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Competency-Based Education: A Framework for a More Efficient and Safer Aviation Industry

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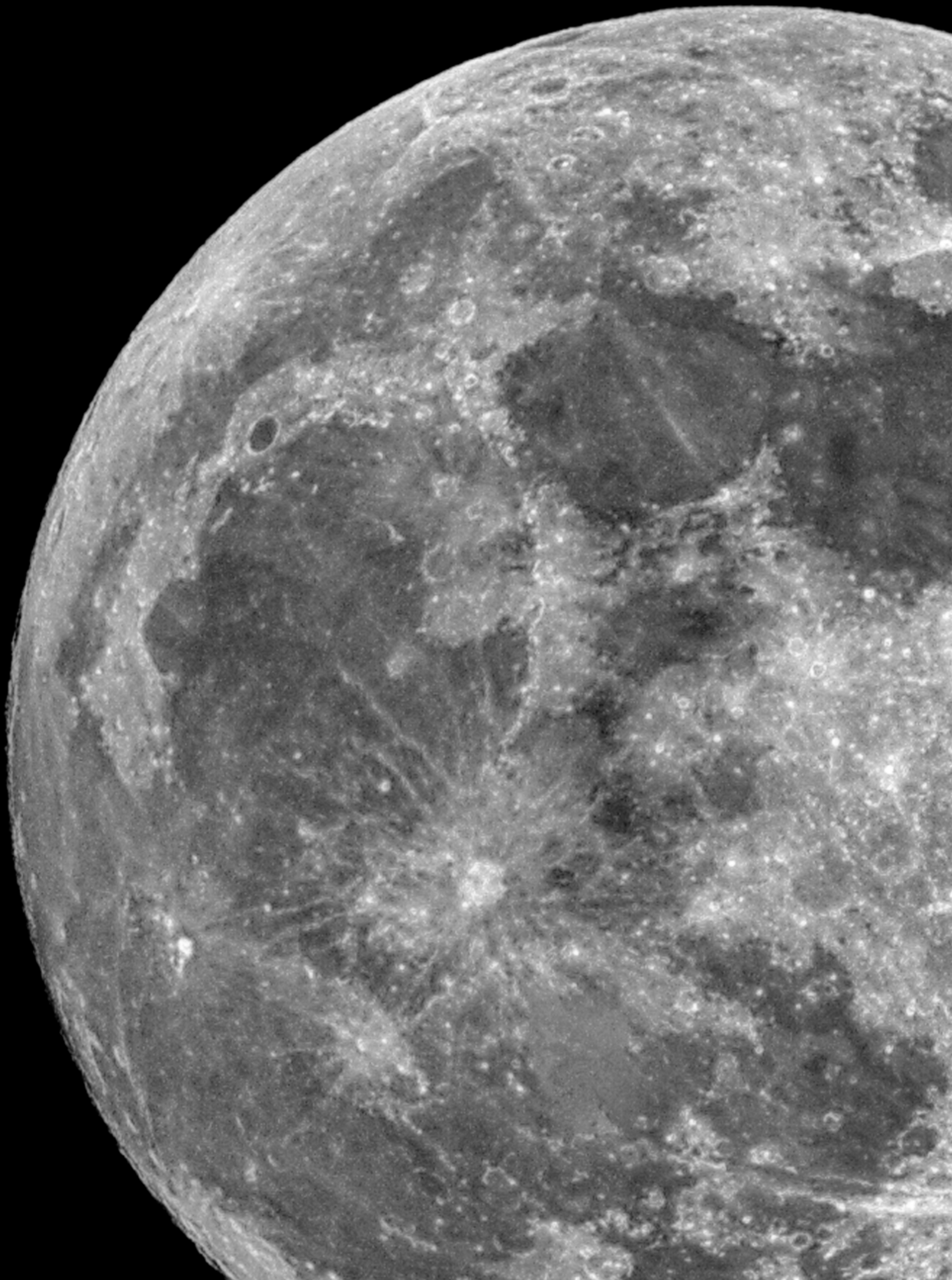

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NASA announced on Dec. 9, 2020, that 18 astronauts were selected to train for the Artemis missions designed to return humans to the lunar surface. As commercial space missions are on the rise in the United States and other nations, the question for ISASI: Do we need a space annex to provide international space safety procedures and investigation authority similar to Annex 13 here on Earth? (See page 4.) Fused photo of a super moon by Gary DiNunno.

