NASA CONTRACTOR REPORT # 177605

ON THE TYPOGRAPHY OF FLIGHT-DECK DOCUMENTATION

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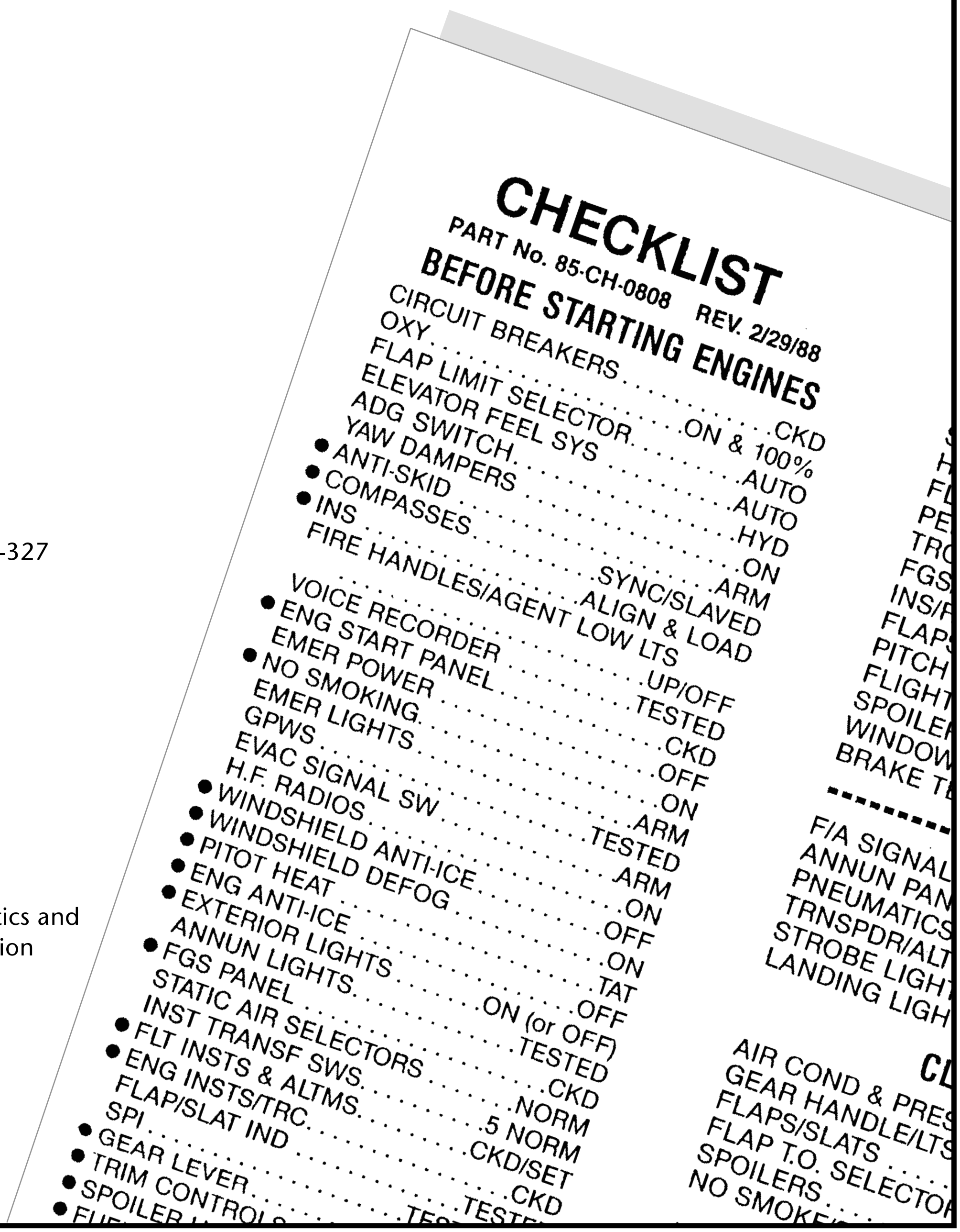

