Bridging the Generation Gap: A Rapid Early Career Hire Training Program

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This paper describes a training program designed to provide Early Career Hires (ECHs) in the aerospace industry with real, rapid, hands-on exposure to multiple phases and multiple disciplines of flight project development. Such a program has become necessary to close the Generation Gap and ensure that aerospace organizations maintain a highly skilled workforce as experienced personnel begin to retire. This paper discusses the specific motivations for and implementation of such a program at the Jet Propulsion Laboratory. However, the essential features are widely applicable to other NASA centers and organizations delivering large flight systems. This paper details the overall program concept, stages of participation by an ECH, oversight and mentoring, program assessment, training project selection, and facilities requirements.

Nomenclature

AO	=	Announcement of Opportunity
CAD	=	Computer Aided Design
Candidate	=	an ECH eligible to participate in the Program
CDR	=	Critical Design Review
ECH	=	Early Career Hire
NASA	=	National Aeronautics and Space Administration
Participant	=	an ECH actively employed in the Program
PDR	=	Preliminary Design Review
PM	=	Project Manager
PRB	=	Program Review Board
PSE	=	Project System Engineer
Program	=	an ECH training program of the type described in this paper
RFC	=	Request for Concepts
SIR	=	System Integration Review
SRR	=	System Requirements Review
TRL	=	Technology Readiness Level
TRR	=	Test Readiness Review

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I. Introduction

THE workforce of NASA and the aerospace industry is aging rapidly. Full-time permanent NASA scientists and engineers over 70 outnumbered those under 25 by nearly a factor of six and a full 33% of NASA employees are eligible to retire today (Fig. 1). Furthermore, the average age of NASA employees is 47.6 and increasing by 0.3 years of age annually (Fig. 2). Other aerospace organizations face similar trends. While the aging workforce and large number of retirement-eligible employees do not necessitate a sudden loss of experienced personnel, they create uncertainty in NASA's human resources for the coming decades. To guarantee future performance, NASA must rapidly hire many talented young workers and pass along to them the knowledge and experience accumulated by its senior staff. NASA flight projects present the greatest demand for experienced personnel, and hence the greatest challenge: flight project training is the main goal of the Program we describe.

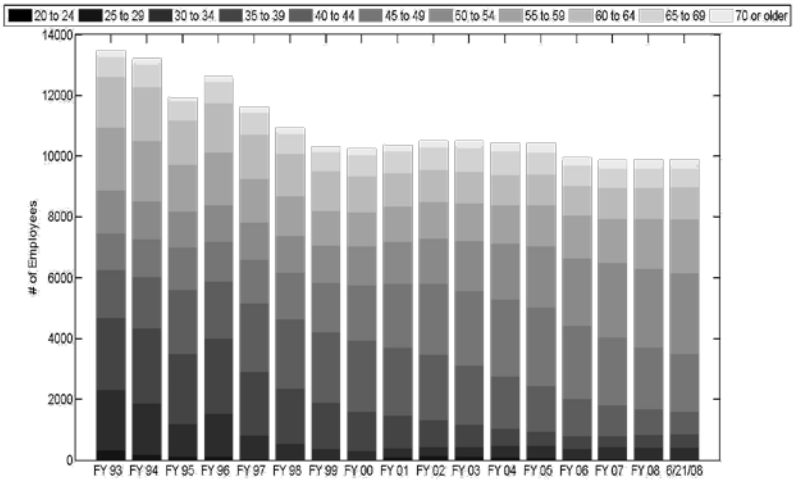

Figure 1. Age distribution of NASA's full-time permanent science & engineering workforce over the last 16 years.[1]

New hires at NASA typically work for at least a few years before taking a position of responsibility on a flight project (if they do at all). This is due in part to the search for a desirable area of work within their NASA center, and in part to the demand of flight projects for personnel with a strong track record. Their first responsibility on a flight project is typically at a low level in the project organization, so that they are not directly involved in analyzing system- or mission-level trade-offs. After a tour of duty on one or more flight projects encompassing most phases of flight system development—typically six years or more—they may be given a subsystem-level responsibility on another flight project, where for the first time they will have to make decisions affecting overall mission performance, cost, and schedule. A large fraction of NASA staff never reach such a position, and develop experience in only one phase or one area of project development. By the time today's new hires have the opportunity to reach such a position, a large portion of NASA's flight project veterans will have left the agency, so that their hard-earned experience can no longer benefit the younger staff replacing them.