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Competency-Based Education:

A Framework for a More Efficient and Safer Aviation Industry

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(Adapted with permission from the authors' technical paper Competency-Based Education: A Framework for a More Efficient and Safer Aviation Industry *presented during ISASI 2019, Sept. 3–5, 2019, in The Hague, the Netherlands. The theme for ISASI 2019 was "Future Safety: Has the Past Become Irrelevant?" The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Aircraft design and reliability as well as pilots' education and training have steadily and significantly improved in the last 20 years. Nevertheless, high-profile accidents still occur, even when the aircraft and related systems are operating adequately. Controlled flight into terrain, runway incursion accidents, and loss of control in flight are examples of mishaps in which inadequate decision-making, poor leadership, and ineffective communication are frequently cited as contributing factors. Conversely, the investigation of accidents (e.g., US Airways Flight 1549, in the U.S. on Jan. 15, 2009) and serious incidents (e.g., TAM Linhas Aereas Flight 3756 in Brazil on June 17, 2011) have shown that flight crews must be flexible and adaptable, think outside the box, and communicate effectively to cope with situations well beyond their individual expertise.

Conventional flight training requirements generally consider only the so-called "technical skills" and knowledge. Interestingly, pilot competencies in important areas such as leadership, teamwork, resilience, and decision-making are not explicitly addressed. The aviation system is reliable but complex. Thus, it is unrealistic to foresee all possible aircraft accident scenarios. Furthermore, there are many organizational variables that could have a detrimental impact in the flight deck of an aircraft.

To further improve flight training, the global aviation industry is moving toward evidence-based training (EBT). EBT provides rigorous assessment and assurance of pilot competencies throughout their training, regardless of the accumulated flight hours. EBT programs must identify, develop, and evaluate the competencies required to operate safely, effectively, and efficiently in a commercial air transport environment. Moreover, EBT needs to address the most relevant threats according to evidence collected in aircraft mishaps, flight operations, and training.

There is some emergent empirical evidence showing that high-quality education and flight training have a greater impact on efficiency and safety than just the total flight hours accumulated by entry-level pilots. Advanced qualification programs are utilized in Part 121 operations. A similar model with the development and assessment of defined competencies can lead to better education and flight training outcomes in collegiate aviation. In keeping with this transition to a competency-based educational model and given an understanding of the benefits of an EBT program for aviation safety and efficiency, the Purdue School of Aviation and Transportation Technology is redesigning its professional flight program. The benefits of this program will include

- establishing advanced training processes that will enhance the acquisition of knowledge, skills, and abilities by the future professional pilot workforce that meet or exceed safety standards;
- amplifying the quality of education and flight training over flight hours; and
- developing empirical data to inform decision-makers such as program leaders and regulators.

The goal of this transformation process is to develop a competency-based program that will attend to academic and regulatory requirements and that are in alignment with the major aviation stakeholders' standards and recommendations. It is important to note that a competency-based degree will require graduates to demonstrate proficiency in competencies that are valued by the aviation and aerospace industries. Therefore, this will be beneficial for both the graduates as well as the industry.

Aircraft Accident Investigation Process

Human errors have been implicated in more than 80% of aircraft accidents. However, those errors should be viewed from a systemic perspective since expressions such as procedural violations, human errors, and/or poor CRM will have limited value in preventing future mishaps. Latent conditions arising in the managerial and organizational sectors frequently facilitates a breach (or breaches) of the complex aviation system's inherent safety defenses. In simpler terms, latent conditions often permit or even motivate unsafe acts by the flight crew (and other aviation professionals).