CONTRACT NCC2-327
December, 1992

National Aeronautics and
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ASAF DEGANI

SAN JOSE STATE
UNIVERSITY FOUNDATION
SAN JOSE, CALIFORNIA

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Ames Research Center
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Ames Research Center
Moffett Field, California 94035-1000

Contents

Summary

Many types of paper documentation are employed on the flight-deck. They range from a simple checklist card to a bulky Aircraft Flight Manual (AFM). Some of these documentation have typographical and graphical deficiencies; yet, many cockpit tasks such as conducting checklists, way-point entry, limitations and performance calculations, and many more, require the use of these documents. Moreover, during emergency and abnormal situations, the flight crews' effectiveness in combating the situation is highly dependent on such documentation; accessing and reading procedures has a significant impact on flight safety. Although flight-deck documentation are an important (and sometimes critical) form of display in the modern cockpit, there is a dearth of information on how to effectively design these displays.

The object of this report is to provide a summary of the available literature regarding the design and typographical aspects of printed matter. The report attempts "to bridge" the gap between basic research about typography, and the kind of information needed by designers of flight-deck documentation. The report focuses on typographical factors such as typefaces, character height, use of lower- and upper-case characters, line length, and spacing. Some graphical aspects such as layout, color coding, fonts and character contrast are also discussed. In addition, several aspects of cockpit reading conditions such as glare, angular alignment, and paper quality are addressed. Finally, a list of recommendations for the graphical design of flight-deck documentation is provided.

1. Background

On May 26, 1987, at 16:45 Central Daylight Time, an Air New Orleans BAe-3101, departed from runway 19 at New Orleans International Airport on a scheduled commuter flight to Eglin Air Force Base, Florida. Flight 962 never reached Eglin AFB that day, nor any altitude above 200 feet. The flight crew felt a severe yawing motion and engine torque fluctuations. The captain proceeded to make an emergency landing on the overrun of runway 19. The aircraft rolled off the overrun, crossed an adjoining highway, struck several vehicles, and came to rest on the far side of the highway. The National Transportation Safety Board (NTSB) concluded that "the engine RPM levers were either advanced to a position less than full forward or they were not advanced at all before takeoff, indicating a lack of checklist discipline on the part of the aircrew" (NTSB, 1988, p. 24). The report also stated that,

> The typeface on the Air New Orleans' checklist is 57 percent smaller than that recommended by human engineering criteria. This smaller typeface reduces the legibility of print even under optimum conditions. Although there was no evidence that checklist legibility was a factor in this accident, the Safety Board believes that under other operational circumstances, this deficiency could compromise the intended purpose of this device. Therefore, the Safety Board believes the FAA should take action to verify that aircraft checklists are designed to comply with accepted human engineering criteria (p. 22).

The NTSB made a recommendation to the FAA to "issue an Advisory Circular to commercial operators recommending the use of a procedural checklist that incorporates human engineering design criteria for size and style of print" (NTSB A-88-72). Figure 1 is a copy of the checklist used by the flight crews of Air New Orleans Flight 962 (note that the poor quality of the checklist in figure 1 is due to several reproductions of the original checklist used by the crew of Flight 962).

On August 19, 1980, a Saudi Arabian Lockheed L-1011 was returning to Riyadh Airport (Saudi Arabia), after warnings in the cockpit indicated smoke in the aft cargo compartment. The crew was searching for the appropriate emergency procedure in their flight documentation. The accident report stated that,

> About 3 minutes were spent by the crew looking for the aft cargo smoke warning procedure. Evidence indicated this difficulty was due to a split of the Emergency and Abnormal procedures into Emergencies, Abnormal, and Additional [sections]. The crew apparently believed that the procedure was in the Abnormal section when it was actually in the Emergency section.... (Flight Safety Focus, 1985)

This, and several other factors led to a horrific accident in which 287 passengers and 14 crew members died of fire and toxic smoke inhalation.