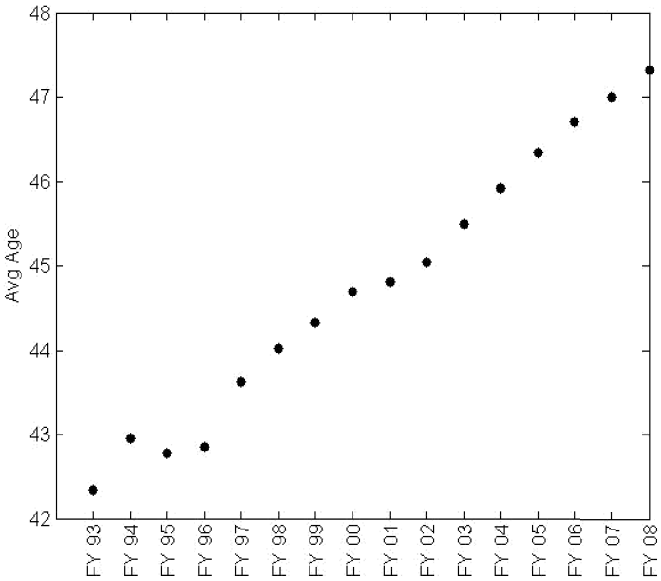

Figure 2. Average age of NASA's full-time permanent science & engineering workforce over the last 16 years.[1]

It is unlikely that NASA flight projects will reduce the qualifications for their positions of responsibility, or that their development timelines will shrink appreciably in the next ten years. The Program we describe trains ECHs in flight project development by giving them positions of system- or subsystem-level responsibility on small-scale projects with short development times. By giving them multiple positions on multiple projects at different stages of development, the Program also ensures their exposure to multiple phases and disciplines of flight project work, preparing them for system- or subsystem-level positions on full-scale NASA flight projects. The Program's small projects bridge the enormous gap between university projects and NASA missions. At the same time, it offers aerospace organizations important strategic advantages in recruiting, retention, networking, and organizational agility.

II. Program Overview

The Program combines a number of established training methods—courses, mentoring, and collocation—with a project-based focus to create a microcosm of the flight project experience for Participants. One of the more revolutionary techniques this Program employs is the ability to provide participants exposure to multiple phases and aspects of a flight project. In order to accomplish this feat, the Program must have multiple projects in development at the same time (Fig. 3). Ideally each project has comparable size and development time, and project start dates are staggered at roughly even intervals, such that a Participant can gain experience in multiple phases of project development during a relatively short training period through simultaneous responsibilities on two different projects (Fig. 3). By assigning the Participant different areas of responsibility on each project, the Participant also gains experience in multiple disciplines. By sizing projects to peak staff levels of 8-15 people, each Participant can have system- or subsystem-level responsibility in the project. The comprehensiveness of this exposure will vary according to the size and timeline of projects and the period and level of commitment of Participants.

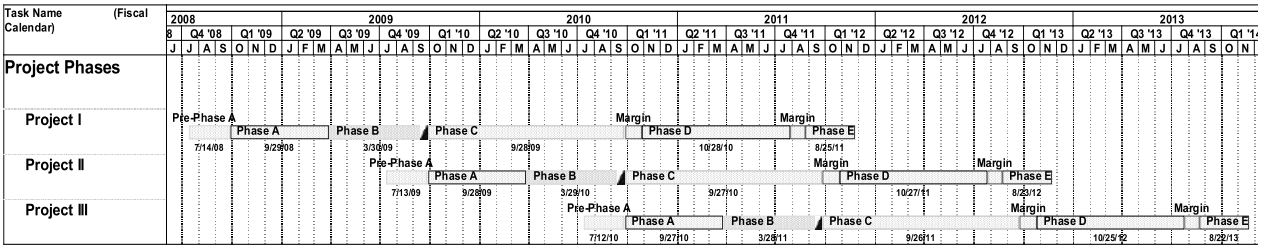

Figure 3. Sample project schedule displaying overlapping design phases.

A version of the Program described here implements ~$2-5M projects, each over ~3 years, with start dates separated by ~1 year. Hence at any given time, the Program has three projects in development, with a total workforce of 15-50 Participants. Participants devote 50-100% of their time over 6-18 months. Within a 12-month period, a Participant can work directly in nearly all the NASA mission phases, from cradle to grave, as shown in Fig. 3.

While all project responsibilities (including the positions of Project Manager and Project System Engineer) are assigned to Participants, the Program involves many experienced personnel in mentoring and oversight roles. Mentors work directly with Participants on specific elements of a project, guiding and reviewing Participants' work on a daily to weekly basis. Depending on projects' depth and difficulty, the Program employs mentors in a 1:1 to 1:2 ratio with Participants: the version described here employs 20-30 mentors in total at any given time. However, mentors have low levels of commitment, averaging ~6 hours per week, making this number equivalent to 3-4 full-time personnel, and hence a reasonable portion of the program budget. The Program also provides independent oversight of projects and Participants through a Program Review Board (PRB) that conducts periodic reviews of both projects and Program.

Projects should emphasize the core disciplines and capabilities of the organization implementing the Program, with similar types of performance objectives. Within NASA, projects may consist of flight technology demonstrators, microsatellites, or payloads on aircraft, balloons, sounding rockets, or existing NASA space missions. To create a “real” project experience, the projects should have compelling value in and of themselves that demand technical requirements taken seriously by the organization.

The project selection process leverages existing efforts and experience by soliciting ideas from across the organization through a Request for Concepts (RFC). The PRB combines veterans' flight project experience with new hires' perspective to select candidate projects for the Program, which the Participants then develop through competitive proposals. While competition yields high-quality projects and provides important experience for future flight project work, the Program also retains the Participants from non-selected proposal teams to ramp up staff for selected projects, so all Participants receive a comparable experience.

