necessity for high technology solutions which are economically viable and provide safe operations present new entrepreneurial opportunities for universities and research-based organizations. In the near future, universities may not have to be subservient to the aerospace companies, but will individually be providing an overall valued contribution to the aerospace industry at a departmental profit. This approach develops graduate students with strong technical, managerial, and business acumen. Universities should alter their scholastic training emphasis from an industry reactionary mode to a future requirements anticipatory role. An example of the benefits gained at Praxis Technologies Corporation through an association with the University of Maryland is highlighted.

BACKGROUND

THE OBJECTIVE of this paper is to present an innovative approach to university aerospace engineering departments to increase the net worth of their graduate students to industry and to focus research activities appropriate to fulfilling industry requirements.

The University of Maryland (UMD) Aerospace Engineering Department has competitively won a US Army Research Office-funded program to establish a Center for Rotary Wing Excellence. This program has provided financial and technical contributions to UMD for almost 10 years. Additionally, UMD has also been successful in obtaining additional funding from various independent sources.

Praxis Technologies Corporation (PRAXIS) is currently enjoying a unique relationship with UMD. Numerous factors have contributed to make this relationship possible: the strong requirement within the aerospace community for a research-based entrepreneurial organization, industry experienced personnel retrained at the UMD graduate level, PRAXIS staff serving as academic lecturers, innovative UMD research applicable to industry requirements, and committed faculty leadership.

This company–university symbiosis instills PRAXIS confidence in the employee–student knowledge gained, permitting immediate utilization of university skills to industry problems. Similarly, the university advantage gained is in establishing research areas which offer near-term supportive promise to industry needs.

By carefully nurturing this relationship, UMD experiences additional research income, insight to industry requirements, successful student graduates, and exposure through contractor relationship and applicable publications. Company organizations receive numerous benefits gained through the association of, and participation in, the substantial research and developmental activities established at various universities.

Financial aspects of this relationship are structured to eliminate costs to the university. While the PRAXIS staff receives compensation for instructing graduate-level design, this expenditure would be required none the less. The graduate level design course provides a new capability to the university and enables the school to participate in nationally recognized scholastic design competitions. Joint proposal efforts are based on faculty participation, requiring no cost, but additional staff member time. Again, this time allocation is not out of line with typical proposal development.

When directly relating specific graduate engineering curricula to the net worth of aerospace vehicle design and technology assessment, it is quickly realized that all aspects of university training are pertinent. Current curriculum specifications endorsed by the Accreditation Board of Engineering Technologies at the undergraduate level and typical course work at the graduate level provide a large mix of disciplines which should be considered vital for a fundamental aerospace education. In a reaction mode to industry, much concern within academia is placed upon the proper

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concentration levels within the various disciplines (i.e. is there enough control theory, what is the proper mix of theoretical development and experimental skills). If anything, the university training should be augmented to include several disciplines which are not extensively addressed and which constitute vital concerns in anticipating future aerospace demands. These areas include requirement developments, economics, reliability and maintainability, management, marketing, and business administration.

To properly ascertain the importance of university-based research as related to applicable industry problems it is imperative to review the concept of systems engineering, the fundamental phases of research, and the design process.

INTRODUCTION

The emerging re-emphasis of smaller, more comprehensive 'think tanks' reminiscent of the Lockheed Skunk Works is again proving to be technologically and economically viable, if not almost warranted by the nature of today's aerospace environment. This approach represents a substantial change in conceptual, preliminary, and detailed design doctrine from current tradition of large corporate development groups. Applications of university aerospace research to real-world design requirements can provide increased predictive accuracy at lower costs. The university–industry symbiosis is a key element in future air vehicle developments, and therefore must be nurtured to realize the potential advantages.

University graduates should not only be aware of, but must be educated to fulfill the emerging need of the aerospace community which encompasses research, design, development, cost, business, and management. Concomitantly, it may behoove the aerospace industry to provide the atmosphere for engineers to expand their horizons and work in a supportive environment conducive to meeting advanced vehicle design challenges. This postulated industry environment could include an association with a research-based aerospace engineering department to support fundamental methodology development.

The value of a theoretical researcher is best exemplified by several organizations which provide military and governmental analyses of questionable programs. These research houses have found success in building an analytical team of doctoral graduates in various technical disciplines. It is experienced that individuals with the capabilities of fulfilling the requirements for a Ph.D. or Sc.D. provide a broad spectrum asset to any investigating team.