AIR NEW ORLEANS BAe 3101 FLIGHT CREW CHECKLIST (7TH REVISION)

BAE-31 NORMAL PROCEDURES CHECKLIST — **Seventh Revision**

BEFORE STARTING (* - First flight of the day)

1. Prop Start Locks/Fuel Caps/Inlet Covers - CHECKED L/R
2. Circuit Breakers - CHECKED
3. Gear Handle - DOWN
4. Battery Master - AS REQUIRED/VOLTAGE CHECKED
5. Parking Brake - 700 PSI/SET

*6. Left/Right Skirt Panels - CHECKED/TESTED
7. Fans/Freon/Gnd Heat - OFF
*8 Fire extinguishers/Hyd Pump Handle - CHECKED/ON BOARD
*9. Emergency Hyd Selector - NORMAL
10. Trims - SET (3)
*11. Feather levers - TEST/OPEN
12. Power/RPM Levers - GROUND START/TAXI/FULL & FREE
13. Pressurization/Temps Panel - SET
*14. Battery Temps - TEST/CHECK
15. EGT - LESS THAN 200°
16. Fuel Quantity - CHECKED
17. Cap Panel - CHECKED/TEST
*18. L.P. Cocks - TEST/OPEN
19. SRL/TTL - ON
*20. Fuel Crossfeed - TEST/NORMAL
21. Boost Pumps - ON
22. Generators - OFF EXTERNAL PWR/ON INTERNAL PWR
23. Avionics Master - OFF
24. Emergency Lights - TEST/NORMAL
25. External Lights - AS REQUIRED

BEFORE TAXI

1. Generators - ON
2. Battery Master - INTERNAL
3. Amp/Volt Meters - CHECK LOADS/SHARING
4. Ground Power - REMOVED AND CLEAR
5. Chocks - REMOVED
6. Avionics Master - ON
7. Windshield Heat - WARM
8. Fans/Freon - AS REQUIRED
9. Flow Selectors - ON
10. Hyd Pressures - CHECKED (4 at 2000 PSI)
11. Start Locks - REMOVED
12. Taxi/External Lights - AS REQUIRED

ONE INCH

BEFORE TAKEOFF

1. Passenger Briefing - COMPLETE
2. Cabin Signs - ON
3. Air/Gnd Switches - AIR
4. Oil Cooler Flaps - AS REQUIRED
5. Radar - STANDBY

CR6. Brakes/NWS - CHECKED WITH TAXI
CR7. Flight Instruments/Stby Horizon - CHECKED/SET
CR8. Oxygen - NORMAL/PRESSURE
CR9. D V Window - SECUREDL/R
CR10. Engine Instruments - NORMAL
CR11. Fuel Quantity - TOTAL IN HOURS
CR12. Avionics - SET/CLEARANCE BRIEFING
CR13. Seat Belts/Harness - SECURED L/R
CR14. Airframe/Eng. Prop De-ice - CHECKED & TESTED
CR15. Flaps - SET/TESTED
CR16. Gust Locks - REMOVED
CR17. Flight Controls - FREE/CORRECT
CR18. Stall Protection - TESTED/ON
CR19. Cap Panel - SRL/BETA
CR20. APR - TESTED/ARM AS REQUIRED
*CR21. TTL - TESTED
CR22. V Speeds/Captain's Briefing - COMPLETE

TAKE-OFF SPEEDS

TAKE-OFF WEIGHT LB	VR KT	V2 KT
15212	111	114
15090	110	113
14840	109	112
14600	108	111
14360	107	110
14110	106	109
13870	105	108
13630	104	107
13380	103	106
<13380	102	105

BEFORE TAKEOFF (FINAL ITEMS)

1. Windshield Heat - ON
2. Pilot Heat - ON
3. Transponder - ON
4. Oil Cooler Flaps - CLOSED/TEMPS NORMAL
5. Lights - AS REQUIRED

CR6. Ice Protection - AS REQUIRED
CR7. Flow Selectors - OFF
CR8. Speed Levers - 100% WHEN CLEARED

Figure 1. Air New Orleans, BAe 3101 checklist (adopted from NTSB, 1988).