Beyond its training value, the Program can give an organization strategic advantages for developing human resources in an increasingly competitive hiring environment. First, the Program can provide an exciting attraction to potential recruits, who value the opportunity to develop their skills and contribute to a meaningful project early in their careers. Training opportunities often influence the employment decisions of new entrants into the workforce. Second, by providing an engaging experience with visible rewards to new hires, the Program can help convince them to remain with the organization, hopefully for their entire career. Finally, the Program provides a mechanism for new hires to connect with experienced personnel in their area of interest, and with each other, building the organization's internal network to facilitate future accomplishments. The social benefits of such networking in turn play a major role in a new hire's decision to stay.

Since new projects begin frequently, the size of the Program can be readily adjusted to organization's hiring rate through the project selection process, and projects can be chosen to respond to immediate training or technical needs of the organization. Since Participants begin their career in the Program, it can serve to pioneer new processes and methods of project work that reflect lessons learned from the past, and gradually infuse them into the organization. Finally, the Program gives the organization direct experience in implementing small, responsive flight systems, an area of growing importance in the aerospace industry.

III. Participation Stages

A participant's involvement with the Program can be described in five stages: recruitment and hiring, selection, training, project work, and transition. This section describes the experience of a typical Program Participant throughout these stages. In addition, we distinguish the special roles of the Project Manager and Project System Engineer on each project and how they differ from the typical Participant experience. See Fig. 4 in the Appendix for a typical project organization chart.

A. Recruitment and Hiring

The Program can be a powerful recruiting tool, exhibiting exciting projects a candidate employee might work on during their first few months of employment. The Program can be presented at university career fairs and other recruiting events, perhaps by current Participants hailing from the host institution. As part of the recruiting and interview process, recruiters can assess interest and relevant skills of candidates for participation in the Program, to aid planning for the next project cycle. To enable these steps, recruiters must be well informed about the Program, and the Program should have external materials (such as a web site and brochure) for publicizing its activities. Finally, during on-site interviews, candidates can meet informally with current Program Participants, establishing personal connections with new hires that can further aid the recruiting process and assist with Participant selection.

Since the Program's principal purpose is to train new hires, the Program should not directly influence hiring decisions. These decisions remain with the organization's existing management, based on long-term needs. However, the Program can work with management during the recruiting process to identify candidates' availability and suitability for participating in the Program after hiring.

B. Participant Selection

The Program is not expected to involve all new hires in an organization, nor even a majority, but rather to provide a sufficient pool of new hires with system-level flight project experience to replace the skills being lost in workforce turnover. Participants for the Program are selected from among new hires by the following criteria:

- *Desire to participate:* Compulsory participation is unlikely to stimulate the level of motivation necessary to successfully complete small flight projects on a tight schedule, or to provide the same level of benefit to participants in any respect. Candidates should understand the demanding nature of the Program, and have a strong interest in developing system-level project skills rather than focusing purely in a single technical area. These Participants represent the strongest candidates to eventually fill the flight project positions for which the Program prepares them.
- *Availability:* The Program should not interfere with the ongoing business of the organization, hence should not involve personnel with important commitments to other projects requiring their knowledge or skills. Candidates should have at least 50% of their time available in order to effectively manage multiple roles on multiple projects in the Program.
- *Relevance of skills:* A strong Candidate should have strong skills in at least one area in need of staff on a Program project. A good background in other areas is important for acquiring other skills during the course of participation in the Program, and for assuming system- or subsystem-level responsibilities on a project.

The Program will typically select a new group of Participants a few times each year (e.g., quarterly), perhaps to align with natural waves in its influx of new hires. By bringing in groups at designated intervals, new Participants can go through an orientation process and background training courses as a group, and projects can time their delivery of documentation and reviews to quickly bring new Participants up to speed.

C. Training

While the Program emphasizes project-based "training through doing," there are elements of any job best prepared for through formally structured training. Such courses offer Participants the chance to absorb large amounts of background information for a limited period before they have become familiar enough with Program projects to work effectively on specific project tasks. They also offer mentors a venue to convey a great deal of already-

structured information to many people at once. Formal training activities include the following elements:

- *Orientation to the Program:* general expectations, available tools and equipment, facilities, introductions to key personnel, project goals and status, schedule, and documentation.
- *Specialized technical courses:* depending on their project and role, Participants may prepare for their project work with some specialized courses in areas dealing with critical item handling, safety, manufacturing, etc.
- *Meetings and reviews:* each Participant attends project- and subsystem-level meetings pertinent to their eventual positions of responsibility, as well as any project-level reviews for all projects in the Program.
- *Shadowing mentors:* each Participant shadows the mentor(s) expert in their eventual areas of work to learn through direct observation of ongoing project work.

Formal training activities typically last for ~1 month. During the training period, Participants are given some basic tasks to complete for their assigned projects, which help solidify their orientation to the Program, and verify their readiness to proceed to project work. After the formal training period, Participants assume their assigned responsibilities on project tasks.

As mentioned above, formal training periods are timed to coincide with the entrance of each new group of Participants, typically multiple times per year. Later on in their tour of duty, Participants taking on new responsibilities or new stages of their work may participate in additional technical courses or spend additional time shadowing mentors to learn new skills. This approach ensures that the education from training courses is obtained just before it is applied, strengthening both immediate and long-term retention.