The aerospace industry represents a significant financial segment of the US economy, both directly and indirectly. The successful operation of large aerospace companies requires a synergistic skill mix of scientific and engineering technology, production and administrative support, and astute business management. The aerospace industry's progressive future depends upon the technical capabilities and business fortitude of recent aerospace engineering graduates. University-based professors are concerned with the daily examination of fundamental research, which is imperative, but usually not the life blood of an aerospace corporation. The major industry emphasis is directed toward producing something that customers desire to purchase. Examining the personnel structure within a typical aerospace corporation, approximately 60% of all employees are directly involved in production, 20% support finance, and the rest are engineers [6]. These statistics illustrate that technical engineering expertise alone does not provide the corporate formula for success.

The aerospace engineer possesses a diversified technological background suitable for employment in various engineering fields. The transportation, communication, and energy industries employ the majority of aerospace engineers. Additionally, many industries benefit from the application of aerospace methodology which has filtered down to companies engaged in flight simulation, materials, dynamics, automatic controls, robotics, and medicine. Historically, the largest demand, and hence the highest starting salaries for aerospace engineers, come from the transport and fighter aircraft industries, followed by the missile, spacecraft and general aviation industries [4].

In the competitive industrial world, it is not surprising to find that companies generally agree that it is industry dollars which transform embryonic aerospace engineering graduates into tangible aerospace design engineers. Although formal education is left behind, the new employee will be exposed to a new industry education process called 'the learning curve' [7]. Depending upon the young engineer's university curriculum, proper assimilation into the professional design ranks may take up to 5 years. To increase the useful worth of an engineer, this learning curve time frame must be minimized.

Several government-funded research organizations such as the Center for Naval Analyses and the Institute for Defence Analyses overwhelmingly employ graduate-level engineers and scientists to conduct complete program analyses at the direction of the Office of the Secretary of Defense or US Armed Forces leaders. These institutions generally rely upon a systems approach in determining appropriate solutions.

SYSTEMS APPROACH

Advanced design is a multi-element and multidisciplinary process which integrates market requirements and customer specifications with the vehicle development through analytical and design trade studies [3]. The development of advanced vehicles to fulfill complex and challenging mission requirements is a perplexing technological task of integrating various configurations, mission equipment packages, environmental conditions, operational uses, and technology readiness [2]. Furthermore, aerospace companies have a fiduciary responsibility to produce the most economical design while adhering to a high fidelity of safe flight operations. This analysis can lead to several thousand combinations of parameters that will satisfy the requirements.

The ultimate objective is to determine a specification for a future aircraft which will best serve the operation for which it is planned. The systems concept can be best viewed in the conceptual design phase where increasing emphasis is being placed on the scientific analysis of managerial decisions. The value of systems design can be illustrated in the desire to achieve overall effectiveness of the system and not to have the parochial interests of one organizational element distort the overall capability. This must be done in an environment which invariably involves conflicting organizational and design objectives. Thus, the system approach to design provides a conceptual framework and involves a systematic examination of comparison of those alternative actions which are related to the accomplishment of desired objectives, comparison of alternatives on the basis of the costs and the benefits associated with each alternative, and explicit condition of risk.

In the defense acquisition process conceptual design and the conceptual phase are called concept explanation. This explanation consists of examination of technical alternatives which seem capable of providing a required new capability. Ideas are defined to detail levels sufficient to develop engineering solutions. A life cycle cost estimate is developed based on the proposed engineering development schedules. The program schedule is generated based on the currently available, and projected future technology.

The systems approach can be divided among industry and academia. Granted, aerospace companies are best suited for concentrating in top-level considerations. This includes strategic program planning, providing organization and advice by identifying critical issues, basic objectives, national value, technical approach, funding, management, schedule, productivity, measures of effectiveness, and other strategies which play a vital role in developing solutions.

Universities possess several positive attributes which can harmoniously blend with industry's application of systems approach to design. This is particularly true in isolating appropriate methodologies, reducing provincial judgements, and establishing appropriate measures of effectiveness.

MEASURES OF EFFECTIVENESS

Engineering analysis and methodology combined with computation techniques enable engineers to examine the interrelationship of user requirements, subsystem functionality, technology readiness, and overall system synergism. The ultimate value of an aircraft is its mission effectiveness. Sometimes, it is in the interpretation as to what constitutes meaningful measurements of effectiveness (MOE) and evaluation techniques. Therefore, before attempting to design an operational aerospace vehicle system, an understanding of mission effectiveness provides essential guidance during the preliminary design cycle.