According to ICAO, the accident investigation process is comprised of three phases: data collection, data analysis, and presentation of findings. The data collection process should focus on obtaining data relevant to the accident, which will include human factors. The data analysis should be concurrently conducted with the data collection process. The analysis of data frequently triggers additional needs that require further data collection. During those two phases investigators should scrutinize whether errors and/or violations by the pilots suggest deficiencies in necessary knowledge, abilities, and skills for efficient and safe job performance. Moreover, investigators should assess if identified flaws in pilot competencies result from training inadequacies.

When the active failures and latent conditions have been identified, the safety investigators should elaborate safety recommendations to prevent the reoccurrence of similar accidents. It is important to note that safety recommendations will generally address any possible combination of three factors: training, technology, and regulations. The following section highlights the investigative process and outcomes for the selected accidents.

Pilot Competencies and Aviation Safety

The global aviation industry is moving toward EBT and rigorous assessment and assurance of pilot competencies throughout their training, regardless of the accumulated flight hours. The aim of the EBT program is to identify, develop, and evaluate the competencies required to operate safely, effectively, and efficiently in a commercial air transport environment while addressing the most relevant threats according to evidence collected in aircraft mishaps, flight operations, and training.

In 2009, Colgan Air Flight 3407, a Bombardier DHC-8-400, crashed during an instrument approach to Buffalo Niagara International Airport in Buffalo, New York, killing two pilots, two flight attendants, 45 passengers, and a person on the ground. The NTSB identified several issues associated with the pilots' decision-making, teamwork, and communication processes. The report emphasized poor leadership by the captain as a factor in this mishap. The board members suggested that leadership training for upgrading captains could both standardize and reinforce the leadership competency of a pilot-in-command during air carrier operations. Lastly, the board issued two safety recommendations covering leadership training for upgrading captains at 14 Code of Federal Regulations Part 91K, 121, and 135 operators.

The Colgan accident became a major catalyst of significant changes in the U.S. aviation industry, mostly focusing on flight crew training and qualifications. The Airline Safety and Federal Aviation Administration Extension Act (Public Law 111-216), passed in 2010, requires pilots to hold an airline transport pilot (ATP) certificate in order to be hired by a U.S. air carrier. In order to possess an ATP certificate, pilots must be 23 years old and have at least 1,500 flight hours. This rule, however, allows some age and flight-hour reductions for specific military and FAA-approved post-secondary academic experiences. Currently, this law has created major challenges for airlines to find and hire qualified pilots. Notwithstanding, accidents that occurred prior and after Public Law 111-216 have suggested that flight hours are not a good predictor of pilot's performance.

In another example, an Airbus A300-600, operating as UPS Flight 1354, crashed short in August 2013 during a nonprecision approach to Runway 18 at Birmingham-Shuttlesworth International Airport in Birmingham, Alabama. The aircraft was damaged beyond repair by impact forces and a postcrash fire. Both flightcrew members were killed as a result. The board highlighted several issues associated with poor decision-making and communication processes by the flightcrew members and inadequate leadership by the captain. The final report indicated several safety recommendations in which some called for improved communication processes by flight crews.

The FAA has mandated CRM for Part 121 operators since 1998. The CRM training provided by air carriers generally includes concepts such as leadership, communication, decision-making, and threat-and-error management. CRM training has enhanced aviation safety and efficiency. Nevertheless, aircraft accidents and incidents in which inadequate CRM processes are identified as contributing factors still occur. There is no empirical evidence to support the claim that more flight hours will make a pilot safer and/or more efficient. For example, the captain and the first officer of Colgan Air Flight 3407 had 3,379 and 2,244 total flying time, respectively. Similarly, the captain and the first officer of UPS Flight 1354 had 6,406 and 4,721 flight hours, respectively.

