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Able Flight at Purdue University: Case Studies of Flight Training Strategies to Accommodate Student Pilots with Disabilities

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This paper documents flight training strategies used to accommodate student pilots with disabilities in the Able Flight at Purdue program; this program benefits participants as well as the institutional sponsor and the aviation industry. All training aircraft, procedures, and operations are compliant with Federal Aviation Administration (FAA) regulations, however, the program utilizes a tailored approach within the regulatory standards to meet the unique needs of each individual. The SHELL model (Software, Hardware, Environment and Liveware) is used as a theoretical framework to illustrate how flight training is adapted for individuals with limited dexterity or limited hearing. The Able Flight at Purdue program is explained, including the preparation before the students arrive on campus and the accelerated flight training program. Two case studies using the SHELL model illustrate training modifications for a pilot who uses a manual wheelchair and a Deaf pilot; both of these students successfully completed the program and earned an FAA Sport Pilot certificate. This Peer Review Practice paper also discusses the benefits of the program. There are direct benefits to the individual participants, both to the student pilots as well as to the certified flight instructors (CFIs), based on qualitative survey responses. The broader impacts of the program include support for diversity and inclusion realized by the institution, the aviation sector, and the community.

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Many developed nations recognize the benefits of social inclusion (Charity Commission, 2001; United Nations, 2007; World Bank, 2013) both for individual growth and for development of a healthy community and society. The World Bank has studied social inclusion (2013) and defines it as, “both an outcome and a process of improving the terms on which people take part in society.” Social inclusion is the opposite of social exclusion, which can result from many factors, including age, sexuality, gender, race, religion, mental illness, and disability. Social inclusion seeks to empower marginalized individuals or groups through integration.

Social inclusion benefits individuals, groups, communities, and nations. The benefits to groups include benefits to companies. Companies that practice social inclusion and promote diversity have a more engaged workforce with increased satisfaction, a better workplace culture, and increased innovation (Moon, Todd, Morton, & Ivey, 2012; Pearce & Randel, 2004). Benefits of diversity and inclusion extend beyond worker satisfaction and culture; companies with greater social inclusion and diversity financially outperform companies that are not diverse (Hunt et al., 2015).

Historically, aviation has lacked social inclusion and diversity (Medland, 2015; Mills, 2017). Research by Hansen and Oster found that employment patterns, including diversity trends, result from a history of both explicit and implicit hiring policies for aviation jobs in the military and at the airlines (National Research Council, 1997). The U.S. Department of Labor estimates there are 595,000 employees in the air transportation sector and the majority of these employees (72 percent) identify as white; 40 percent are women and 17 percent are African American (Bureau of Labor Statistics, 2016). Pilot demographics are even less diverse. Based on Federal Aviation Administration (FAA) data, only 6.7 percent of the 584,362 active pilots are women, and only 1.1 percent of Airline Transport Pilots (ATP) are women (Federal Aviation Administration, 2017).

Initiatives that promote inclusion in aviation are important in all facets of the aviation workforce. Programs such as the Able Flight at Purdue program could have a positive impact by attracting individuals who would not traditionally be found in the aviation industry to a wide variety of possible employment options, including not only pilots, but also maintenance technicians, dispatchers, air traffic controllers, FAA employees, airline employees and airport employees. Programs such as the Able Flight at Purdue also provide the secondary benefits that inclusion promotes (Hunt et al., 2015; Moon, Todd, Morton, & Ivey, 2012; Pearce & Randel, 2004).

The Centers for Disease Control and Prevention identifies inclusion strategies targeting people with disabilities. Inclusion strategies include universal design principals, accessibility standards, reasonable accommodations, and assistive technologies (Center for Disease Control and Prevention, 2017). These strategies are very broad. This paper provides specific examples that illustrate how reasonable accommodations and assistive technologies can be incorporated into flight training to allow student pilots to obtain the Sport Pilot certification as well as to foster inclusiveness. Able Flight at Purdue is one program targeted to promote diversity and social inclusion in aviation. Able Flight is a nonprofit organization that provides aviation related scholarships to individuals with disabilities. Purdue University was one of Able Flight's first partners, and since 2010 Purdue University has successfully delivered flight training for pilots with a wide variety of disabilities in an inclusive environment.

Following a brief literature review that includes a discussion of STEM activities for people with disabilities, this paper presents information about the Able Flight at Purdue program including: an explanation of the program, two case studies regarding how flight training is adapted to meet the needs of pilots with disabilities using the SHELL model as a theoretical framework, lessons learned from eight years of program experience, and documentation of the program benefits based on the results of a qualitative survey and the continued involvement in aviation by program graduates. Benefits are realized by individuals, by the sponsor institution, and by the aviation community. The information provided in this paper will support the inclusion of pilots with disabilities at other flight training schools.

Literature Review

Inclusive Programs

Due to the technical nature of flight training, learning to become a pilot incorporates many aspects of Science, Technology, Engineering, and Mathematics (STEM) education. The National Science Foundation has emphasized the importance of developing a diverse STEM workforce in the United States (U.S.) (National Science Foundation, 2000, 2004; National Science Board, 2010); reports accentuate the benefits of broadening participation and the inclusion of individuals with disabilities and other populations that have been traditionally underrepresented in STEM programs.