D. Project Work

The hands-on training of project work occupies the bulk of a Participants' time in the Program. A Participant is typically assigned one primary responsibility (such as subsystem lead) in one area of one project, and a secondary responsibility (such as subsystem testing) in a different area of another project. A Participant's primary responsibility should fall under a strong area of their prior expertise, while their secondary responsibility should fall under an area in which they can readily expand their breadth of knowledge.

Since each Participant is closely involved in two different, relatively small projects at different stages of development, they become aware of the project-level issues facing each project, and see these issues from the perspective of two different disciplinary areas. This gives them a system-level view unparalleled by other types of experience they could obtain in a comparable timeframe with traditional training programs. Moreover, they typically work in close proximity to one or more additional projects in the Program in which they have no assigned responsibility (see Section VII), which gives them a window into still other disciplines and stages of development through conversation and observation.

E. Transition

During the beginning of their tour of duty in each area, each Participant works for ~1 month in tandem with another Participant with the same responsibility, who gradually hands off ownership to the new Participant while preparing them to take over the position as they transition out of the Program. In turn, during the end of their tour of duty, each Participant is responsible for preparing new Participants to take over their positions again. This overlapping transfer of responsibility helps to avoid loss of project-specific skills and knowledge in the relatively rapid turnover of personnel. At a higher level, mentors provide continuity across an entire project through continual contact with Participants in their area.

The transition period for an outgoing Participant includes several elements. First and foremost, the Participant's day-to-day work familiarizes the new Participant with basic procedures and issues required for doing the job. Second, the Participant creates and/or updates documentation reflecting the development, activities, and current status of each task, as a reference for future work and review in that area. Finally, the Participant gives an open seminar to the organization presenting the material in the documentation and its relevance for the project. This allows any continuing project personnel to ask relevant questions before their departure, and allows interested members of the organization to observe the activities and training value of the Program.

In the transition period, the Participant is responsible for seeking new role(s) in the organization to absorb their time following completion of their Program training. Their relationships with mentors in the Program, and experience gained therefrom, can be extremely helpful in this regard. In addition, their breadth of experience in the Program helps them to determine which position(s) in the organization will suit them best.

F. Special Cases

Each project has two special full-time roles, the Project Manager (PM) and Project System Engineer (PSE), handled differently from those of other Participants. The Participants filling the roles of PM and PSE assume these responsibilities only after some time (typically ~6 months) spent working on the corresponding project, and remain in the Program for longer than most Participants (typically ~12-18 months in total). This ensures a level of experience and continuity in each project's leadership that is not required for other positions on the project.

Candidate Participants for the roles of PM and PSE are identified by the Program Manager and Lead Technical Advisor, and by the existing PM and PSE, during their initial participation in another project role. After ~3 months, a candidate for each role is selected according to interest, availability, and qualifications, and the candidates spend the following ~3 months in an extended transition period, working in tandem with the existing PM/PSE. During this transition, they ramp down their prior responsibilities on the project, and ultimately ramp up their project-level responsibilities to full time, assuming the roles of PM/PSE after ~6 months in the Program. They may also take additional training courses in management and systems engineering. This extended transition, with the help of mentors advising the PM/PSE, helps to smooth the small number of turnovers in each project's leadership.

IV. Programmatic Oversight

The Program places primary responsibility for all project roles in the hands of ECH Participants, including management, system and subsystem engineering, proposal development, scientific analysis, business administration, mission assurance, and any specialty areas required by particular projects. This responsibility is essential for actively absorbing the experience available from the senior staff advising the Program. At the same time, like any real-world program, independent oversight ensures that both the Program and its projects accomplish their respective goals. See Fig. 5 in the Appendix for a typical Program organization chart.

A. Program Management

A full-time Program Manager, Lead Technical Advisor, and Administrative Assistant provide everyday oversight of all projects and Participants. These roles employ experienced personnel from the organization, ensuring that Participants are able to make mistakes and learn from them, but guarding against failures that could endanger the Program or its personnel.

The Program Manager's responsibilities include:

- Program-level budget and distribution among ongoing projects
- Program-level logistics and facilities
- external interfaces to the organization and partner institutions (e.g., universities)
- management of the Request for Concepts (RFC) and project selection process
- assembly and management of the Program Review Board (PRB)
- organization of Program-level reviews

The Lead Technical Advisor's responsibilities include:

- guidance and assessment of Program training goals
- assembly and management of relevant project mentors
- assignment of Participants' areas of responsibility
- dispensation of technical advice and oversight to all Program projects
- organization of project-level reviews

B. Mentors

As described above, the Program employs mentors in a 1:1 to 1:2 ratio with Participants, at relatively low levels of involvement. Mentors typically remain with a project throughout its lifetime, or as long as their areas of expertise are relevant, providing continuity for project tasks across several responsible Participants. The Program maintains a database of mentors with contact information, a biography, and a description of their areas of expertise to facilitate finding mentors appropriate to any given task.

