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Evaluating the Efficiency and Accuracy of Different Keyboards

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Abstract

Non-voice data exchanges will become a primary method of communication between pilots and Air Traffic Controllers as the Federal Aviation Administration's plan for the Next Generation Air Traffic Control System (NextGen) evolves. In support of this communication evolution, pilots will need the most efficient interface tools in order to accurately and quickly exchange text messages with Air Traffic Control. Keyboards, or similar input devices, will be become a necessity in the cockpit. This study aims to investigate and compare the typing speed and accuracy possible using three sizes of two-hand, QWERTY[1] keyboards: a full size (100%), a medium size (92%), and a small size (thumb typing home theater PC keyboard) that could be used for aviation data exchanges. Each study participant was administered 15 typing tests having aviation specific content, on each keyboard, including 5 tests of short length, 5 tests of medium length, and 5 tests of long length. The results of this study suggest that in terms of words per minute typing speed, participants using the medium size keyboard had a slightly faster typing speed than with the large keyboard, while the small keyboard produced a considerably slower typing speed than either the medium or large keyboards. In terms of accuracy, participants using the small keyboard had the highest level of accuracy, followed by the medium keyboard, while the least accurate keyboard tended to be the large keyboard. Overall, findings suggest that the optimal size of two-handed, QWERTY keyboard for use in an aircraft cockpit was the medium keyboard.

[1] For a picture of the QWERTY keyboard, see appendix A.

Literature Review

Aircraft cockpit design has evolved over the years as improvements in automation and navigation capabilities have changed the way pilots interact with automated aircraft and air traffic control services. A probable reason for this is Moore's Law, which states that every twelve to eighteen months, the processing power of computers double while its corresponding cost holds constant (Downes, 2009). Because of this reality, new technologies, powered by computers are being quickly developed to better control and navigate aircraft, as well as providing for improved communication between them. This can be observed in cockpit changes that include the use of LCD monitors and complex digital displays for aircraft and flight information instead of traditional, analog-style gauges. Flight Management Systems (FMS) are increasingly utilized to program the flight from takeoff to landing. Additionally, a related trend is the effort to move from traditional voice to a text-messaging type of communication know as Data Communications (Data Comm). These changes are part of the first phase of the Next Generation Air Transportation System (NextGen).

A compelling reason to transition from voice communications to Data Comm is that a text reference does not have to be remembered while a voice communication does. Risser's study (2004) using Datalink - a text system used to exchange messages between Air Traffic Control (ATC) and pilots - demonstrated an advantage in receiving text commands over voice commands, particularly those with longer lengths and more complex content. DeMik (2008) conducted a similar experiment using Datalink in a simulated single-pilot general aviation environment, and replicated earlier results validating those findings. DeMik states:

> The results of this study [Text communications in single-pilot general aviation operations: Evaluating pilot errors and response times] revealed a statistically significant

> decrease in both human performance measures of errors in pilot recall/execution and response times in moving from the conventional voice ATC commands to the CPDLC [Controller-Pilot Data Link Communication] text commands for pilots operating an FTD [Flight Training Device] that simulated the single-pilot general aviation work environment. It was also shown that results were significant across all levels of air traffic control command loads (high, moderate, and low). (2009, p. 39)

However, Data Comm should not completely replace voice communications, but rather add to a dual modality of communication (Demik, 2009).

As a consequence of these initial findings, the FAA has made Data Comm a part of NextGen. According to the Federal Aviation Administration (FAA):

> Data Communications (Data Comm) will assume an ever-increasing role in controller to flight crew communication, contributing significantly to increased efficiency, capacity, and safety of the National Airspace (NAS). The evolution of Data Comm in the operational environment will be based upon the incremental implementation of advanced communication capabilities. Data Comm represents the first phase of the transition from the current analog voice system to an International Civil Aviation Organization (ICAO) compliant system in which digital communication becomes an alternate and eventually predominant mode of communication. (*Data Communications*, 2009, par. 1)

Currently, human factors research is being conducted on the Data Comm human interface, and a Network Service Provider is being solicited. In 2011, a revised departure clearance capability for Data Comm will occur. Between 2012 and 2016, en route clearance capability for Data Comm will become available (U.S. Department of Transportation, Federal Aviation Administration, 2010).