Throughout the industry, aersopace engineers have been determining more quantitative estimating methodologies for establishing measurable systems. This includes developing required inputs to the air vehicle design, and then comparing them to the design outputs. The development of quantitative design objectives is characterized by a series of broad and highly iterative analytical studies. Techniques used are numerous and usually include mathematical modeling, manual or computerized simulation, war gaming, and systems analysis.

The university role in supporting industry by defining appropriate MOE methodology is virtually untapped. Here, universities generally have superior understanding of the applicability of available analytical techniques and their associated limitations. Industry could rely upon the universities for validation of methodologies which are in the public domain. These methodologies could provide a substantial database of techniques accepted by leading research authorities. The responsibility of applicability of university-based fundamental research lies upon industry. Also, further enhancements could be directed by aerospace user groups. For example, PRAXIS relies upon UMD research in circulation control aerodynamics and aeroelastic rotor dynamics in assessing the feasibility of futuristic conceptual designs.

One potential research application can be related to the development of future military aircraft. Military aircraft design requirement concerns include technical areas which are not readily available at the university level. One research area is in the classical air-to-air (ATA) combat or 'dogfight' arena. Here, differential gaming theory as suggested by Van der Platts to assess the engagement encounters of pursuer–evader tactics. The future of ATA must include additional parameters beyond basic performance and control algorithms. It is imperative that mission requirements include the special considerations associated with environmental operations, mission equipment package (MEP) including advanced avionics, weapons selection and deployment, air vehicle and propulsion designs, and micro-analyses of dynamic encounters for air-to-air roles.

The guidance and control laws associated with various weapon-integrated systems can be initially developed from Locke. Rules must be developed for the effective use of energy weapons, missiles, rockets (flechettes), and guns which will achieve high probability of kill and survivability. Research currently funded by the Defense Advanced

Research Projects Agency (DARPA) investigates linking aircraft flight controls and weapon field-of-regard firing solutions with an on-board computer which will take command of the aircraft in an actual ATA engagement.

Once the design requirements are developed, it is now possible to utilize the salient aircraft's performance as a measurable quantity for mission effectiveness. Therefore, engineers are tasked with analyzing and assimilating all requirements to produce, through technical competence, optimization and computational techniques, an air vehicle system that has the highest probability of mission completion. It becomes evident that there are numerous research topics which could find immediate application to industry concerns.

RESEARCH AND DEVELOPMENT ACTIVITY

Many major aerospace programs have requirements which go beyond basic computation analyses, encompassing extensive research, development, and testing programs. Inherent in most advanced technology development efforts are little-known research areas which warrant further investigation. For the smaller aerospace firms, research and development activities are costly and usually are not fully supported with appropriate staff or facilities.

All PRAXIS engineers are encouraged to pursue graduate studies at UMD with academic emphasis on technical areas which augment their industry work efforts. UMD can provide a comprehensive education in theoretical and experimental techniques which might not even be attainable within smaller corporations. Additionally, UMD faculty can perform fundamental research in support of industry problems more cost effectively than smaller, or sometimes even large corporations.

UMD has been successful in educating PRAXIS engineers on a graduate level. In some individual cases, the PRAXIS employee attends UMD graduate school for completion of either the Master's or Doctorate's course work. Upon returning to PRAXIS, the employee can work part time on the thesis requirements. The thesis work effort is congruent with a joint corporate/university research topic. This approach is quite favorable and productive to industry. PRAXIS benefits from the student's increased academic training without a lengthy absence from the job.

There exists several technology areas whereby universities can support corporate activities. The various contributions of technology flow to the development of a system are illustrated in Fig. 1 [1]. Also indicated are the appropriate areas where universities can participate.

Phase 1 technology levels consist of broad spectrum, fundamental research. Phase I technology represents future availability, and may or may not be within expected program timeframe. Here, universities are best suited to provide the fundamental research activities for general applications. The productivity of every research dollar expended is