In general, mentors fall into two categories:

- *Principal mentors:* These mentors are regularly involved in day-to-day project work, devoting up to ~6 hours per week of their time (~15% time). They take a proactive role in ensuring that critical questions are addressed, tasks are appropriately managed, and key problems are resolved. With only a small amount of weekly time to devote, these mentors must be particularly enthusiastic about their role to avoid becoming disengaged.
- *On-call mentors:* These mentors have no regular schedule of involvement, but are available when needed to

help with questions, problems, tasks, facilities, or equipment in a particular area. They can be contacted by participants as needed, and then charge appropriate time to the Program to resolve the issue at hand.

The organization's management should encourage senior staff to participate as mentors in the Program. Most senior staff are enthusiastic to work with new hires and impart their considerable experience to younger people, and these are often the most effective teachers. However, an organization having difficulty recruiting mentors may consider tangible rewards or other incentives to stimulate this critical aspect of the Program.

C. Review Boards

The Program Review Board (PRB) provides external and independent oversight of the Program and its projects. While assembled by the Program Manager, the members of the PRB should have no direct role in accomplishing any aspect of the Program, hence should act as an impartial judge of success. While the PRB will not be directly involved in Program activities, the Program's credibility will rest with the reputation of the PRB and its assessment, hence the PRB is essential to maintaining the support for and quality of the Program.

The PRB consists mainly of senior staff at the organization chosen for their strong flight project experience. These individuals are best qualified to judge whether the Program is successfully preparing Participants for significant roles in future flight projects. The PRB also consists of a small number of ECHs (preferably alumni of the Program), who provide perspective on the incoming capabilities and weaknesses of ECHs and their current-day training needs. In the version of the Program described above, the PRB consists of 12 senior staff and 4 ECHs.

The PRB's responsibilities include:

- *Downselection of RFC concepts:* The PRB selects 3-4 concepts from among submissions to the RFC to be developed into detailed proposals by ECH teams. These concepts are selected to be those of greatest value to the organization from among the feasible concepts meeting the Program's training goals (see Section VI). Each concept is developed into a detailed proposal by a team of Participants.
- *Selection of proposed projects:* The PRB selects one project to proceed to implementation from among the 3-4 proposals developed by the Participants for a given project cycle.
- *Recruitment of mentors:* The members of the PRB are expected to leverage their experience and connections in the organization to identify and recruit excellent mentors for the Program.
- *Program-level reviews:* At periodic Program-level reviews organized by the Program Manager, the PRB assesses how well the Program is meeting its training goals and providing overall value to the organization, and provides recommendations to the Program Manager on improvements to the Program.
- *Project-level reviews:* At the project reviews ending each stage of a project's development (e.g., SRR, PDR, CDR), the PRB assesses how well each project is meeting its technical objectives, and provides recommendations to the Lead Technical Advisor and project team on how to ensure project success. The PRB may be augmented by technical experts in relevant disciplines for project-level reviews.

The PRB should include at least one member of the organization's senior management, who can help justify and defend the Program to the organization at the highest level. Without such an advocate, it is difficult for such long-term investment to maintain consistent funding in the face of pressures from an organization's current business interests.

V. Program Assessment

The Program described here is a long-term, multi-faceted investment, whose effectiveness is difficult to measure. However, this section discusses a number of methods for assessing how well the Program is meeting its objectives. These methods relate to different Program objectives, and only some are *comparative*, that is, assess the differences between the Program and other training opportunities previously offered by an organization. However, many naturally provide suggestions for corrective action. Taken together, these methods may be helpful to the PRB in making its regular assessments of the Program, and justifying continued funding from the organization:

- *Participation rate:* The simplest criterion for Program success is the number of ECHs successfully completing a tour of duty in the Program, both in absolute numbers and as a portion of total ECHs entering the organization. If this rate is too low to meet the organization's needs, the Program must be expanded, or combined with or replaced by other approaches. Since many factors may influence participation rates, this measure is not comparative.
- *Participant evaluations:* Participants' subjective assessment of the personal training value they gain from the Program can be measured through entrance and exit surveys. If Participants do not have a positive experience, it suggests they will not work effectively in the Program, which in turn reduces the effectiveness of the training experiences and chances of project success. In addition, it will severely curtail

benefits associated with recruiting and retention of new hires. Follow-up evaluations later in Participants' careers may be useful to gain a retrospective assessment of the Program's impact, though this is a lagging indicator. Since Program participation will influence Participants' other training choices and experiences, this measure is not comparative.

- *Candidate evaluations:* Complementary to Participant evaluations are evaluations from Candidates who elected not to participate in the Program or were not selected for the Program. These evaluations may balance a possible pro-Program bias in Participant evaluations, but are likewise non-comparative.
- *Mentor evaluations:* Among the experienced staff, mentors have the greatest opportunities to observe the accomplishments and professional development of Participants, the expertise required to assess their growth, and a less biased perspective on the Program. For these reasons, their evaluations may carry more weight for the organization than those of the Participants themselves. For mentors previously (or simultaneously) involved in other training activities, they may also provide some meaningful comparative assessment.
- *Project reviews:* The feedback from the PRB and other reviewers at project reviews can indicate the Program's success in achieving its training goals, as well as in developing organizational processes suitable for small projects. Since most training approaches do not produce projects of this kind, and each project carries its own advantages and disadvantages, this is not a comparative indicator.
- *Project outcomes:* The actual results of projects, compared against their stated goals, can (to some extent) objectively verify the feedback from project reviews. However, this assessment is likewise project-specific and non-comparative.
- *Participant outcomes:* Statistics from the organization's human resources department may indicate the Program's impact on recruiting, retention, and training future project staff, by comparing the career outcomes of ECHs who participate in the Program with those who do not, while controlling for variables such as hiring qualifications, Program eligibility, the external labor market, and other organizational changes that may affect human resources development. While these measures will require time and effort to obtain meaningful results, any large effects should be visible, and they may provide the only objective, comparative assessment of Program success.
- *Organization evaluations:* Though not as objective as Participant outcomes expressed by organizational level and compensation, evaluations of Participant strengths and weaknesses by supervisors of their post-Program careers (for instance, as part of the organization's regular employee assessment process) can more specifically identify areas of improvement for the Program. These measures depend on many factors specific to the Participant's eventual career choices and context, hence will have less comparative value than measures subject to statistical analysis.