At the present time, Data Comm works by the Air Traffic Controller sending a text clearance to the aircraft. The FMS acknowledges receipt of the transmission by displaying a bold 'message' text at the top of its screen in the cockpit, which alerts the pilot that a communication has been received by the aircraft. The pilot depresses a button to view the detailed message, reviews the message, and then pushes a 'will comply' button to signify acceptance of the clearance (U.S. Department of Transportation, Federal Aviation Administration, 2010). This works effectively for ground clearances and ATC messages, but offers scant opportunity for pilots to send custom messages back to ATC, such as pilot reports or other helpful information they might want like to convey. Currently, the only way to submit a non-voice message to ATC from most aircraft is to use the single-hand, alphabetic keyboard on the FMS.

The FMS has been a familiar part of advanced cockpit instrumentation. Traditionally, an alphabetic, one-hand keyboard was used to facilitate FMS input. It can be inferred that this style keyboard was intended for one hand use due to its size and cockpit placement. Recently, however, some FMS keyboards have been designed with a QWERTY layout instead of the popular alphabetical layout. QWERTY keyboards have been installed in the cockpit of the Airbus A380, and Airbus plans on using the same FMS and keyboard on their next generation of the A350 (Kingsley-Jones, 2006). There have been issues with older FMS interfaces, and this change could be an effort to make programming the FMS easier through use of a keyboard style that is ubiquitously used in many other common computer interfaces. For example, in an evaluation of the American Airlines Flight 957 accident, Endsley & Strauch (1997) noted that due to the difficulty of the FMS interface, "The requirement to reprogram the FMS and cross check the entries at the last minute certainly played a role in this accident" (p. 4). A QWERTY layout might conceivably be a fix to these types of concerns.

The A380 features a full (100%), two-handed QWERTY keyboard that is primarily used with the Onboard Information Terminals (OIS) where some data can also be sent from the OIS to the FMS (Dornheim, 2006). It can be inferred that this keyboard was intended for two-handed use due to its and size and cockpit placement. Even though Airbus is shifting from an alphabetically arranged keyboard to QWERTY keyboards, Boeing is still using an alphabetic keyboard for the FMS input on their latest model aircraft, the 787 (Kingsley-Jones, 2006).

FMS keyboards were initially designed for insertion of flight plan data prior to takeoff, and to accommodate changes to the plan while in-flight. However, as part of the Next Generation Air Transportation System (NextGen), Data Communications (Data Comm) are also being transferred to the cockpit, where FMS keyboards are utilized to execute the communication. Testing the effectiveness of Data Comm as a replacement for traditional voice communication has been accomplished, but there has been little testing to determine which keyboards are best suited for use in the cockpit. The current study will attempt to answer that question.

Most studies of keyboard design and layout have focused on ergonomics - the field of study dedicated to designing devices and equipment that best fits the human body. However, some design work has emphasized creation of customized keyboards that are dependent upon the type of text to be entered. For example, Francis and Oxtoby (2006) utilized a computer program, Keyboard Tool, to create a custom keyboard best suited for specific text to be typed using only a single hand. Test results showed a decrease in text entry time, but the researchers acknowledged that it would be better to have standard 10-finger, two-handed typing if the physical environment would allow it.

Another study compared the learning curves of full-size, two-handed split-angle, chord, contour split, and Dvorak[2] (named after its founder, Dr. August Dvorak) keyboards against a conventional QWERTY keyboard (Anderson, Mirka, and Kaber, 2009). The split fixed-angle, chord, and contour split keyboards were designed to be ergonomic, and presented a layout similar to a QWERTY keyboard. The Dvorak keyboard is a layout alternative to the QWERTY keyboard and was designed to allow faster typing speeds. Analysis of results suggested the learning curve was highest (90.4%) for the split fixed-angle keyboard, which was significantly different from the learning curves of the chord (77.3%), contour split (76.9%), and Dvorak (79.1%) keyboards (Anderson, et al., 2009). Moreover, Anderson, et. al. (2009) noted that one of the difficulties often faced when introducing changes to the workplace is the negative impact these changes may have on immediate and short-term worker productivity. Therefore, it would seem advantageous to utilize a keyboard most familiar to pilots (QWERTY) so that data entry errors could be minimized.