STEM oriented programs targeted to individuals with disabilities have proven successful. Three successful programs that illustrate a range of approaches are described below.

- **Vocational Rehab.** The Experiential Learning for Veterans in Assistive Technology and Engineering (ELeVATE) program provided support to service members with a disability as they transition to postsecondary institutions. The main goals of the ELeVATE program were to create a model for veteran vocational rehabilitation transition and to demonstrate the success of such a program in terms of promoting academic and career success. Results indicate that participants were more confident in their ability to succeed upon completion (Goldberg, Cooper, Milleville, Barry, & Schein, 2015).
- **Learning Communities.** One university found that Student Learning Communities that provided knowledge, skills, and abilities curricula for students with disabilities were successful in engaging this unrepresented group to pursue STEM degrees (Izzo, Murray, Priest, & Mcarrell, 2011).
- **Mentorship.** Many studies have documented benefits from mentorship. One successful mentoring program was the Research Initiative for Science Excellence (RISE) program. This training program is specifically targeted to prepare and support students with

disabilities as they obtain STEM degrees; the program provides both research experience and mentorship (Schultz et al., 2011).

Programs that specifically target people with disabilities are not the only way to promote social inclusion. The use of assistive technologies can help a person with a disability fully engage in life activities (Center for Disease Control and Prevention, 2017). Automobiles can be adapted with assistive technologies to allow the gas and brake to be operated with hand controls. Hand controls in an automobile grant greater independence and improve quality of life (Barnes, 1997; Tachakra, 1981). Other considerations related to adaptive technologies and the selection of the proper vehicle include the choice of vehicle, mode of access (ramp versus transfer), use of seat cushion, and steering wheel knob (Murray-Leslie, 1990).

People with disabilities are not the only individuals that may need adaptive technologies for full inclusion. Abled-bodied individuals of short stature may require assistive technology when piloting an aircraft. Pilot shops and some training centers provide elevator cushions to allow shorter people to see over the aircraft nose (Sporty Pilot Shop, 2018b). Other adaptive equipment includes rudder pedal extensions to bring the pedals closer to the pilot (Sporty Pilot Shop, 2018a).

Adaptive equipment, technologies or procedures may be required due to personal characteristics or medical conditions. Medical requirements vary for different kinds of pilots. The Sport Pilot rule allows a pilot to fly a light-sport aircraft without an FAA medical certificate as long as they have a current, valid U.S. driver’s license (Federal Aviation Administration, 2015). A Class I medical certificate (the most rigorous) is required for an Airline Transport Pilot; a Class II medical certificate is required for a Commercial Pilot; a Class III medical is required for a private pilot, student pilot or recreational pilot (Aircraft Owners and Pilots Association [AOPA], n.d.). A special issuance granted at the discretion of a Federal Air Surgeon may offset a disqualifying condition; this has an associated time limit and requires periodic interim medical reports. A waiver or Statement of Demonstrated Ability (SODA) may be issued for static conditions that are not likely to change such as monocular vision or an amputee (Aircraft Owners and Pilots Association (AOPA), n.d.). A waiver is part of the medical certificate and demonstrates that you have satisfied the FAA and can exercise the privileges of the certificate held (AOPA, n.d.). The Sport Pilot rule, the special issuance, and the SODA all provide avenues for pilots with disabilities.

Adaptation to the work environment may also be required for people with disabilities. Example adaptations to the work environment include specialized equipment, modifications to the work space, or adjustments to schedules, and can be referred to as reasonable accommodations (U.S. Department of Labor, n.d.). Reasonable accommodations are legally required under the Americans with Disabilities Act, so long the accommodation does not create *undue hardship* on the employer. For an individual with an ambulatory disability, a workstation or transportation can present challenges that may require accommodation strategies (University of Washington, 2018).

Generally, programs that target people with disabilities have a positive impact by providing resources, education, and guidance that otherwise might not be available due to a lack of inclusion. In addition to programs, assistive equipment, technologies and procedures can help bridge a gap and create an inclusive environment. This paper describes how an aviation program, Able Flight at Purdue University, has successfully provided an inclusive environment to deliver flight training tailored to meet the needs of individuals with disabilities.

Able Flight at Purdue

Able Flight is a national program that began in 2007, when the program's first Full Flight Training Scholarship was awarded. Able Flight currently offers four scholarships:

- *Full Flight Training Scholarships* for people to earn a Sport Pilot certificate,
- *Return to Flight Scholarships* for people who have pilot certificate and subsequently became disabled to return to flying under the Sport Pilot regulations,
- *Flight Training Challenge Scholarships* for people who would benefit from dual instruction only, and have no current plans to seek a Sport Pilot certificate,
- *Career Training Scholarships* for people to earn a Repairman Certificate (Light Sport Aircraft) with Maintenance Rating, or a Dispatcher License, or to defray academic expenses while training for an aviation career (Able Flight, 2016b).