The efforts required to implement these methods of assessment will require strong organizational support, another reason for direct involvement of the organization's senior management in administering the Program. Some of these measures may be strengthened by beginning the Program on a small scale and gradually ramping up to a level meeting the organization's long-term training goals.

VI. Project Selection

One important advantage of the Program within a large organization is its ability to develop smaller-scale, higher-risk projects that lie somewhere between individual research efforts and full-scale flight projects, as these typically have difficulty finding funding from other sources. This inevitably leads to an abundance of project concepts in this niche, which must be pared down through a selection process.

Within NASA, the Program relies on a 2-stage proposal process modeled after the typical NASA AO Step 1 and Step 2 stages, appropriately scaled down to the smaller scope of projects for the Program. However, the training objectives of the Program require some further changes to this model. First, the Program aims to include initial conceptual design as part of the training experience for Participants: hence concept submissions to the Program from outside sources need not provide the level of detail typical of NASA Step 1 proposals, but rather only a compelling direction for detailed proposal development. Second, the Program wishes to employ participating ECHs over a relatively fixed period, regardless of the concept ultimately selected for project implementation: since proposal teams are naturally smaller in size than project teams, the Program simply divides its workforce in the proposal phase into 3-4 proposal teams, then recombines the workforce in the implementation phase to work on the winning proposal.

Candidate concepts for the Program must also meet different standards than typical NASA missions. Program concepts are judged primarily according to their value for training new hires within the Program cost and schedule

constraints, and secondarily on additional "project value" to NASA and the broader community. Nevertheless, novelty and innovation are essential to attracting and challenging new hires to prepare them for future work at NASA. The comparatively small investment in Program projects allows them to carry a higher level of mission risk than typical NASA flight projects, which may aid development and testing of new technologies. However, projects must admit graceful degradation in performance with cost- and schedule-induced reductions in technical objectives in order to satisfy the time constraints of the Program's project cycle. In this respect, Program projects are similar to NASA flight projects with an externally fixed launch window and a hard cost cap.

A. Selection Process

The project selection process begins with a Request for Concepts (RFC) issued to the community of interest, in our case a NASA center and possibly its partner institutions. The RFC helps to bring in ideas from a broad base of experienced NASA employees, many of whom already have project concepts meeting the Program's objectives that could not obtain funding through existing channels. ECHs may also submit concepts to the RFC, but it is essential to take advantage of the existing experience and perspective of non-ECHs in generating project ideas, which does not detract from the Program's training goals.

Concepts submitted to the RFC are evaluated by the PRB. The PRB combines its members' knowledge of current and desired ECH capabilities and interests, and their own project experience, to judge the feasibility and training value of the concepts submitted. The PRB selects 3-4 concepts to proceed to the proposal phase, and returns reviews of the remaining concepts to their authors to help improve submissions for the following project cycle.

The Program then divides participants for the new project cycle into proposal teams, one for each of the concepts selected. Each proposal team is led by an assigned Participant proposal manager and mentored by experienced staff selected on the basis of each concept. The proposal teams develop a detailed proposal to the PRB over a ~2-month period, following a scaled-down version of the typical Step 2 proposal criteria.

On the basis of these proposals, the PRB selects one concept to proceed to project implementation. The Participants from all proposal teams are then combined into the initial project team, whose staff level ramps up further toward delivery as the total staff level of other projects in the Program ramps down. The proposal development stage provides excellent opportunities for participants new to the organization to demonstrate their strengths and knowledge, allowing the Program Manager to appropriately assign staff positions in the eventual project team.

B. Project Selection Criteria

The technical content of projects in the Program may vary widely, both among projects and among the organization in which the Program is based. Within NASA, the Program will generally focus on preparing Participants for roles in NASA flight projects. In this case, each project should include experiences pertaining to as many elements as possible of flight project development, including:

- science / technology definition
- requirements analysis
- mission concept development
- payload engineering
- mission design
- subsystem engineering
- operations planning
- systems engineering
- software development
- mission assurance
- assembly and test
- integration and launch operations *
- flight operations *
- data analysis and publication / technology transfer *

The last three elements above (*) often require a launch opportunity that may lie outside the budget and schedule available within the program. In these cases, the projects should incorporate detailed planning and simulation of these phases, and include relevant considerations in the execution of earlier phases. Each project should demand relatively balanced efforts in each of the major project elements, so that all Participants can be meaningfully involved in a range of activities during their short time in the Program.