The QWERTY keyboard became the standard over the more efficient Dvorak keyboard, not because it was superior, but because of previous adoption. Since the QWERTY keyboard developed into the international standard, and it was widely adapted, change became virtually impossible. Moreover, the potential burdens of retraining time and replacement costs have hindered more efficient text entry methods from being adopted (Riordan, Curran, & Woods, 2005). Since the Dvorak keyboard layout has been removed from widespread use, it was important to compare text input speeds of different QWERTY keyboards. Consequently,

[2] For a picture of the Dvorak keyboard, see appendix A.

Riordan, et. al. evaluated the QWERTY keyboards of a full-size, two-hand computer keyboard, a personal organizer (miniature) keyboard, and a PDA (soft) keyboard for text entry speeds (2005). Their evaluation demonstrated that, "…the full size QWERTY computer keyboard is the fastest means of text input, followed by the mini QWERTY keyboard of the personal organizer, and then by the PDA soft QWERTY keyboard" (2005, p. 195). From these results it can be theorized that a full-size, two-hand QWERTY keyboard would probably be optimally suited to the cockpit.

Because of the clear, measurable advantages of communicating via text commands rather than voice commands (Risser, 2004 & DeMik, 2008), Data Comm will likely become the norm in the future, and the utilization of keyboards in the cockpit will become more prevalent. Some aircraft manufacturers have adopted the use of QWERTY keyboards for the FMS in their cockpit, while others have elected to continue using the traditional alphabetic keyboards (Kingsley-Jones, 2006). Even though it has been demonstrated that there are significant efficiencies gained from using custom layouts for single-hand typing, most researchers recognize that if it is possible, a two-handed keyboard is preferential (Francis & Oxtoby, 2006). It has also been shown that people learn to type faster on a keyboard that they are more familiar with (Anderson, et al., 2009), that the QWERTY keyboard is the most common keyboard layout, and people type faster on a larger QWERTY keyboard rather than a smaller QWERTY keyboard Riordan, et. al., 2005).

Research Problem And Question

Because of the proliferation of aircraft automation and the phasing in of Data Comm to reduce voice communications, it is evident that utilization of keyboards in the cockpit will increase. However, with some cockpit sizes and layouts, it is not always feasible to install a full-size, QWERTY keyboard. Therefore, the research question for this study was which size of two-handed, QWERTY keyboard would be the most efficient, in terms of words typed per minute, and accuracy? The three keyboard types that were evaluated included a full-size (100%) keyboard (most commonly found on desktop computers), a partial-size (92%) keyboard (most commonly found on netbooks), and a small, thumb-typing keyboard (most commonly found on cell phones or home theater PC keyboards). Comparison of the test results suggested conclusions regarding optimal sizes for two-handed, QWERTY keyboards for use in aircraft cockpits.

Methodology

Participants

Participants for this study included volunteers with at least a Federal Aviation Administration (FAA) private-pilot certificate. Ten student participants from the Purdue University Aviation Technology Program were recruited via mass distribution e-mail for this research.

Measures

The Asus Eee PC 1005HAB Netbook was used as the primary display for the participants. A 100% QWERTY keyboard (the Logitech MX5000), a 92% QWERTY keyboard (the keyboard on the netbook), and a small, thumb-typing keyboard (the Lenovo Mini N5901) were used to input typed communications. The Custom Typing Test, found at http://free-typing-tests.com/wpm-typing-tests/wpm-test-v9/, was chosen to record the number of words typed per minute and also the accuracy of the typing. The testing software automatically calculates the words per minute typing speed and accuracy after the participant has begun typing. The test's text turns red when a mistake occurs that requires correction. Scoring data were displayed after the participant completed the test. An external monitor was connected to the netbook with another keyboard and mouse so the test administrator could see and record the test scores as well as enter a new text message.