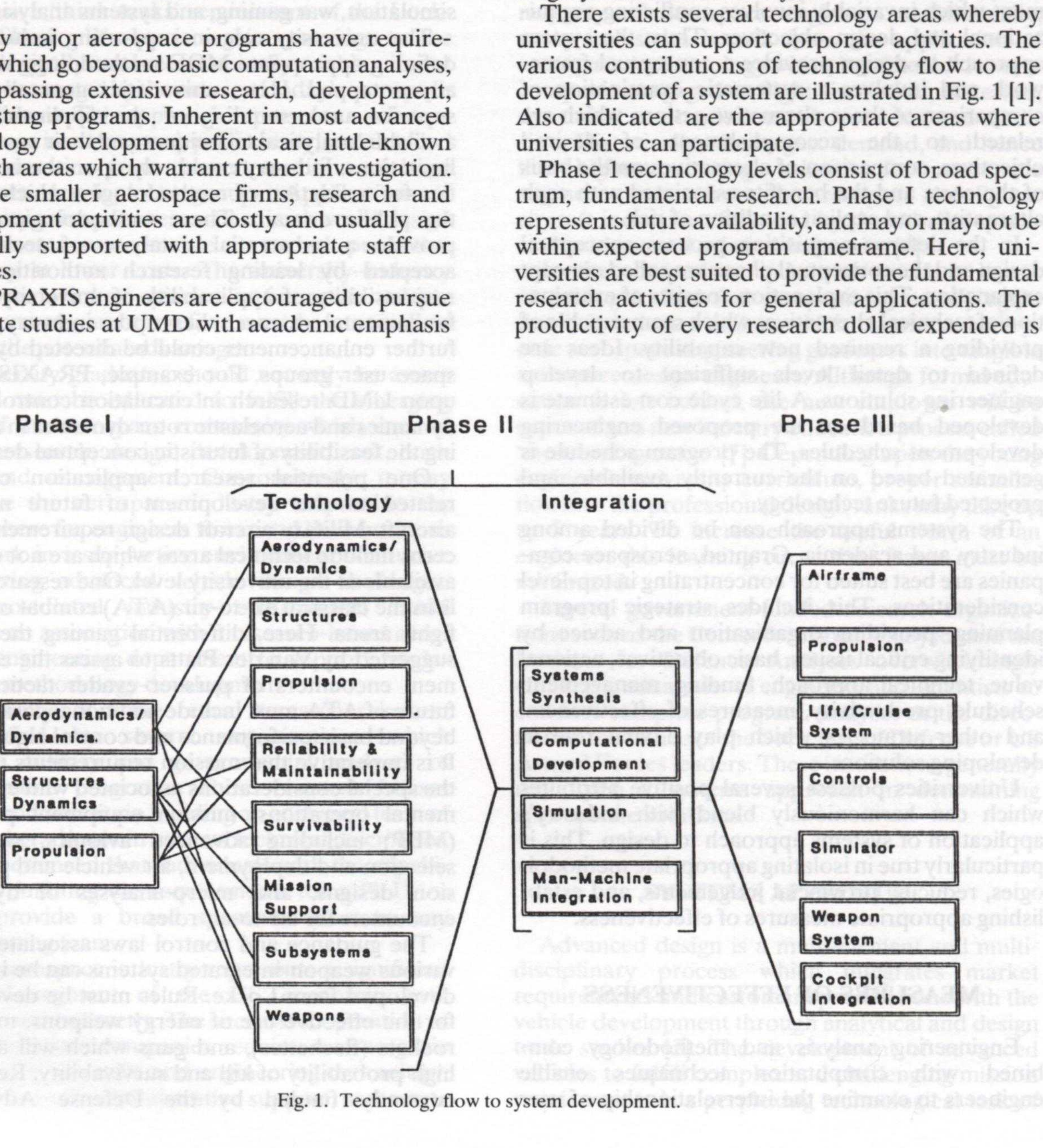


Fig. 1. Technology flow to system development.

significantly higher than industry can provide. Through corporate links with a university on Phase I research, much-needed industry near term developments can be better focused. During this phase, the universities are more adept at technology management whereby a corporate team member can provide overall program management.

Noteworthy, and timely, developments in Phase I feed into Phase II, providing available levels of technology for systems design. Phase II can be divided among technology and integration. Continued technology refinement must be continued, predicated upon development of fundamental methodology executed under Phase I. This portion is still best suited for university involvement. Universities capable of providing experimental testing support may provide additional support to the industry. The integration of developed technologies and methodologies is primed by corporate needs. This attribute enables appropriate utilization of university developments towards corporate problems.

Finally, Phase III represents present technology and is usually best provided by corporate systems developers. This phase is accomplished through a close relationship of sponsor or client and the subcontracting corporation. University roles are minimized at this stage.