In the first three years, Able Flight activities were limited in scope and conducted at a variety of locations, including a personal hangar in Oshkosh, WI. In 2010, Able Flight partnered with Purdue University, which allowed the program to expand and provide a more structured training experience that focusing on the Full Flight Training Scholarship.

The Purdue University School of Aviation and Transportation Technology has a large professional flight program and all education and flight training is conducted at the Purdue Airport (LAF) on campus. As a result, there are numerous university and aviation resources that provide excellent support for the Able Flight program, which typically starts in mid-May and finishes in early July. This summer schedule allows Able Flight participants to utilize university and aviation resources when the demand from university students is reduced.

Able Flight participants live in a recently constructed, fully accessible residence hall, and receive access to campus dining courts throughout their flight training. Each participant has their own private bath, which provides independence and privacy. Since basic housing and meals are provided, Able Flight participants can focus their time, energy, and attention on the flight training program, which requires a significant commitment from the student pilots. Many hours spent studying and flying are needed to become a confident, competent, and safe pilot. Confidence extends beyond the cockpit, which is recognized by Able Fight's mission statement, "individuals with a disability are presented with a unique way to challenge themselves through flight training, and by doing so, gain greater self-confidence and self-reliance" (Able Flight, 2016b). The following sections provide information about how flight training is tailored to address the individual needs of student pilots with disabilities.

Methodology

This paper documents how flight training can be adapted to accommodate pilots with disabilities, illustrated by two case studies that are described using the SHELL model. The SHELL model is a theoretical framework that provides a consistent method to describe the adaptations used in the Able Flight program in a format embraced by the aviation community. The two case studies selected, a student pilot who uses a manual wheelchair and a deaf student pilot, illustrate very different methods of accommodation and represent adaptations that have been implemented numerous times in the Able Flight Program at Purdue.

Benefits of the program are also discussed. Benefits are assessed based on the completion rate for participations, as well as qualitative benefits which are based on feedback from participants and flight instructors in the 2017 Able Flight class; and, all six instructors and six students participated in a survey and provided their perceptions and reflections of the 2017 summer program. Other benefits include broader impacts, which have accrued due to the news stories about the Able Flight at Purdue program.

SHELL Model: A Human Factors Approach to Flight Training

The SHELL model is a widely used framework for human factors in aviation. It was presented in 1972 (Edwards, 1972), modified more than a decade later by Frank Hawkins (Hawkins, 1987), and subsequently endorsed by ICAO (International Civil Aviation Organization, 1989). The SHELL model defines human factors in terms of the software, hardware, environment, and liveware components, which interact around a central liveware (humans), as illustrated in Figure 1a.

The SHELL model has been utilized to explain human factors considerations for pilots, maintenance technicians, and air traffic controllers (Chang & Wang, 2010; Kozuba, 2011; Wang & Dong, 2011). Based on Purdue’s eight years of experience, the next section uses the SHELL model to explain flight training using the student pilot is the central liveware; this liveware interacts with the software, hardware and other liveware in the flight training environment as shown in Figure 1b. Following a general discussion of flight training and the Able Flight program, two case studies illustrate some of the most significant adaptations implemented to support the Able Flight training at Purdue.

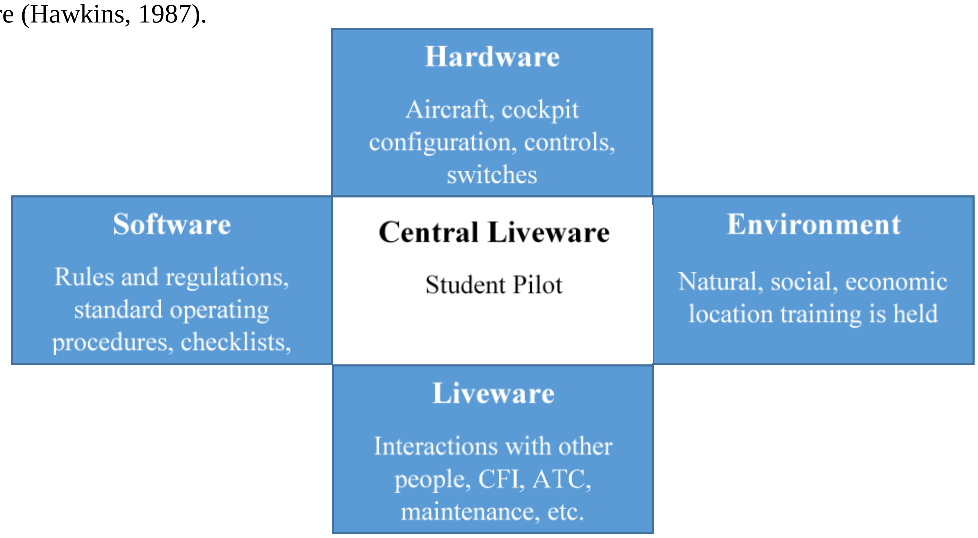
Findings

The findings include a general discussion of the SHELL model for flight training for student pilots, with discussion regarding how this is applied in the Able Flight program at Purdue. Two case studies illustrate specific adaptations that have been implemented successfully at Purdue. The first case study is for a student pilot who uses a wheelchair and the second for a student pilot who is deaf. Following these case studies, the program benefits are discussed.