Aircraft design and reliability as well as flight education and training have steadily and significantly improved in the last 20 years. Nevertheless, high-profile accidents still occur, even when the aircraft and related systems are operating adequately along with experienced pilots. For instance, controlled flight into terrain, runway incursions, and loss of control in flight are mishaps in which inadequate decision-making, poor leadership and/or teamwork, and ineffective communication processes are frequently cited as contributing factors. Interestingly, pilots involved in the mentioned accidents were arguably experienced.

Conversely, the investigation of accidents, for example, US Airways Flight

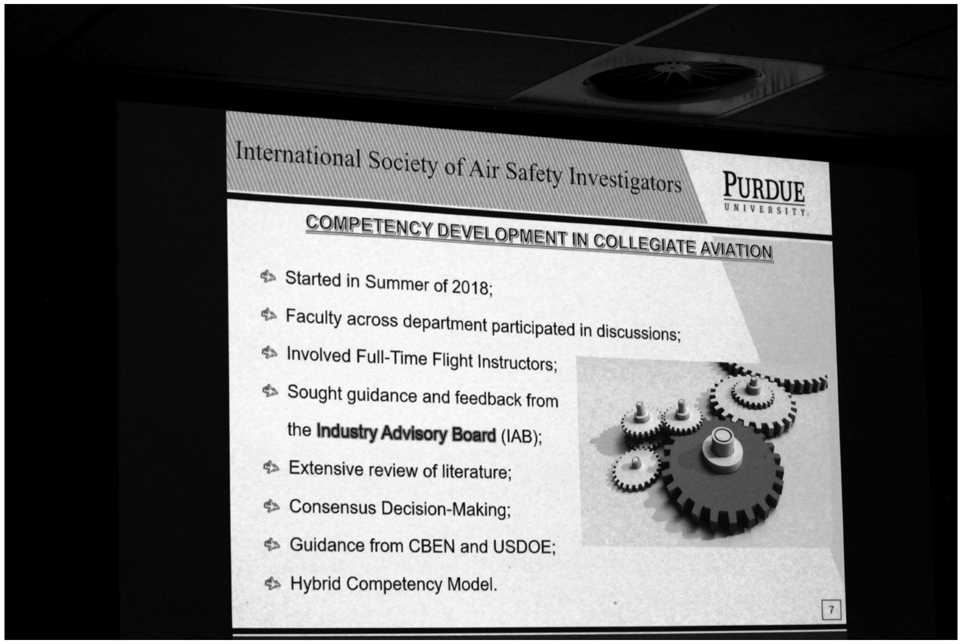
1549 in the U.S. on Jan. 15, 2009, and serious incidents indicated that flight crews have to be flexible and adaptable, think outside the box, work as a team, and communicate effectively in order to cope with situations well beyond their individual expertise. Such abilities could reduce the risk, probability, and/or severity of accidents.

The investigation of aircraft accidents and incidents, an important reactive component of the elements contained in the safety management systems framework, allows the identification of the latent conditions and active failures contributing to the mishap. In addition, such a process often uncovers other deficiencies and hazards that, although not a causal factor to the mishap, could become a contributing factor in future safety occurrences if not effectively addressed. This process can support top-management (e.g., new and/or updated safety processes) and even state (e.g., new policies to promote safety) decisions regarding the development of mitigation strategies and corresponding effective allocation of frequently limited resources.

Therefore, in a "safety management environment, the accident investigation process has a distinct role, being an essential process that deploys when safety defenses, barriers, and checks and counterbalances in the system have failed." Nevertheless, findings of a well-conducted aircraft accident (or incident) investigation process will be transferred throughout the organization so that everybody will be aware of hazards and associated risks within specific areas of operation. Additionally, findings will lead to new or updated safety training so that personnel have the skills, knowledge, and abilities to perform their duties efficiently and safely. Safety promotion efforts are paramount to advancing desired outcomes.