Procedures

Participants completed the typing tests while sitting in a chair at a desk. Prior to beginning the test, they were asked to orient the computer and keyboard(s) in a way that would be most ergonomically comfortable for them. Then they would type the message presented to them on the display.

Each participant was administered a total of 15 typing tests[3] on each keyboard, including 5 tests of short length (1-35 characters; e.g., United 124 climbing to FL320), 5 tests of medium length (36-70 characters; e.g., Southwest 848 turning to heading 100 and climbing to 10000 ft), and 5 tests of long length (71-105 characters; e.g., Delta 290 flying direct to ORD airport heading 360 passing through FL230 and climbing to FL330). The order of the keyboards, as well as the order of the 45 typing tests were randomized. A thick sheet of paper was used to block the netbook's screen in-between tests to prevent participants from observing the next text message before they started to type.

The researcher recorded the words-per-minute typing speed as well as the accuracy achieved during each interaction. The two *dependent variables* were: (1) the words per minute typing speed, and (2) the typing accuracy of the test. The two *independent variables* were: (1) the type of keyboard being used, and (2) the length of the text typed.

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[3] For all typing test text, see Appendix B.

Data Analysis Procedures

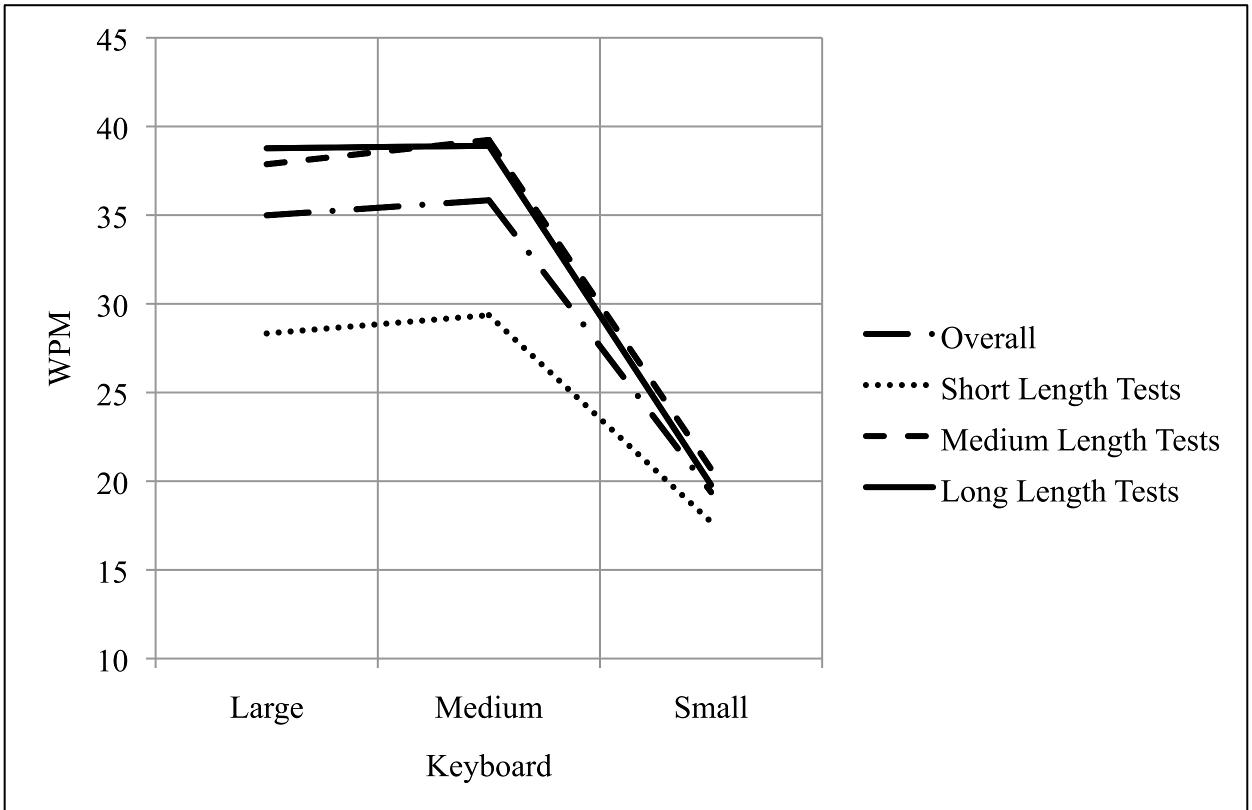
All data from this experiment were analyzed using only descriptive statistics. For such a small sample size, distribution-free statistics (meaning statistics not tied to a normal distribution, which emphasize the Central Limit Theorem) were most appropriate (Salkind, 2006). From these results, conclusions were inferred on what size two-handed, QWERTY keyboard was most efficient and accurate for use in the cockpit for Data Comm.