Central Liveware. The student pilot is the central liveware. Traditionally, the first certification a student earns is a Private Pilot certificate which requires an FAA medical exam, as well as written and practical exams. The Sport Pilot license became an option on September 1, 2004, and does not require a medical exam if the pilot has a valid U.S. driver license (AOPA, 2004). All flight training requires a student pilot certificate which must be issued by FAA before training begins.

Application. In addition to obtaining the student pilot certificate, to receive a Full Flight Training Scholarship, all Able Flight at Purdue students must go through a two-phase selection process that includes a written application (personal statement, list of achievements, references, and future goals) and an in-person interview with an Able Flight representative. The thorough application process ensures that participants' interests and capabilities are compatible with the rigorous training schedule, and that flight training can be adapted to the individual's skill set and abilities.

(a) SHELL components include the Software, Hardware, Environment and Liveware centered around the human Liveware (Hawkins, 1987).



(b) SHELL model for flight training with student pilot as central liveware.

Figure 1. The SHELL Model for Human Factors.

Liveware-Software. Software consists of online training tools, and aviation regulations and laws. Software includes checklists, manufacturer's pilot operating handbook or airplane flight manual, and other written documents that encompass standard operating procedures.

Application. In addition to the standard software used in traditional flight training, the Able Flight program provides the King Schools online training course for student pilots two months before they arrive at Purdue (King Schools, 2018). Students are highly encouraged to complete the online course to ensure they are familiar with training topics before full-time training begins; this ensures success with the accelerated training schedule. The online module includes a wide variety of topics, such as aviation rules and regulations, performance measures, and airspace. In addition to online training, students must complete a comprehensive ground school that is conducted via daily classroom lectures at Purdue. While FAA regulations are always followed, enhancements and adaptations may be used to support inclusion, such as an American Sign Language (ASL) interpreter to support classroom activities, when needed.

Liveware-Hardware. Hardware includes the aircraft and aircraft components, such as the seats and cockpit instrument layout, the instrumentation and how it presents information. Most traditional student pilots can utilize any single piston aircraft for flight training, and the Cessna 152, Cessna 172, and Piper Warrior are commonly used training aircraft.

Application. Properly matching aircraft characteristics with the physical characteristics of the central liveware (student pilot) is extremely important. Since light sport aircraft are used for flight training, ensuring the aircraft is a good match for the student in terms of physical size is important for weight and balance to ensure a reasonable fuel supply is available without exceeding aircraft limitations. Aircraft used in flight training at Purdue include the Ercoupe 415C and Sky Arrow L600. Table 1 contained a list of aircraft and liveware compatibility characteristics.

Table 1.

Able Flight Pilot Liveware Must Be Matched with Aircraft Hardware to Ensure Compatibility

Aircraft	**Aircraft Characteristics**	**Pilot Characteristics**
B&F Fk9	Side by side pilot and co-pilot	Deaf or hard of hearing
Flight Design CTLS	Side by side pilot and co-pilot	Deaf or hard of hearing
	Larger cockpit	Tall pilot
	Hand control for rudder and brakes	Limited voluntary use of legs
	Ease of access to seat	Landing gear does not prevent wheelchair users from getting close
Ercoupe 415C	Hand control for rudder and brakes	Pilot with limited use of legs
Sky Arrow L600	Ease of access to seat	Landing gear does not prevent wheelchair users from getting close

The general guidelines in Table 1 are useful for conceptual discussion, however, individual characteristics and capabilities are more important than general guidelines. This is evidenced by Able Flight pilot Jessica Cox, who demonstrates that a lack of arms does not restrict her from using the standard operating controls in the Ercoupe 415C, as shown in Figure 2.

Figure 2. Jessica Cox was born without arms and flies an Ercoupe 415C (Able Flight, 2016a).

Liveware-Environment. The environment is the physical location where any of the other components (software, hardware, liveware) function, and can include the natural environment (weather and geography), social environment (interaction with peers), and economic environment (cost of flight training). Student pilots generally obtain flight training at a fixed-base operator, in a university setting, or through a community college.

Application. The Able Flight program provides an enhanced environment for flight training for a number of reasons. First, the social environment is focused on inclusion. All students are housed in the same resident hall, promoting social interaction. The value of a common living area was demonstrated by a study performed by Wilson, Bjerke, and Marin (2015); the results indicate that aviation students in Living Learning Community had greater success than those not surrounded by peers. Another component of the enhanced environment is the economic environment. The economic environment is positive because not only is flight training paid for, but so is housing and basic meals. Able Flight also makes accommodation for the natural environment, which may have a greater effect on Able Flight pilots than traditional pilots. For example, an individual with a spinal cord injury may not be able to regulate their body temperature, making them more susceptible to the heat. This can be accommodated by a training schedule that minimizes flights during the hottest part of the afternoon, and shifts flights to the early morning and evening when temperatures are lower. Daily ground school is conducted during the hottest time of the afternoon to ensure efficient use of time.