THE PRELIMINARY DESIGN PROCESS

While most companies have their own preliminary design group, the fundamental process of design is generally the same regardless of the end product. Since university graduates will most likely support in some manner corporate design activities, it is important to understand the design process. As discussed previously, preliminary design is a multi-element and multi-disciplinary process which integrates market requirements and customer specifications with the vehicle development through analytical and design trade studies. The corporate preliminary design teams must be able to meet the increasing demand for ever changing advanced mission capability.

The development of advanced aerospace vehicle concepts requires innovative design, appropriate methodology, and ultimate application of technology readiness. A review of the published literature illustrates a multitude of conceptual paper studies depicting numerous configuration schemes for lift and forward propulsion. However, limited hardware development and flight testing data indicate extreme difficulty in achieving success with many of these advanced concepts attributed to technology and methodology limitations. Newer and newer requirements continuously lead to exceeding the boundaries of current technology, either available within industry or at the university level. Cost and manufacturability constraints require system development at minimal cost and risk. These paradoxical requirements warrant through development of predictive methodologies which can be incorporated within the various phases of the design process.

The typical preliminary design process is shown in Fig. 2. An analysis of needs (perceived or real) leads to a specification or requirement. Analytical and design trade studies supported by various

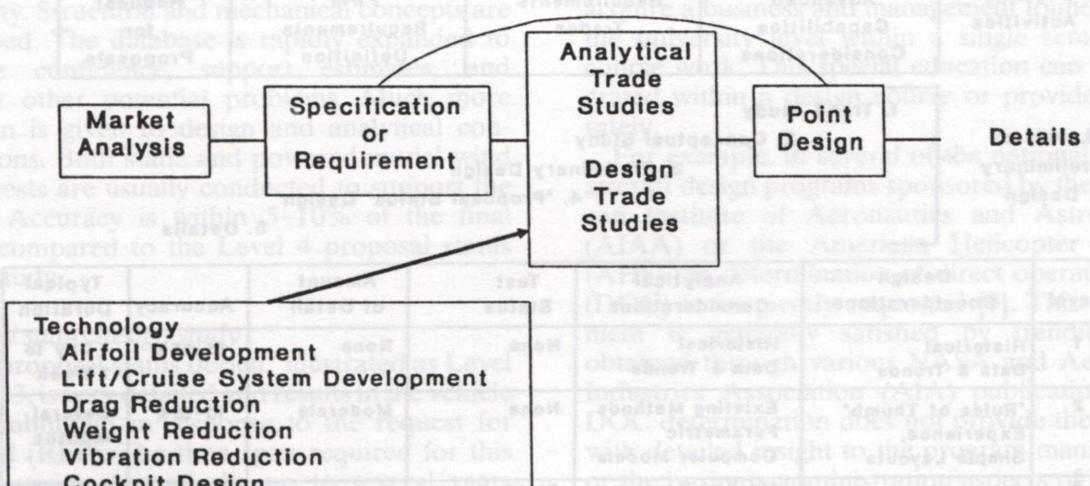


Fig. 2. The role of technology in the design process.

technology developments are conducted which lead to candidate point designs. The designs are compared to the original specifications and iterations are made until a final design is selected.

Furthermore, there are at least four various levels of detail within the preliminary design process, and include, in ever increasing level of detail and complexity [10]:

(1) Trend study
(2) Conceptual design study
(3) Preliminary design study
(4) Proposal status design study.

Figure 3 provides highlights of the various levels and details within the design process.

Trend study

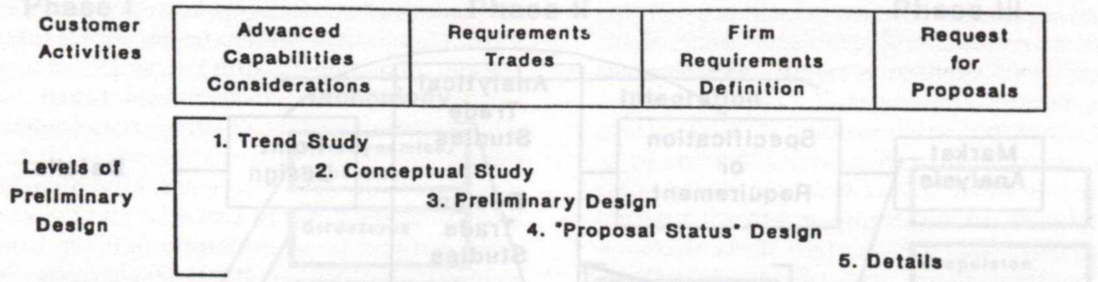
Figure 3 displays some of the details of the Level 1 trend study. The trend study typically supports the customers' 'advanced capabilities considerations' and requirements studies. This study provides big picture answers and direction for more detailed studies. Seldom, if ever, are many details known. It is usually based on historical data and trends with no specific supporting test data base. Accuracy of the Level 1 trend study may be within 15–25% of the final design. The importance of the trend study is in quickly providing direction for further studies.