Discussion of Results

The purpose of this research study was to investigate and compare the typing speed and accuracy of three sizes of two-hand, QWERTY keyboards that could be used both for aviation communications and FMS input. From these findings, conclusions were developed about which size two-handed, QWERTY keyboard was optimal for use in an aircraft cockpit.

The results were consistent across all message lengths in words per minute typing speed. Generally, the medium sized keyboard generated a slightly faster typing speed than the larger keyboard, while the small keyboard induced a considerably slower typing speed than either the medium or large keyboard. Therefore, the medium sized keyboard performed the best across all typing length tests in terms of typing speed. (see Table 1)

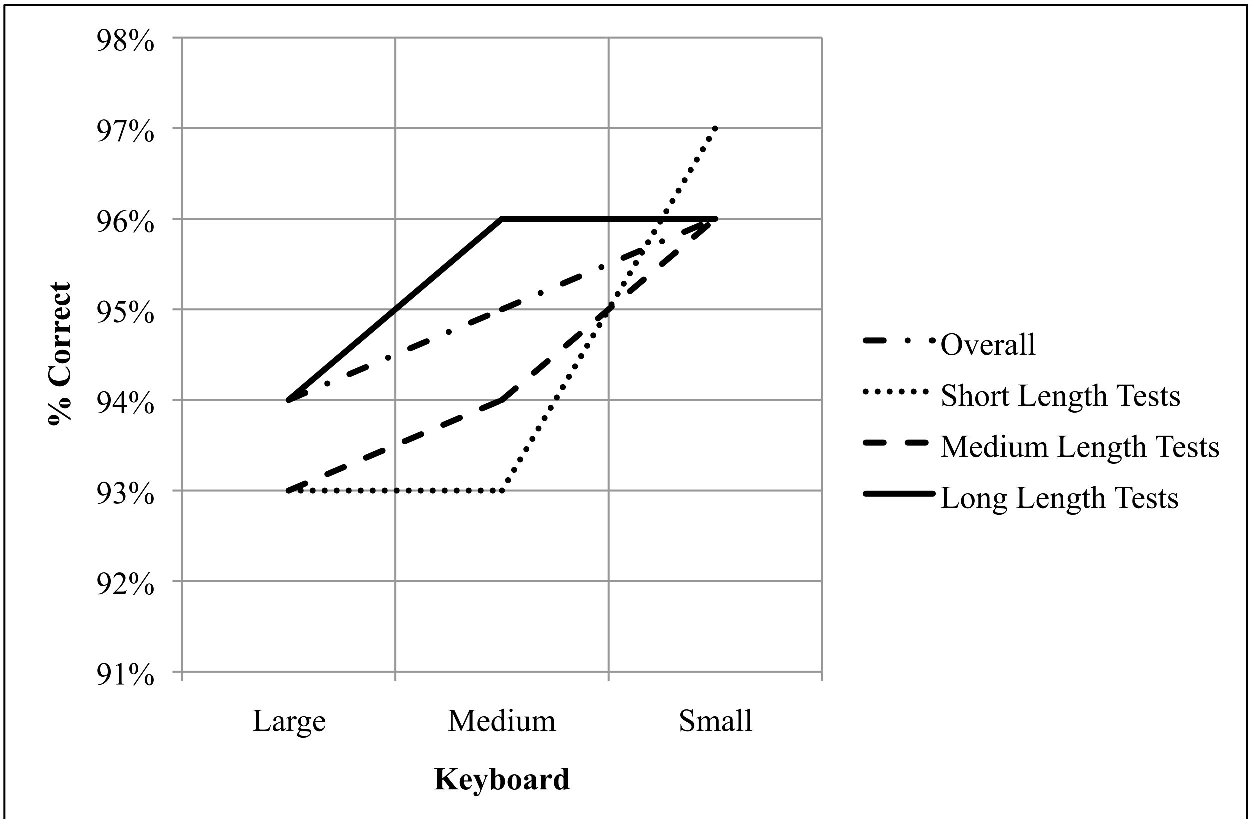
Table 1
Mean Typing Speeds for Three Keyboards