Able Flight has also positively affected the environment at Purdue. As a result of the program, accessible ramps and bathrooms were added to the flight operations buildings to ensure compliance with the Americans with Disabilities Act. During the program, extra accessible parking spaces are designated both at the airport and at the residence halls used by the Able Flight pilots.

Liveware-Liveware. Interaction between the liveware student pilot and other liveware is often via verbal communication during traditional flight training. Liveware includes air traffic controllers, certified flight instructors (CFIs), maintenance personnel, other student pilots, and administration staff. Verbal communication during flight training is often face-to-face on the ground and during ground school, and via the radio using aviation headsets while in the aircraft.

Application. Full Flight Training Scholarships have been awarded to deaf student pilots. This may require coordination and a common understanding for expectations regarding communication among the CFI, student pilot, and Air Traffic Controllers (ATC) since training is conducted in controlled airspace. At Purdue, deaf pilots rely on ATC to provide light gun signals when operating in a controlled airfield. The Purdue airport control tower upgraded their signal lamp to accommodate these operations.

Case Study: Paraplegic Wheelchair User

A person may use a wheelchair as a mobility aid for a variety of reasons, including congenital disorder, motor vehicle accident, skiing incident, military incident, or amputation due to disease. Just as the reasons for wheelchair use vary widely, the characteristics of individual wheelchair users vary widely, encompassing many body types and physical characteristics, as well as ranges of motion and dexterity for different movements. This case study describes flight training strategies to support the successful completion of the Able Flight program by one of the participants who uses a wheelchair due to a T6 complete spinal cord injury.

Central Liveware. The central liveware in this case is the student pilot with a T6 complete spinal cord injury, which means that there is no feeling or movement below the T6 vertebrae, resulting in no voluntary use of the lower extremities. This individual uses a manual wheelchair as a daily mobility aid, has full dexterity in their fingers, and has full range of motion with their arms. This individual cannot not stand or walk.

Liveware-Software. An important software component for flight training is the preflight checklist. In this case, the preflight checklist for the Sky Arrow L600 is a good match for this student pilot for a variety of reasons. Almost all tasks can be completed by the student pilot with assistance only needed for tasks related to height (e.g., oil check and fueling). The internal aircraft preflight checklist items require the fuel and instrumentation to be checked prior to engine start, the Sky Arrow’s cockpit controls and switches can be reached without getting into the aircraft, facilitating this process for a pilot that uses a wheelchair. The external preflight checklist includes a visual inspection of the wings to ensure that there is no damage and the leading edge of the wing is smooth. This visual inspection can be completed by “lowering the tail” of the aircraft (see Ffigure 3). Placing the aircraft in this position allows the student pilot seated in a wheelchair to see on top of the wings, which is necessary to successfully perform a thorough visual inspection.

The preflight checklist component that requires assistance for a wheelchair user is checking the oil and fueling the aircraft. On the Sky Arrow, the oil is located above the wing and checking the oil level requires a ladder. To successfully complete the oil check during pre-flight, the student pilot in a wheelchair uses the flight instructor. The student pilot provides verbal instructions and describes in detail what should be seen to the flight instructor, who checks the oil and takes a photo of oil level with a smart phone. The photo can then be inspected by the student pilot for compliance. The same method is used for fueling the aircraft. After the preflight inspection is complete, the student can get into the aircraft.

(a) Normal position (b) Tail lowered for visual inspection of wings

Figure 3. Different static positions of the Sky Arrow during the preflight checklist

Liveware-Hardware. It is imperative to match the correct hardware, in this case the aircraft, to the characteristics of the central liveware, the student pilot. Just as all pilots have different characteristics, so do all aircraft. This pilot's physical characteristics made the Sky Arrow L600 an ideal aircraft for training.

Getting into the aircraft requires minimal assistance from the flight instructor. Since the student cannot move their lower limbs voluntarily, the flight instructor assists by holding the wheelchair in a stable position and helping get their legs into the aircraft. For a wheelchair user, getting into the Sky Arrow is easier than getting into traditional training aircraft such as the Cessna 152. The Sky Arrow's main landing gear is positioned behind the pilot and the aircraft's wing strut is not in the way (Ffigure 3), this leaves ample space to bring a manual wheelchair close to the cockpit, facilitating transfer from the wheelchair into the front seat.

Once in the aircraft, flight controls are accessible using hand controls. The rudder, which is controlled with the feet in many general aviation aircraft, is controlled with a T-handle (Figure 4). This T-handle is an optional configuration from the manufacturer and can be installed in less than a minute without any specialized tools. The Sky Arrow also has differential finger brakes rather than toe brakes on the rudder pedals. Hand and finger controls makes the Sky Arrow L600 ideal for someone with limited use of their lower limbs.

(a) Without adaptive control

(b) With T-handle adaptive control

Figure 4. Photo of cockpit without (a) and with (b) adaptive T-handle in the Sky Arrow L600

Liveware-Environment. The environment includes the hangar and classroom where flight training was conducted, which are both fully accessible. The environment also includes the living arrangements while in the Able Flight program. The university resident hall where students live goes beyond required accessibility standards and includes a private wheelchair accessible bathroom and shower stall connected to the bedroom. A front-loading washer and dryer on the same floor as the bedroom facilitate independence.