Safety Management Systems (SMS)

SMS is a "formal, top-down business-like approach to managing safety risks. It includes systematic procedures, practices, and policies for the management of safety (including safety risk management, safety policy, safety assurance, and safety promotion)." It is a tool that establishes processes to identify hazards and mitigate the associated risks with



A slide shown during the authors' ISASI 2019 presentation.

a significant enhancement in aviation safety. It translates the organization's safety concerns into effective actions to mitigate hazards.

The benefits of an effective SMS include compliance with regulatory requirements, improved productivity and morale, a healthy safety culture, best use of the resources available, and more business opportunities leading to a competitive advantage. Most importantly, a robust SMS will reduce the risk (probability and/or severity) of aircraft accidents. SMS comprises four key components: safety policy and objectives, safety risk management, safety assurance, and safety promotion. Part of safety promotion is the process of training and education.

Often, conventional flight training requirements generally consider only the so-called "technical skills" and knowledge. Yet, pilot competencies in important areas, such as leadership, teamwork, resilience, and decision-making, are frequently not explicitly addressed. The aviation system is reliable but complex. Thus, it is unrealistic to foresee all possible aircraft accident scenarios. After all, there are many organizational variables that could have a detrimental impact in the flight deck of an aircraft.

Nevertheless, empirical evidence indicated that high-quality education and flight training have a more positive impact on aviation safety and efficiency than accumulated flight hours. A competency-based education program could provide pilots with technical and nontechnical competencies needed to safely and efficiently operate in a highly complex social-technical system. Developing a competency-based training program can be daunting. The following section outlines the development within a collegiate aviation flight training program.

Competency Development in Collegiate Aviation

By 2036, the aviation sector will need 554,304 new pilots, 106,800 new air traffic controllers, and 1.3 million aircraft maintenance personnel. Boeing's Pilot and Technician Outlook forecasts there is a need for 790,000 new pilots, 665,900 new technicians, and 923,179 new cabin crewmembers by 2037. However, focusing on U.S.-based demand versus supply, it is estimated that the demand is about three times the supply. As a result of this massive gap in supply, there is a severe pilot shortage across the nation, and this issue has garnered attention from the mainstream news media. As a result, most of the national and global conversations are focused on quantity rather than quality of the workforce. However, educators and researchers in several industries have advocated competency-based education for decades to focus on quality.

In the aviation industry, ICAO and

IATA have recognized the need to develop and evaluate the performance of flight crews according to a set of competencies. Interestingly, both ICAO and IATA encourage operators to identify and develop their own competency system and related behavioral indicators, encompassing the nontechnical and technical knowledge, skills, and attitudes to operate efficiently, effectively, and safely in the aviation industry. Early efforts to use a competency-based approach to develop the knowledge requirements, establish assessment tools, and run preliminary tests support the notion that a competency-based approach could (a) identify weaknesses in pilot candidates and (b) enable hiring airlines and training providers to improve the success rate in the initial training, thereby simultaneously addressing both quality and quantity aspects of pilot training.

ICAO defines competency as a "combination of knowledge, skills, and attitudes required to perform a task to the prescribed standard." According to the U.S. Department of Education, a competency-based program leads to better student engagement because the content is relevant and tailored to each student's unique needs. Other benefits of a competency-based program include more efficient use of technology, identification of target interventions to meet specific learning needs of students, increased productivity and reduced costs, and the incorporation of active learning strategies into the curriculum. Thus, development and assessment of defined competencies can lead to better education and flight training outcomes. In order to develop competencies, a rigorous process needs to be partaken.

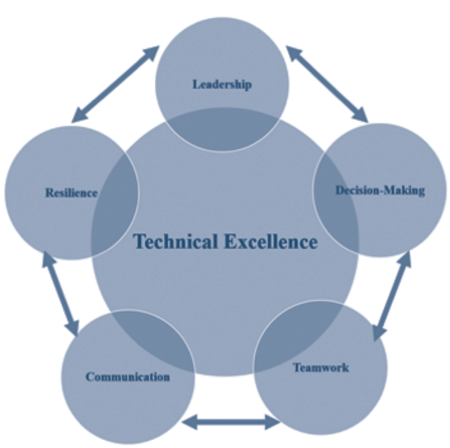


Figure 1. Conceptual model of professional flight competencies.