	Large Keyboard	Medium Keyboard	Small Keyboard
Overall	34.99	35.84	19.38
Short Length Tests	28.33	29.36	17.70
Medium Length Tests	37.87	39.24	20.69
Long Length Tests	38.77	38.91	19.79

In terms of overall accuracy, the small keyboard performed best, followed by the medium keyboard, while the least accurate was the large keyboard. For short message length, the smaller keyboard was the most accurate, while the medium and large keyboards produced the same accuracy. For medium length messages, the small keyboard had the highest level of accuracy, followed by the medium keyboard, and the least accurate was the large keyboard. For long length messages, the small and medium keyboards had the highest level of accuracy, and the large keyboard was the least accurate. As a result, the keyboard with the highest level of input accuracy across all tests was the small keyboard, with the medium keyboard tending to have the second highest accuracy, followed by the large keyboard. This might be explained by the participants being more familiar with the large and medium size keyboards, and therefore over confident and consequently more likely to make mistakes. By contrast, they were probably least familiar with the small keyboard, and perhaps more careful with their typing input. However, when comparing the accuracy achieved on each typing test, they keyboards were only separated by a few percentage points across all tests. (see Table 2)

Table 2
Mean Accuracy for Three Keyboards



	Large Keyboard	Medium Keyboard	Small Keyboard
Overall	94%	95%	96%
Short Length Tests	93%	93%	97%
Medium Length Tests	93%	94%	96%
Long Length Tests	94%	96%	96%

Using volunteer student participants from Purdue University, and comparing these three keyboards, findings suggest that the optimal size of two-handed, QWERTY keyboard for use in an aircraft cockpit was the medium keyboard. This conclusion seems logical even though the participants' usage of the medium keyboard did not consistently produce the highest accuracy across all typing lengths. Additionally, it was only separated by a few percentage points from the small keyboard while producing an appreciably faster typing speed than the small keyboard and only a slightly faster speed than the large keyboard across all typing length tests.

Conclusions

Determining the optimal size of two-hand, QWERTY keyboard that would result in the most efficient and accurate message input for cockpit applications can aid aircraft manufacturers and cockpit designers in enhancing cockpit layouts to support the Next Generation Air Traffic Control System. However, not all cockpit layouts can accommodate the use of all varieties of keyboards. Consequently, the advantages and disadvantages of each keyboard must be carefully considered when designing a cockpit. Based on the findings from the current study, the optimal size of two-handed, QWERTY keyboard for use in an aircraft cockpit appears to be the medium keyboard. However, this experiment was prepared for flight crews controlling large aircraft operating in an instrument environment, the tests did not accurately represent actual cockpit or flying conditions, the participants' preference in keyboard size and type was not considered, and the number of participants was too small to demonstrate statistical validity.