Trending data have limited application to unique advanced vehicle configuration assessment through integration of uncoupled subsystem characteristics. However, as more details regarding a particular design are required, limitations in trending data and applicable methodology will introduce inaccuracies and potential errors. During this design phase, universities can potentially augment the design validity by isolating appropriate methodologies for advanced vehicle designs. Moreover, methodology voids ascertained through university involvement can provide further avenues of research for both industry and academia.

Conceptual design study

The conceptual design study indicated in Fig. 3 as Level 2, provides enough depth of information to permit reasonable comparisons between configuration types and points to possible problem areas. The conceptual design process begins with the layout drawing of a potential aircraft design based on past experience and engineering judgement and relied on the knowledge of government specifications. Although the design will most likely change many times in the future as more detailed studies are conducted, many key features of the initial design will frequently be retained in the final configuration. Usually no model testing is done. Sufficient details are known to estimate size and cost, establish feasibility and make recommendations for follow-on studies. Past experience and existing methods are utilized. Accuracy of the answers is typically to within 10–15%.

Figure 4 shows the steps in a typical conceptual design study. From the initial layouts, ground rules are established, propulsion systems are selected and engineering calculations are made. Sizing and



Level	Design Considerations	Analytical Considerations	Test Status	Amount of Detail	Accuracy	Typical Duration
1	Historical Data & Trends	Historical Data & Trends	None	None	15-25%	1 Day to 1 Week
2	"Rules of Thumb" Experience, Simple Layouts	Existing Methods Parametric Computer Models	None	Moderate	10-15%	Several Months
3	Volumetric Sizing Airframe Lines, Mechanisms, Structural Concepts	Method Development, Detailed Computer Analysis	Static Wind Tunnel Rotor Tests	Considerable	5-10%	Months to 1 Year
4	Detailed Sub-System, Structural, Sizing, Mockups	Detailed Testing, Computation	Dynamic Wind Tunnel Material Tests Subsystem Tests	Extensive	2-5%	Months to 1 Year

Fig. 3. The preliminary design process.

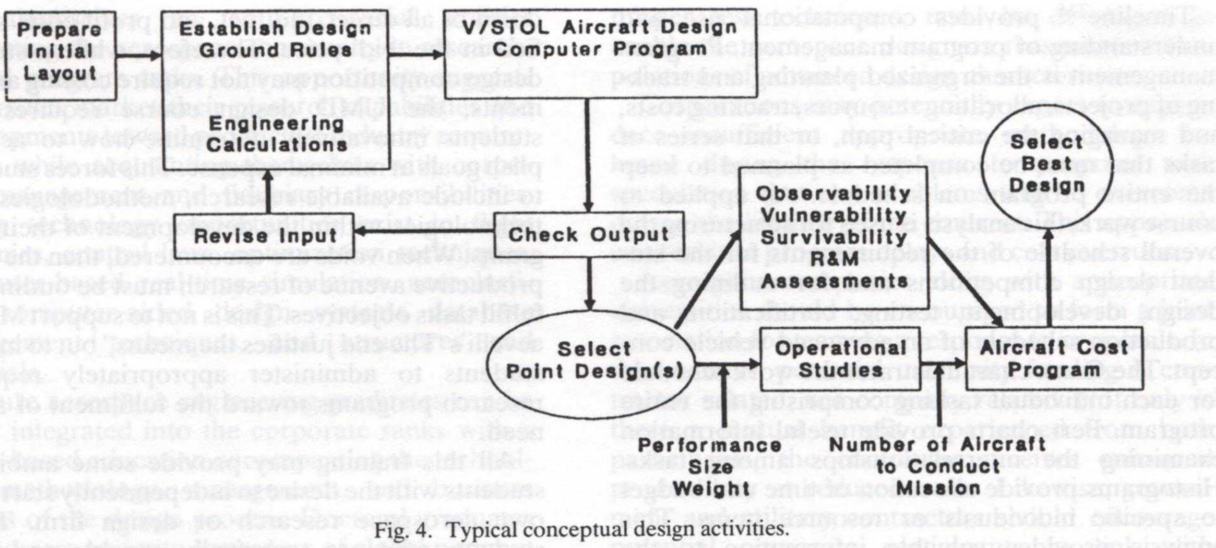


Fig. 4. Typical conceptual design activities.

performance codes are then used to establish engine sizes, vehicle geometry, weights, maneuver boundaries, and off-point design capabilities. These parameters are then iterated as required to meet selected mission profiles and requirements. Air vehicle design selection is based on various measures of effectiveness to provide the highest probability of mission completion.