Documents, manuals, checklists and many other paper forms are used in the cockpit. Ruffell Smith (1979), reported that excluding aircraft flight manuals, the amount of paperwork needed for a flight from Washington D.C. via New York to London, had a single side area of 200 square feet (Figure 2). One recent report submitted to NASA's Aviation Safety Reporting System (ASRS) speaks to this issue:

> Both the copilot and I wrote our flight clearance, which included the KIRN 2D departure, as we received it from clearance delivery.... I briefed the crew on the departure, including emergency items, and read aloud the KIRN 2E departure procedure. During our departure, radar [ATC] asked why we had turned early.... Radar reminded us that we were to fly the KIRN 2D departure of this flight.... I and other pilots I know are concerned about the amount of information presented to us for the operation of our flights. For the flight prompting this report we had over *30 feet* [italic added] of computer printout of information for this flight including 30 navigation waypoints, later to be revised enroute. Together, the two airports at Paris (Orly and Charles De Gaulle) have procedures and info that make up a small volume of 89 pages. The 25 pound flight bag I carry contains 5 volumes of information in a constant state of revision. Too much information could cause important items to be overlooked--lost in the maze of print. Important items of information and procedures should be concise and printed as to be easy to read--especially at night. (ASRS Report No. 157620)

Although flight-deck documentation and written procedures are an inherent part of flight operation, there is a drought of research regarding this aspect of cockpit activity. The topic of procedural design and its associated display has long been neglected by the human factors profession; partly because human factors research has traditionally focused on the hardware interfaces in the cockpit (controls, displays, etc.). Nevertheless, flight-deck documentation are an integral part of the interfaces in the cockpit—specifying and dictating the actions by which the pilot is expected to interact with the machine.

In a recent study, Degani and Wiener (1990) studied the human factors aspect of checklist procedures. While conducting that study, the authors encountered many flight-deck documentation, such as flight plans, fuel sheets, manifests, dispatch material, that were poorly presented (graphically and typographically). Those documentation were not only difficult to follow, but also difficult to read and comprehend. Those findings prompted this work.

Figure 2. Paperwork needed for a flight from Washington, D. C., to London (adopted from Ruffell Smith, 1979).

2. Objectives and Scope

The intent of this report is to provide a literature review of the basic research on typography and suggest compatible approaches for designing flight-deck documentation. The report focuses on several typographical and environmental factors that affect the ability of the pilot to use, read, and comprehend flight-deck documentation and written procedures. The efficiency and accuracy of reading checklists, maps, airport charts, flight plans, fuel slips, manifests, etc., depends in part on typographical and graphical factors. Moreover, during emergency or abnormal conditions, the flight crew efficiency in accessing, reading, comprehending, and executing procedures has a significant impact on flight safety (de Ree, 1991; Degani and Wiener, 1991).

There is very little experimental data in the literature regarding reading and using printed text in the airline cockpit. Therefore, the data reported in this study is based on laboratory studies. *These experiments were not conducted in a cockpit*; the majority were conducted while the subjects (usually college students), were seated by a desk and the printed matter was lighted with normal room lighting.

This report attempts to "bridge" this gap between empirical research and "the real world" by providing a summary of the basic research findings to the documentation designer. Hence, the information presented here only serves to provide a baseline. The designer should make an initial assumption from the data and the author's recommendations, then validate the design in an appropriate flight simulator using his/her own company documentation and a representative sample of the pilot population. For an example of this process, conducted for a major international airline, see de Ree (1991).