To provide realistic requirements and engage Participants, projects must accomplish meaningful technical

objectives that motivate the project independent of its training objectives. Projects that meet the program's training criteria are evaluated based on anticipated project value to NASA and the broader community, as well as potential for recruiting capable ECHs into the program. Projects may incorporate various combinations of scientific, technological, and strategic objectives, but should accomplish something novel and useful. Finally, projects should offer graceful degradation of their project value in response to program cost- or schedule-driven reductions in scope, in order to satisfy the project lifecycle constraints of the Program.

A complete set of NASA-centric project selection criteria for the Program is arranged in Table 1. Some of these criteria reflect the inherent uncertainty associated with the availability and success of launch opportunities. The criteria in Table 1 must be tailored to the needs of the specific organization in which the Program resides.

Table 1. Project selection criteria.

Feasibility	Training experience	Additional project value
• Cost and schedule • Facilities required • Overall level of development risk • Alignment with capabilities of ECHs and organization staff	• Cost-effectiveness of technical approach toward project objectives • Balance of exposure to all major organization project elements • Alignment with interests and capabilities of ECHs • Opportunities for operations experience prior to flight	• Benefits to science or technology development • Overall level of performance risk • Flexibility to accommodate scope reductions • Opportunities to obtain results prior to flight • Applications to future organization projects or proposals • Availability of external partnership and outreach opportunities • Additional strategic value for the organization

VII. Facilities

ECHs are entering the aerospace workforce from a university environment that has changed significantly from the educational model used from the 1960s through the early 1990s. Gone are programs consisting entirely of lectures and recitations. Current university programs utilize hands-on laboratory work in almost all courses, with much of this laboratory work conducted in open laboratory plazas. The modern university experience turns out ECHs who not only are accustomed to working in teams, but prefer working in a collocated team environment.

Such open work environments, combined with technology trends, lead ECHs to expect near-instantaneous face-to-face communications, and the ability to review all information across their team at any time. Collaborative spaces, personal computers, wireless communications, and digital projectors enable such free flow of information in university laboratories, and can do likewise in modern engineering facilities. Such facilities run counter to the norm of “cubicle farms” that isolate individuals and deliberately hinder open communication. These facilities are essential for rapid development of small technical projects like those comprising the Program. Below, we describe the features of a model facility for the Program.

The facility has an open floor plan largely devoid of fixed-wall offices or other walls that divide the work areas. Each main area in the floor plan is designated for different tasks. First, an “engineering bullpen” provides a center for computer aided design (CAD) and software development with high-performance workstations. The bullpen contains a networked projector system to allow designs or code from any workstation to be displayed for review to an assembled team. Each workstation area contains enough free desk space for additional laptops and notebooks that offer other platforms for analysis or communication.

Second, a “general engineering” area contains worktables, each with a dedicated digital or dry erase board and projector system. Each worktable offers connections for power and projection to and from laptop computers. The tables can be easily moved on wheels to reconfigure the room for different work sessions, meetings, or project reviews. Tables and chairs are elevated above the normal height to facilitate working while standing, promoting fluid movement in and out of individual and collaborative settings.

Third, a “coffee shop” area provides comfortable chairs or couches to facilitate more informal discussions of project topics between periods of intense individual work. This area also provides power and projection facilities for laptops, along with dry erase boards for sketching ideas.

Finally, two separate office areas give the Project Manager and Project System Engineer dedicated space for their own full-time work and for one-on-one meetings as needed. However, these spaces have a fixed, wide opening

in place of a door, encouraging informal communication between the project leadership and other Participants.

The entire facility should have a robust wireless network allowing mobility of laptop computers and personnel. Practical constraints demand an exception to this mobility for intensive software tasks, which can be done on shared high-performance workstations. Such mobility raises the bar on current wireless connectivity in typical aerospace organizations, where robust access is only intended for conference rooms. Even higher-bandwidth connections should be available for desktop workstations.

Laboratory facilities associated with a particular project should be located as close as possible to the design facility described above. The laboratory requirements vary from project to project, but should provide space for hardware prototyping as well as assembly of final project system(s). Any laboratory facilities must comply with health, safety, and hardware protection requirements of the organization.

Beyond physical facilities, the Program must provide state-of-the-art data sharing facilities to enable the smooth flow of information throughout. The rapid decrease in the cost of data storage over the last few years has made it possible to have redundant storage of all project documents on a single storage device. Collaboration software, such as modern wiki systems, allow a user or group to retrieve the latest version of a record, edit it, and upload their revised version while automatically maintaining the same network location for the most recent version and archiving the previous version. Wiki systems also provide a shared "notebook" that allows team members to maintain unofficial notes about individual records, procedures, tasks, or project elements.

Most mainstream collaboration tools can be accessed via a standard internet browser, providing two advantages. First, project personnel have uniform access from any machine using any operating system, allowing them to blend it into their computing environment of choice along with other tools they typically use. Second, personnel have access from any location, supporting the irregular work schedule of many ECHs. Collaboration software combined with redundant network storage provides the Program with a simple yet effective way of documenting the entire life of all of its projects without substantial burden its staff.