Liveware-Liveware. No significant changes are required for liveware-liveware interactions in this case study.

Limitations. One of the negatives associated with the Sky Arrow for this student pilot and wheelchair user is that there is not enough cargo room in the aircraft to store a manual wheelchair. This makes it extremely difficult to land at another airport and exit the aircraft for a rest stop or for food. This could also present a challenge in an emergency landing, since the pilot is without their mobility aid.

Case Study: Deaf Pilot

A person may be deaf or hard of hearing for a variety of reasons, including congenital disorder, accident, or repeated exposure to loud noise. Hearing loss may be partial or complete. The characteristics of individuals vary widely; some people may use sign language and/or read lips; others may rely on written communication. This case study describes the adaptations used by an Able Flight participants who is Deaf and uses and prefers ASL for communication.

Prior to participating in Able Flight, this individual researched opportunities for flight training but was not able to find a CFI willing to train a deaf student pilot who had no prior flight experience. The Able Flight program at Purdue was able to provide a CFI interested in working with a deaf pilot, an interpreter certified in ASL for ground school, and a deaf-friendly environment for flight training.

Central Liveware. This case study describes a Deaf individual who successfully completed the Able Flight program and obtained a Sport Pilot certificate. This student pilot was pursuing an undergraduate degree in aviation from another university when they participated in the program, and had completed a Private Pilot ground course for college credit prior to the start of Able Flight.

The term *Deaf* (with a capital D) represents an individual who self identifies with the Deaf culture, while deaf with a small d refers to a physical condition based on medical terminology. Deaf sociolinguist, Dr. Barba Kannapel, defines the American Deaf culture as a, "set of learned behaviors of a group of people who are deaf and who have their own language (ASL), rules, values and traditions" (Gallaudet Univsersity, 2015, p. 2). Some people, particularly those who become deaf later in life or who are raised and educated primarily among non-deaf people, may not affiliate with the Deaf community, and as a result would typically describe themselves as deaf. In this case study, the term Deaf will be used to reflect the preference and self-identify of this Able Flight student pilot.

Liveware-Software. No significant changes are required for liveware-software interactions in this case study.

Liveware-Hardware. For this individual, the B&F Fk9 light sport aircraft is utilized. This aircraft has a side-by-side seat configuration, as was presented in Table 1 and shown in Figure 6. This seating configuration facilitates communication between the Deaf student and CFI. Details of this communication will be explained in greater detail in the liveware-liveware section of this case study. Other common training aircraft such as Cessna 152, Cessna 172, and Piper Warrior also have side-by-side cockpit seating configuration and would be suitable for training a deaf individual. Aircraft such as the Sky Arrow have a tandem seat layout which makes it difficult for a Deaf student pilot, since they would need to repeatedly look behind them to communicate with the flight instructor.

(a) Tandem seat layout

(b) Side-by-side seat layout

Figure 6. Two different seating configurations

Liveware-Environment. For this Deaf individual, creating an inclusive or deaf-friendly environment to support learning was key. The use of light gun signals, a CFI who was willing to learn basic sign language (i.e., numbers, airplane, and airport), access to an ASL interpreter, and a windsock on the airfield are all components of a deaf-friendly environment. Additionally, the resident hall is equipped with a visual alerting system (e.g. strobe lights) that provides notification in case of a fire or other emergency requiring evacuation. At Purdue, the CFIs do not have any formal training in ASL, however, the CFI works with the Deaf student pilot to learn the basic signs needed for communication. The ASL interpreter has extensive training and is certified to provide interpretation, as needed, in the classroom setting.

Liveware-Liveware. Communication is one of the first training issues that needs to be addressed while training this Deaf student pilot. For most people, verbal transmission and aural processing is the primary means of communication in aviation. Since ASL is the preferred means of communication for this student pilot, an interpreter is available for all classroom training. However, the ASL interpreter is only available during ground school, which is practical due to its regularly scheduled meeting time. Utilization of an interpreter is not possible in the aircraft during flight training because the training aircraft only has two seats.

Communication between the CFI and the Deaf student is an important consideration, since the CFI does not know ASL. To minimize flight deck distractions, each training lesson is discussed on the ground, using pen and paper or a computer, prior to flight. Initial communication in the aircraft is slow, and information is shared using a small white board, pen and paper or via text on cell phones. To maintain a safe training environment, communication in the aircraft necessitates that the Deaf student maintain straight and level flight while the CFI writes or reads (and vice versa). This requires that most communication occur during low risk phases of flight or on the ground. The student pilot taught the CFI basic signs related to flight instructions to expedite communication. Important ASL signs for the CFI to learn include “airplane” and the ability fingerspell numbers from zero to nine using one hand (as used in ASL). Since ASL is a visual language, the CFI can use the airplane sign in conjunction with orientation and movement to enhance communication. Numbers can be used to communicate the desired altitude after pointing the altimeter. This saves time and is preferable to writing on a small white board or typing on a phone. In this case, it is helpful to pair the Deaf student pilot with the same CFI throughout the program.