Although it is beyond the scope of this report to discuss concepts of human perception, the author would like to raise one "warning flag" regarding the data in this report. I believe that information from data books and graphs regarding human sensing of physical energies may be *insufficient*. While it is true that the data reported in the literature are well established, it is also very important to realize that the data cannot be used as a simple look-up table to predict what will happen when an observer is confronted by a particular display (in this case a printed matter). The specification of a printed document in terms of physics can ensure that the information is available. However, whether that information is perceived accurately by the observer also depends on how she/he processes that information. What is perceived by the observer is a combination of [1] what the data books detail about human sensory detection and [2] the observer's strategies of information processing (Foley and Moray, 1987).

An example of the above combination in human perception is the Delta Air Lines Flight 1141 accident. The aircraft, a B-727, crashed shortly after lifting off from runway 18L at Dallas-Fort Worth International Airport, following a no-flap/no-slat takeoff. The NTSB concluded that "the flight crew did not extend the airplane's flaps or slats for takeoff" (NTSB, 1989, p. 92). However, the cockpit voice recorder indicated that in response to the second officer prompt "*flaps*," the first officer responded "*fifteen, fifteen, green light.*" Presumably, the first officer's response is based on a visual check of the needle position on the inboard and outboard flap/slat position indicators ("*fifteen, fifteen*") and illumination of the leading edge flaps and slats indicator light ("*green light")*. However, all these indicators displayed something very different from what the first officer responded (the flap/slat gauges indicated zero). In this case, as in many other reported incidents (ASRS, 1987, 1989), the active strategies of information processing of the first officer played a dominant role in determining what he actually perceived. Hence, the mere existence of the display and its information is not predictive of what the observer will perceive.

Effective appearance of flight-deck documentation is affected by the correct graphical presentation and the environmental conditions that influence reading in the cockpit. These two factors should agree with the unique physical condition of the cockpit, the capabilities and limitations of the human operator, and the method of using the documentation as dictated in the standard operating procedures (Degani and Wiener, 1991; 1994). Some of these considerations will be discussed in the following sections.

3. Typography

3.1 Principles of Typography

Typography is defined by the Webster's dictionary as "the arrangement, style, or general appearance of matter printed from type." In order to select and use the appropriate typography, there are two factors that the document designer should consider.

Legibility of Print (Discriminability). This characteristic of an alphanumeric enables the observer to quickly and positively identify it from all other letters and characters. Legibility depends on stroke width, form of characters, illumination on the page, and the contrast between the characters and the background.

Readability. This quality of the word or text allows for rapid recognition of a single word, word-groups, abbreviations, and symbols. Readability depends on the spacing of individual characters, spacing of words, spacing of lines, and the ratio between characters area to background area (Heglin, 1973; Sanders and McCormick, 1987). These criteria are important for all printed matter; however, they are crucial for the typographical design of flight-deck documentation. Reading conditions in the airline cockpit is characterized by some of the following:

1. Non-optimal viewing conditions (during night operations, dim lighting, and direct sunlight);

2. Fast and frequent changes of accommodation between far- and near-vision (looking for other traffic and then reading an approach plate);

3. Interruptions and distractions while following procedural sequences from manuals and checklists (ATC communications, flight attendants, company calls, etc.);

4. Several age groups with different viewing abilities within the pilot population.

The following sections will detail some of the basic research findings regarding aspects of typography and graphical design. Some of these aspects will be illustrated here using a checklist of a wide-body airliner. Nevertheless, the reader is cautioned that these basic research findings are not specific for flight-deck documentation. Therefore, the author's recommendations provided at the end of each sub-section, cannot be used as specifications; each recommendation must be evaluated by the designer for his/her unique application.