Further research to compare keyboard applications that are aircraft and cockpit specific is merited to develop more informed conclusions about which keyboard size and style is most effective for specific aircraft. Since the typing tests were designed for *transport category aircraft* operating under Instrument Flight Rules (IFR), it is conceivable that typing tests designed for *general aviation aircraft* operating under Visual Flight Rules (VFR) would be more appropriate to determine the best keyboard for smaller aircraft use. Additionally, the tests were not conducted in either simulated or actual flight conditions. Consequently, a typing test administered during a simulated or actual flight would likely be more definitive, especially when considering specific cockpit layouts. Furthermore, keyboards designed specifically for aircraft cockpits, instead of a computer, might be optimal. Additionally, participant preference in keyboard size was not considered. Thus, when considering a similar experiment, incorporating participants' preference in keyboard size might be useful, especially if one keyboard produces more hand or finger fatigue, which could affect typing speed and accuracy. Finally, to derive more meaningful conclusions about which size keyboard would be optimal, it is imperative that a larger sample population be recruited and evaluated.

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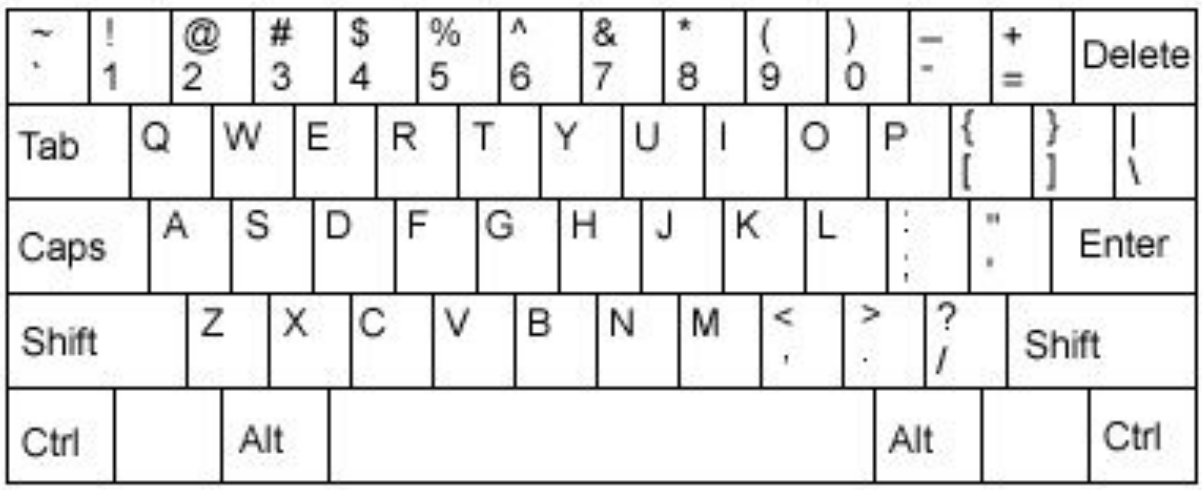
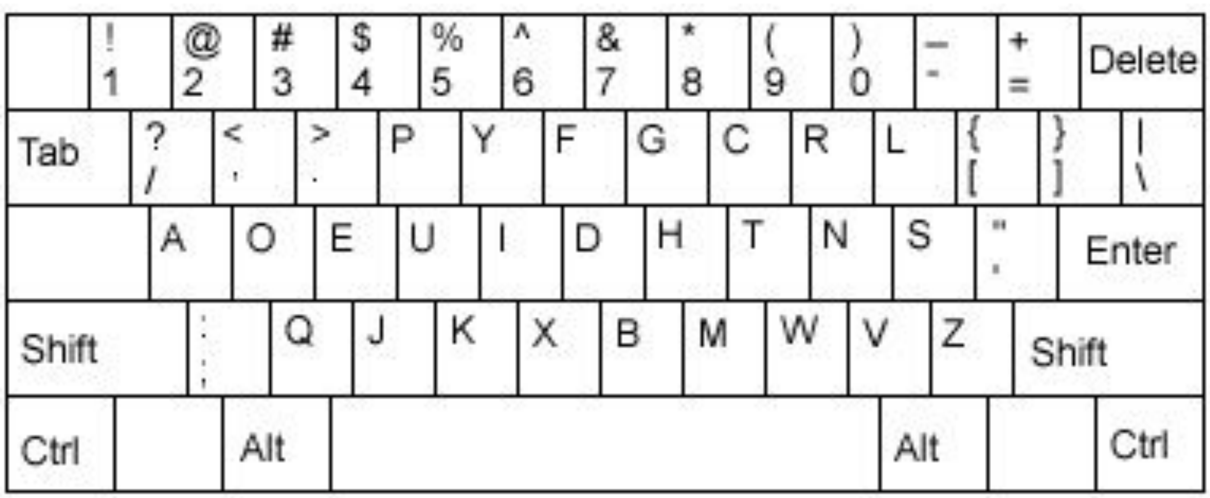
Appendix A