Another important liveware interaction for the Deaf student pilot is communication with ATC. Even though the FAA does not require verbal communication for pilot certification, hearing and talking on radio frequencies is standard protocol, especially at a controlled airport. Able Flight utilizes an airport that has an ATC tower during daytime operating hours. To facilitate communication and safety, prior to the student’s first flight, ATC representatives met with the Deaf student, the CFI, and an interpreter. This meeting establishes an operational protocol for all parties involved; this protocol utilizes standard FAA light gun signals as shown in Table 2. At Purdue University, the following protocol was developed and is used:

1. Prior to the start of each flight, the Deaf pilot calls the tower using a video relay service to get information about which runway is in use and let tower know the intentions of the flight (e.g. pattern work, local flight, cross country flight, etc.). Video relay service allows people who use ASL to communicate with voice telephone users through video equipment rather than typed text.
2. When ready to taxi from the ramp, the student pilot faces the nose of the aircraft to the airport tower.

3. When the ATC sees the Deaf pilot lined up in their aircraft, ATC communicates by using light gun signals (
4. Table *2*) to indicate the pilot is cleared to taxi. It is understood that the pilot needs to hold short of all runways until additional clearance is given.
5. Each time ATC signals the light gun, the Deaf student pilot clicks the radio's push-to-talk button twice to acknowledge the light signal and then proceeds accordingly until the runway in operation is reached.
6. After the run-up is performed, the Deaf pilot positions the nose of the aircraft to face the tower, now signifying they are ready for takeoff.
7. The student waits for a steady green light from ATC for takeoff clearance.
8. When the Deaf pilot intends to return to the home airport, they circle at an agreed upon location and wait for a light gun signal from the tower.
9. While flying at an airport without a controlled tower, the Deaf pilot uses visual cues (e.g., windsock or the pattern of other aircraft) to determine the appropriate runway for takeoff or landing and the pattern.

Table 2.

Airport Traffic Control Tower Light Gun Signals (Federal Aviation Administration, 2016)

Color and Type of Signal	**Movement of Vehicles Equipment and Personnel**	**Aircraft on the Ground**	**Aircraft in Flight**
Steady greed	Cleared to cross, proceed or go	Cleared for takeoff	Cleared to land
Flashing green	Not applicable	Cleared for taxi	Return for landing (to be followed by steady green at the proper time)
Steady red	STOP	STOP	Give way to other aircraft and continue circling
Flashing red	Clear the taxiway/runway	Taxi clear of the runway in use	Airport unsafe, do not land
Flashing white	Return to starting point	Return to starting point	Not applicable
Alternating red and green	Exercise extreme caution	Exercise extreme caution	Exercise extreme caution

When flying to other towered airports, this Deaf pilot uses pre-coordination to ensure safe flight and increase controller awareness. Pre-coordination allows controllers to inform other pilots that there is an aircraft without a radio in the area. For uncontrolled airports without an air traffic control tower, pilots are not required to use radio communication, and the Deaf pilot must see and avoid other aircraft.

Benefits of Able Flight

Able Flight is one example of a program that successfully supports diversity and inclusion in aviation. As of August 2017, Able Flight at Purdue has realized a 98% completion rate with 42 out of 43 individuals earning a Sport Pilot certificate. While an important outcome of a Full Flight Training Scholarship is a Sport Pilot certificate, the program benefits extend beyond certification. Additional benefits to participants include a sense of accomplishment and empowerment, and a better appreciation for personal capabilities; these benefits are realized due to their achievements as well as the inclusive environment. Secondary benefits include broadening the perspective of participating CFIs who interact with Able Flight participants, fostering an inclusive environment at Purdue, and positively influencing the culture and diversity in the larger aviation community.

Benefits are identified based on the results of surveys approved by Purdue University's Institutional Review Board. Surveys were distributed before, during and at the end of the 2017 Able Flight program, and consisted of opened-ended questions to gain insight regarding the feelings, expectations, and experiences of the participating CFIs. Survey responses indicate initial CFI concerns include the accelerated training schedule, using a new aircraft, and trying to treat the student pilots as normally as possible. Concluding feedback from the CFIs indicate that the CFIs enjoy meeting and interacting with people from different walks of life, they expand their abilities because they need to adapt their training style and are more creative with their teaching skills. In one case, the CFI reports that they gained a new appreciation for the definition of "motivation." Instructors also enjoy having flexibility to develop and tailor the training schedule, adapting it to best meet the needs of their student pilot. CFIs said that their perceptions of the disabled community change as a result of the program, giving them a new appreciation for the capabilities of people with disabilities, and making them more comfortable interacting with people with disabilities. Based on this feedback, the Able Flight program provides benefits that include fostering an inclusive environment at Purdue, changing the perspective of CFIs and increasing the exposure of the Purdue community to people with disabilities. These impacts may be significant, since the CFIs and other people who interact with Able Flight participants will carry these inclusive attitudes with them throughout their career in aviation.