The confluence of an open design workspace, quality laboratory space, and network-based collaboration tools allow ECHs to bring their own well-developed ways of working to bear on Program projects, while at the same time introducing them to the organization's existing best practices for flight project development.

VIII. Conclusion

The aerospace workforce is aging, a trend that threatens a serious Generation Gap in critical knowledge and skills for flight project development in NASA and other organizations. A new generation of talented ECHs must be hired, trained, and retained in order to continue driving the industry forward. The knowledge and experience of the current workforce must be effectively passed on to a younger generation before it is lost for all time. The Program described above provides a means to do this through small project-based training experiences that transfer this knowledge and experience through direct application in a real-world, hands-on setting. This approach offers the best hope for rapidly preparing new hires to contribute to future flight projects.

The Program trains participating ECHs in proposal development, detailed design, hardware and software development, system integration, testing, and operations of meaningful small-scale projects with real value to their sponsor organizations. These projects place responsibility for all roles on ECHs to maximize their sense of motivation and accomplishment, but provide strong guidance through mentoring and oversight from senior staff. Participants in the Program experience project-level decisions over multiple project phases from the perspective of multiple different disciplines, all during a relatively short timeframe.

Beyond its value for training new hires to replace the experience leaving the workforce, the Program we describe provides additional strategic value to its implementing organization. It further strengthens workforce development by improving an organization's potential to recruit and retain the most talented ECHs. In addition, it provides a channel for small project development within an organization, which in turn develops tools and processes well suited to smaller, more responsive flight project development. While we have focused here on the role of such a Program within NASA centers, its essential features are applicable to nearly any organization developing large flight systems.

A Program using the aforementioned strategy has been implemented at the Jet Propulsion Laboratory in Pasadena, California under the name of Phaeton. The idea was spearheaded by the seven authors, all ECHs. More information about Phaeton can be found online at http://phaeton.jpl.nasa.gov.

Appendix

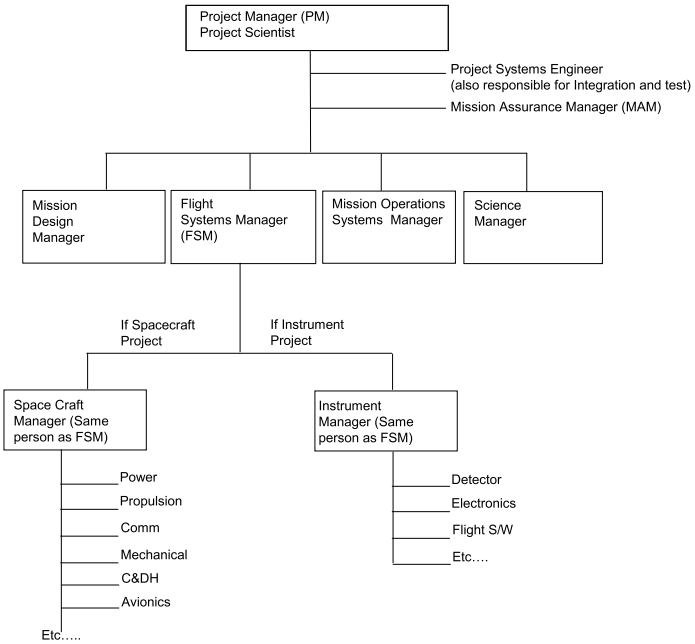

Figure 4. Sample organization chart for each project

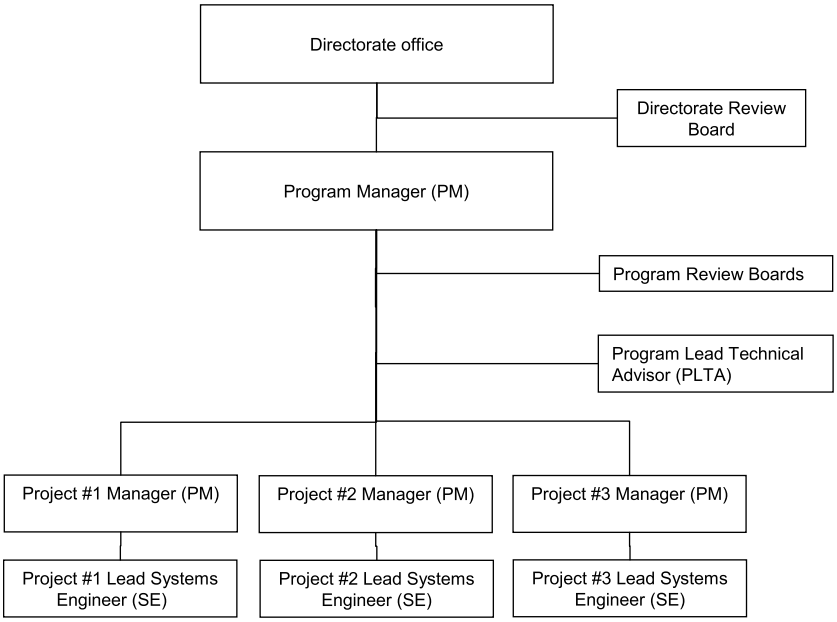

Figure 5. Sample organization chart for program oversight

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