A consensus modeling approach was utilized to facilitate the process of developing the competencies described herein. Consensus decision-making refers to all members of a group agreeing on the chosen tasks, in this case competencies. A high level of participation between both the faculty and industry representatives, all leaders in their respective areas, was obtained. The first task of the faculty was to conduct a thorough literature review and identify 10 competencies. Once the 10 competencies were identified, focus groups and discussion were completed. These groups were a mix of faculty, flight instructors, limited-term lecturers, and industry representatives.

Additionally, a session was held with faculty from the other majors: aviation management, aeronautical engineering technology, and unmanned aircraft systems to provide another external perspective. The goal of the faculty was to write the competencies so that assessment in the classroom, flight, and simulators was feasible. Lastly, an outside representative from a university that focuses on abilities-based curriculum was sought. Some competencies were combined (e.g., intercultural and teamwork), leading to six pilot competencies in technical and nontechnical areas. The expert concurred with the selected and defined competencies after revisions. The results section outlines the unanimously selected competencies, description and rationale, and broad outline of the assessment strategies.

Both technical and nontechnical competencies were identified through extensive literature review and external review. The six program competencies are as follows:

- Technical excellence,
- Communications,
- Leadership,
- Decision-making,
- Resilience, and
- Teamwork.

The professional flight degree program seeks to develop these competencies within an integrated, high-consequence, and meaningful educational environment. Figure 1 illustrates how technical excellence is at the center of what we do. However, all competencies are connected and influence each other.

Each competency will be mapped to specific learning experiences within the flight program, and it will be developed at one of three levels of proficiency: Emerging (Level 1), Developing (Level 2), or Proficient (Level 3). Thus, over the length of the professional flight degree program, each student will progressively develop their competencies from emerging through proficient levels. Finally, at the conclusion of the program, all graduates will be expected to achieve proficiency across all the competencies.

This competency-assessment is grounded in Bloom's taxonomy to include psychomotor, cognitive, affective, and interpersonal aspects. Bloom's taxonomy will be used to describe instructional objectives in the professional flight degree program educational documents, conduct objectives-based assessments on the professional flight degree program students' achievement, and for aligning curriculum and assessment. The three suggested proficiency-level descriptors for the professional flight degree program are as follows:

Level 1–Emerging: Students within this category demonstrate airmen certification standards for the appropriate certificates and ratings, learning basic and some advanced aviation knowledge and skills for immediate needs, as well as beginning to employ appropriate academic and discipline-specific characteristics.

Level 2–Developing: Students within this category are challenged to reflect upon strengths and weaknesses pertaining to the airmen certification standards, increase their aviation knowledge and skills in an increasingly greater number of situations, and learn a wider variety of professional attributes.

Level 3–Proficient: Students within this category shows appropriate knowledge, skills, and abilities for operating transport-category aircraft, exhibit lifelong learning habits, and demonstrate the ability to conduct themselves in accordance with discipline professional standards.

A competency-based collegiate professional flight degree program could yield the following advantages: (a) significantly enhance aviation safety; (b) establish advanced training processes that will enhance the acquisition of knowledge, skills, and abilities; (c) meet or exceed personnel safety standards; and (d) emphasize quality of education and flight training over flight hours.

Discussion and Conclusions

The aviation industry plays a major role in global economic activity and development. "One of the key elements to maintaining the performance of civil aviation is to ensure safe, secure, efficient, and sustainable operations at the global, regional, and national levels." According to Airbus, safety efforts have steadily reduced the rate of aircraft accidents since 1960. During the last two decades, there has been a 70% and 95% reduction in the hull losses and fatal accident rates, respectively. Such achievements can be largely attributed to new technologies (e.g., traffic collision avoidance system), effective safety regulations and policies (e.g., SMS), and continuous improvements in safety training (e.g., CRM).