Purdue University's School of Aviation and Transportation Technology has increased diversity and inclusion through two actions. First, through the additions of accessible ramps and bathrooms to the flight operations buildings. Second, by having three students (seven percent of the Able Flight at Purdue cohort) enroll in the Aviation Management program after completing the Able Flight program. Other graduates of the Able Flight program have continued their involvement in aviation in a variety of ways, including the following:

- Randy Green was born without hands or feet, but earned his ATP rating, the highest pilot certificate FAA recognizes. Randy received training through a Career Training Scholarship from Able Flight and is now flying professionally.
- Kevin Crombie received an Able Flight Full Flight Training Scholarship in 2011. After completing Able Flight at Purdue, Kevin enrolled in Purdue University's undergraduate aviation program. After graduation, Kevin took a job with FAA in the Commercial Space sector in 2015. Kevin purchased a Piper Cherokee 180 and continues to fly.

- Raymart Tinio is Deaf but dreamed to fly since he was a teenager. This dream became reality and was made possible through an Able Flight Full Flight Training Scholarship in 2015. After Able Flight, Raymart went on to earn a Private Pilot certificate, and as of fall 2017 is working on his Instrument Rating. Raymart is enrolled in the Aviation Management graduate program at Purdue University where he is conducting research is to improve communications between deaf pilots and air traffic controllers.
- John Robinson is a quadriplegic who received an Able Flight Full Flight Training Scholarship in 2015. After successful completion of the program, he founded AV84all, a 501(c)(3) public charity with a mission to provide aviation for all and allow pilots with disabilities to fly (Robinson, 2016).
- Wesley Major was paralyzed in a motorcycle accident prior to participating in Able Flight in 2012. As a result of his positive experience in Able Flight, Wesley enrolled in the graduate program at Purdue where he earned a master’s degree and is now a Ph.D. Candidate. Wesley’s graduate research focuses on improving the airline transportation experience for disabled passengers. He has been a volunteer in the Able Flight program at Purdue since his Able Flight graduation, providing administrative support and serving as a mentor, as well as recruiting program participants, interviewing candidates, and providing media outreach.

The participation of these Able Flight alumni in the aviation sector provides ongoing benefits to support diversity and inclusion in aviation. The Able Flight at Purdue program also supports inclusion in the community through public relations activities. Able Flight at Purdue accomplishments were featured in local and national news, including features on local television (Sullivan, 2015), in local newspapers (Flores, 2015; Higgins, 2015), on the internet (Holden, 2017), and on national programs such as the Big Ten Network (Tolley, 2016). This media attention fosters a broader impact by changing how individuals and society perceive people with disabilities, including their capabilities, accomplishments, and positive contributions to society.

Able Flight is a program that changes lives, and uses flight training to expand opportunities for people with disabilities while challenging societal norms. Purdue Professor Bernard Wulle initiated the Able Flight at Purdue program and recognizes that it is an important catalyst both for participants and all who have the opportunity to interact with these pilots (Wulle, 2015). Able Flight at Purdue changes how people think, and opens minds to the unlimited possibilities.

One limitation of this study is that it reflects only two disability types: paraplegia and deafness. As noted previously, even the same disability type can have varying levels of severity (e.g., two individuals with paraplegia may have different capabilities, and two individuals who are both deaf may be able to hear and communicate in different ways). The flight training methods in this case study may not work for all wheelchair users or deaf student pilots. Another limitation is that the qualitative survey results are from a small sample, and the experiences and perceptions from one year may not be representative of the experiences and perceptions for all participant in all years.

Conclusions

The Able Flight program at Purdue has successfully supported the certification of 42 pilots with disabilities, and has provided secondary benefits of supporting inclusion at Purdue University and in the aviation industry. Similar benefits could be realized elsewhere, if other flight schools provide flight training for people with disabilities. This paper describes basic components of the Able Flight program and uses the SHELL model as a framework to explain necessary modifications to allow flight training for people with disabilities.

In the SHELL model, the Able Flight pilot is the central liveware, and successful adaptation to the software, hardware, environment, and other liveware are critical to support the goal of Sport Pilot certification. A tailored approach to match student pilot capabilities with training methods and resources is important, and is demonstrated through two case studies which illustrate how the needs of a pilot who uses a wheelchair are very different from the needs of a pilot who is deaf.

The Able Flight program at Purdue is successful, as measured by a high completion rate: 98% of participants have attained their Sport Pilot certification at Purdue University since the program began in 2010. The Able Flight program at Purdue is also successful as measured by other benefits. Benefits extend beyond the completion rate, with broader impacts both to the individual participants, CFIs, the institution, the aviation sector and the community, reflecting the positive impact the program has on promoting diversity and social inclusion at all levels.

The mainstream media generated by Able Flight supports broader impacts in the community with compelling illustrations that highlight the capabilities of people with disabilities; this challenges preconceptions, and changes the public perception, focusing attention on the capabilities and positive contributions to society by people with disabilities.

Flight training opportunities for people with disabilities, such as the Able Flight program at Purdue, can be implemented elsewhere using the human factors model explained in this paper. Future research to document case studies that illustrate training adaptations for other types of disabilities would be useful for the aviation community. Additional quantification of the benefits, including the perceptions of the aviation community and employment in the aviation sector by program participants, is also recommended for future research.

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