Preliminary design study

The preliminary design study, shown as Level 3 in Fig. 3, is in support of meeting stated firm requirements. This phase begins the process of solving the potential problems uncovered in the earlier conceptual design phase. Internal and external dimensions are carefully checked to ensure feasibility. Structural and mechanical concepts are developed. The database is rapidly expanded to increase confidence, support estimates, and uncover other potential problems. Much more attention is given to design and analytical considerations. Both static and powered model wind tunnel tests are usually conducted to support the design. Accuracy is within 5–10% of the final design compared to the Level 4 proposal status design study.

Proposal status design study

The 'proposal status design,' illustrated as Level 4 in Fig. 3, is very detailed and results in the vehicle finally submitted in response to the request for proposal (RFP). The time span required for this process varies dramatically up to several years depending on the complexity of the requirements, the existing political climate and the availability of funding.

BUSINESS CONCERNS

A career in aerospace engineering can provide many challenges in both business and technological skills. An aerospace career path leading to a 'mahogany row' with the three initials CEO after your name does not necessarily warrant a Ph.D. in engineering. As emphasized in this paper, in order to climb those coveted 'rungs' one must have a panoramic view of the aerospace industry [11].

As most graduate engineers are initially schooled in concentrated technical areas, a background in business is also imperative for the successful engineer. There are no strong industry requirements for a Masters in Business Administration (MBA) or Management (MM) as most larger companies will have a prospective management candidate formally trained at a local college or even as a Sloan Fellow at a prestigious university. However, the budding aerospace engineer can acquire a business and management foundation at the university level within a single semester of course work. This special education can be integrated within a design course or provided separately.

For example, in several of the national student aircraft design programs sponsored by the American Institute of Aeronautics and Astronautics (AIAA) or the American Helicopter Society (AHS) the determination of direct operation cost (DOC) is frequently requested [9]. This requirement is generally satisfied by trending data obtained through various NASA and Aerospace Industries Association (AIA) publications. The DOC determination does not provide the student with detailed insight to the program management or the business administration aspects of bringing an advanced design to fruition. Additional studies should include program management techniques depicting Gantt and Pert charting, resource histograms, and business administration concerns outlining direct and indirect costs associated with each program. At UMD, these educational qualities are preliminarily covered by using existing software available for public purchase: Timeline™ and DAC-Easy™.

Timeline™ provides computational use and understanding of program management. Program management is the organized planning and tracking of projects, allocating resources, tracking costs, and managing the critical path, or that series of tasks that must be completed as planned to keep the entire program on schedule. As applied to course work, this analysis is used for structuring the overall schedule of the requirements for the student design competitions and for outlining the design, development, testing, certification, and production schedule of an advanced vehicle concept. The Gantt chart illustrates the work schedule for each individual tasking comprising the entire program. Pert charts provide useful information examining the interrelationships among tasks. Histograms provide allocation of time and budget to specific individuals or resource items. This analysis provides valuable information to the program manager and to the employees/students with specific tasking objectives and overall direct labor costs.

The program management approach is applicable not only to actual hardware development, but to progressions in software and fundamental research. As the graduate student must plan to finish the doctorate degree within the guidelines of the funding source, the industry engineer–researcher must develop applicable solutions within similar guidelines. Therefore, if the industry researcher must adhere to specifications set forth by Gantt, Pert, and histogram charts, then the student researcher should be exposed to these requirements.

In addition to program guidelines and direct labor costs, the successful industry engineer will eventually be exposed to the restrictions of financial management. This could potentially include the requirement to monitor the processing of purchasing, accounts payable, billing, accounts receivable, and inventory activities. These features are presented within a full general ledger with budgeting which can assist the managing engineer with complete financial statements and forecasting capabilities. It should be noted that large aerospace companies have internal accounting groups which record expenditures for the program manager. However, the program manager has the responsibility of spending allocated money which yields the highest productivity to the company's program. This requirement dictates that the manager must be fully cognizant of all expenses associated with the program.