The global air traffic is expected to double every 15 years. The fleet growth rate is overwhelming, with the industry delivering approximately 2,000 aircraft per year. More flights will most likely increase the number of accidents unless the aviation industry challenges itself with more ambitious approaches to reduce the accident rate. The current and expected growth of the aviation industry associated with the mandatory retirement age for the baby-boom generation has created a demand for pilots all over the world that exceeds supply. Thus, it is expected that new pilots will often become air carrier captains at a younger age and with less flight experience than in the last decades.

Moreover, with increasing substantial changes in operational and/or organizational complexity, rapid advances in aircraft technology, single-pilot commercial operations, and fewer predictable hazardous conditions, training must reflect the relevant needs of professional pilots. A flight competence-based degree approach could provide the aviation industry effective opportunities to address several issues afflicting the industry. Most importantly, it could provide pilots with the knowledge, skills, and abilities to respond effectively to unanticipated hazards and threats that could (will?) arise during flight operations. A competency-based flight program represents a paradigm shift in flight crew training. Such an approach is focused on developing and/or strengthening competencies that are fundamental to operate effectively, efficiently, and safely in an extremely complex social system while addressing hazards and associated risks identified during the investigation of aircraft accidents, incidents, and flight operations. As bonus benefits it will

- provide empirical data that could assist in expediting the development of performance and expertise among new pilots;
- develop empirical data that could assist aviation stakeholders, especially policy makers, in assessing the effectiveness of the "1,500 hour rule";
- provide opportunities for research;
- optimize the safety training (e.g., CRM) of pilots; and
- significantly enhance aviation safety.

The organization of the proficiency-level descriptors represents professional flight skills development across a continuous spectrum of increasing proficiency, starting with basic competencies professional flight students possess when they enter the program and concluding with the lifelong learning in which all aviation professionals engage. The three levels represent three stages of development, describing expectations for knowledge and skills at each level as the breadth of capabilities expands and concepts transition from ideas to practice.

As the development of the hybrid competency-based education model to be employed in the program progresses, program faculty will develop the related student learning outcomes based on the competencies presented, using the suggested proficiency-level descriptors to delineate the outcomes into measurable categories. Associated competencies will then be measured for the three levels (developing, emerging, and proficient) of student achievement. Each competency will need to be mapped to the proper course for evaluation. Formative and summative assessments must be developed along with appropriate rubrics. Testing and research processes will have to be conducted to ensure reliability and validity. Additionally, a robust data management plan will have to be developed for continuous improvement efforts.

The development of competencies based on empirical data will provide the faculty another means of assessment within the classroom and flight courses. This data will allow for more precision in understanding student progress as well as the program overall. Furthermore, in the future, there may be opportunities for the development of a true competency-based education program in aviation. The processes explained in this study to determine and assess the professional flight program competencies, as well as the corresponding student learning outcomes using the proficiency-levels descriptors, will lead to a more comprehensive and consistent learning process across the courses that comprise the professional flight program curriculum.

Practical Implications

The core competencies will be fully integrated within different forms of pilot training (e.g., core courses, flight simulator) so that students can develop their technical and nontechnical competencies. In addition, training will include challenges and the context of flight activities flight crews face during regular flight operations. Strategies used to develop, strengthen, and assess the identified competencies will be based on course needs identified at an industry level. Those needs will be determined by analyzing large datasets that will include data from flight operations quality assurance and line operations safety audits programs and from the investigations of aircraft accidents and incidents.

Nevertheless, it is also important to consider situations in which flight crews' competencies contributed to effective crew performance and to the successful management of challenging situations. Most importantly, we truly understand that feedback from ISASI is paramount for this flight competence-based approach to achieve one of the most expected and desired outcomes—safety enhancement. ◆