QWERTY keyboard



(Computer Hope, n.d.)

Dvorak keyboard



(Computer hope, n.d.)

Appendix B

Typing Test Text

Short Length (1-35 characters in length)

1. United 124 climbing to FL320
2. Southwest 195 FL260
3. Continental 567 descending to FL200
4. Delta 696 heading 120
5. Frontier 367 turning to 180

6. Republic 956 passing through FL270
7. USAir 724 descending to 10000 ft
8. SkyWest 267 FL280
9. JetBlue 734 heading 100
10. AirTran 768 FL360

11. American 147 climbing to FL270
12. Hawaiian 239 FL280
13. Alaska 927 descending to FL290
14. Comair 539 leaving IND airspace
15. UPS 698 at 16000 ft

Medium Length (36-70 characters in length)

16. Southwest 848 turning to heading 100 and climbing to 10000 ft
17. United 567 passing through heading 360 and climbing to FL320
18. Continental 367 heading 060 and at FL210
19. Frontier 124 turning to heading 145 and descending to 16000 ft
20. Republic 769 climbing to 10000 ft and turning to heading 320

21. National 899 descending to FL180 heading direct to MDW
22. Empire 367 heading 275 and descending to 6000 ft
23. Tradewinds 832 turning to 010 to intercept 150 radial of BOL VOR
24. Mesa 169 turning to intercept ILS 10 approach
25. Compass 637 heading direct to JFK will intercept ILS 28 approach

26. FedEx 478 passing through FL230 and turning to heading 150
27. Mesaba 486 heading direct to SFO and climbing to FL340
28. Piedmont 328 passing through 12000 ft and climbing to FL290
29. Compass 274 passing through heading 100 and turning to heading 230
30. GoJet 157 turning to heading 190 and climbing to 14000 ft

Long Length (71-105 characters in length)

31. Delta 290 flying direct to ORD airport heading 360 passing through FL230 and climbing to FL330
32. Qantas 946 heading 060 and at FL210 climbing to FL320 heading direct to DFW
33. Emirates 349 turning to heading 090 to intercept 150 radial of LBO VOR and climbing to 10000 ft
34. KLM 159 descending to 13000 ft and turning to intercept ILS 28 approach
35. Virgin America 259 descending to 9000 ft and turning to intercept GPS 05L approach

36. Virgin Atlantic 794 heading 340 climbing to FL280 and heading direct to TWO intersection
37. Air France 473 flying direct to IAD airport heading 220 passing through FL210 and climbing to FL320
38. British Airways 159 descending to 6000 ft and turning to intercept ILS 36 approach
39. Korean Air 698 descending to 8000 ft and turning to intercept GPS 18R approach
40. Spirit 478 passing through FL230 descending to 14000 ft and turning to heading 130

41. Allegiant 945 heading 090 climbing to FL260 and heading direct to LSI intersection
42. Great Lakes 123 climbing to 12000 ft and crossing 155 radial of KVR VOR
43. ExpressJet 367 flying direct to LAX airport heading 160 passing through FL190 and climbing to FL290
44. Southwest 289 passing through FL240 descending to 15000 ft and turning to heading 030
45. AirTran 629 descending to 7000 ft and turning to intercept GPS 05 approach