To illustrate the format and detail of financial transactions, DAC-Easy™ is presented to UMD graduate design students. As applied to course work, this analysis is used for acquainting the student with real costs associated with any industry program. For example, mostly all companies and universities (not just limited to aerospace) participate in submitting responses to proposals for the purpose of receiving funds for a specific project. The proposals generally require the detailed breakdown of all direct, indirect, and profit costs specified in the 'bid' price. Therefore, while a student design competition may not require costing assessments, the UMD design course requires that students innovatively determine how to accomplish goals at minimal expense. This forces students to include available research, methodologies, and technologies within the development of their programs. When voids are encountered, then the most productive avenue of research must be outlined to fulfill tasks objectives. This is not to support Machiavelli's 'The end justifies the means,' but to initiate students to administer appropriately required research programs toward the fulfilment of a real need.

All this training may provide some ambitious students with the desire to independently start their own aerospace research or design firm. These students who are technically capable and have augmented their knowledge with business and management acumen may find that corporate aerospace does not provide a suitable environment within a resonable timeframe to enable these embryonic 'entrepreneurs' to develop their own research and development programs. Enter universities! Most universities welcome those individuals with the ability to conceive of viable research topics, and then write winning proposals, provide program and financial management, and technically conduct valid scientific and engineering studies. The life of the university researcher may develop roots during the graduate study phase, obtaining early knowledge of complete program attributes. On the other hand, there may exist a desire to go solo.

Opportunities for entrepreneurship in aerospace vehicle research and development appear to be virtually nonexistent since most endeavors require large initial capital investments [5]. However, there are various levels of entrepreneurs which can best be defined by Thoreau as: 'If a man does not keep pace with his companions perhaps it is because he hears a different drummer. Let him step to the music which he hears however measured or far away.' Obviously, not all entrepreneurs are inventors with a new concept of aerospace vehicle design. The industry offers many opportunities for a well-educated and experienced individual to establish a solo practice as a professional consulting engineer. Because of the superstructure of the industry framework, consultants to smaller subsystem business organizations are more readily obtained than within the larger companies. However, these solo practitioners must be adroit in not only technical areas, but must possess those management and business skills which are part of the formula for success.

CONCLUSIONS

Because of current and long-term projected aerospace market opportunities, universities can position themselves as entrepreneurial entities supporting the aerospace community in research-related program tasks. This opportunity suggests universities market their research capabilities and developments toward productive industry requirements while acquainting themselves with corporate management and fiduciary responsibilities. Strong technology opportunities exist in flight dynamics, control laws, optimization techniques, computer-based real-time simulation, aeroelasticity, computer-aided design systems database management techniques, and structures and materials.

Future aerospace engineering graduates can be better integrated into the corporate ranks with a broad-based education encompassing the technology, methodology, management, and business aspects of the design process. Doctoral graduates who possess an acute awareness of global parameters constituting a major research and development program provide the industry with higher productivity and lower 'learning curve' time and costs associated with front end training [8]. The educational emphasis is placed upon thorough comprehension of methodology development, but should not exclude corporate management and business concerns which make the research environment a real-world business opportunity.

The development of predictive methodology requires prior theoretical knowledge of the complex technologies and physical mechanisms associated with the science of flight. Comprehensive understanding of physical systems provides a foundation for the application of innovative design, technology, and methodology. The industry and universities as a whole must provide special consideration on identification of technology and methodology voids which will surface during initial assessment phases of advanced aerospace vehicle development programs. Interim and permanent solutions in basic methodology, validated through proper test techniques, must be developed to enable the aerospace designers reasonable extrapolations of advanced design characteristics.

Corporations may potentially expect to experience insufficient appropriate methodology in-house during the response to proposal with speculation that any problems will be overcome during the lifetime of the contract. This approach can result in program delays and cost overruns.

Aerospace companies along with appropriate universities should be encouraged to form a joint association for teaming a response to proposals. In this manner, potential university funding is contractor related, not company related. Not only is there a mutual benefit experienced from both participants, the contractor receives enhanced productivity at reduced costs. Likewise, government and military contractors should encourage potential corporate participants to link with universities wherever and whenever appropriate.

Graduate studies receive the most benefit from a teaming arrangement between universities and corporations. The university could encourage the student to have a more panoramic awareness of the business and management requirements associated with successful industry operations. This knowledge, combined with a strong academic background, provides the student with tremendous growth opportunities within the aerospace community and valuable insight to real industry concerns.

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