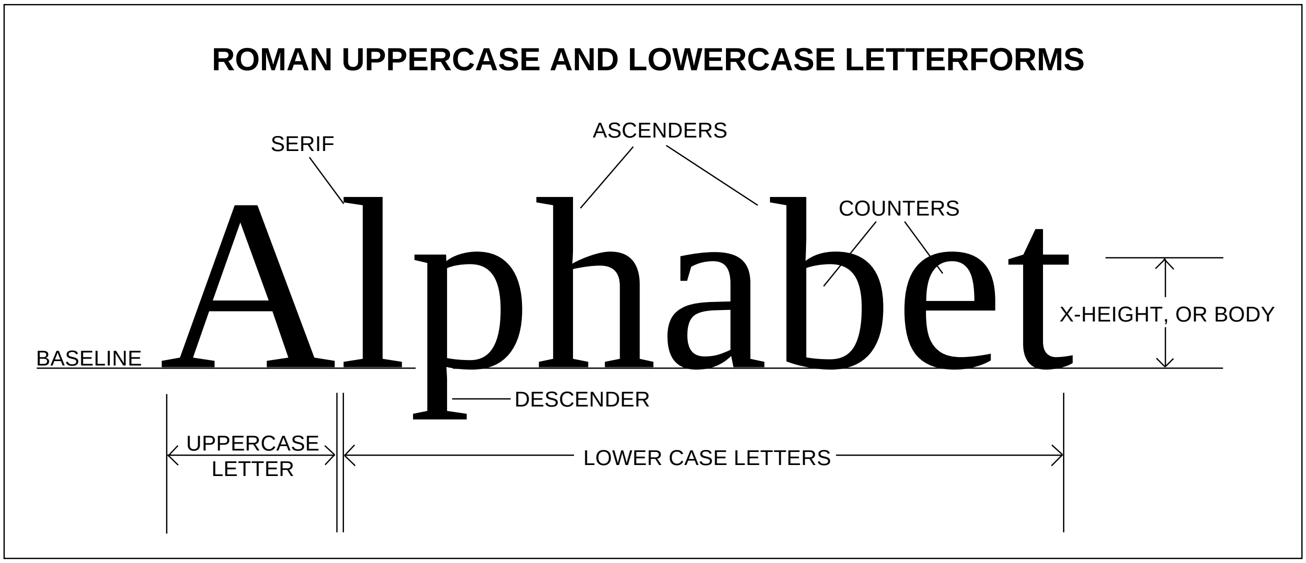


Figure 3. Letterforms (adopted from Craig, 1980).

3.2. Typeface (Fonts)

Typefaces or fonts refer to the style of the alphanumeric used in printing. There are over 2300 typefaces available today. Two major groups of fonts are applicable for use on the flight deck: roman and sans-serif. Roman is well known since it is used daily in newspapers, journals, and books. Sans-serif is a contemporary font that does not include the little strokes (serifs) that project horizontally from the top or bottom of a main stroke (Figure 3).

Several researchers have reported that when other typographical factors are controlled, sans-serif fonts are more legible than roman. The premise behind this statement is that absence of serifs presents a more simple and clean typeface, and therefore improves the legibility of the print (Cheetham and Grimbly, 1964; Heglin, 1973; Poulton, 1965). Serifs disrupt character discrimination and may add uneven appearance to the shape of strokes and characters. However, it is also evident that they somewhat aid the horizontal movement of the eye along the printed line—the serifs at the top and bottom of a character create a "railroad track" for the eye to follow along the line of print. Therefore, when using a typeface without serifs, adequate spacing between the lines of print should be used in order to prevent the eye from bridging (slipping) to the adjoining line (Craig, 1980). The designer should safeguard against this factor as it may lead to skipping a line while reading a long list.

HELVETICA
Many types of paper documentation are employed on the flight deck. They range from a simple checklist card to a

TIMES
Many types of paper documentation are employed on the flight deck. They range from a simple checklist card to a

PALATINO
Many types of paper documentation are employed on the flight deck. They range from a simple checklist card to a

FUTURA
Many types of paper documentation are employed on the flight deck. They range from a simple checklist card to a

MELIOR
Many types of paper documentation are employed on the flight deck. They range from a simple checklist card to a

OPTIMA
Many types of paper documentation are employed on the flight deck. They range from a simple checklist card to a

GARAMOND
Many types of paper documentation are employed on the flight deck. They range from a simple checklist card to a

Figure 4. Comparison of several fonts (adopted from Poulton, 1965).

Gill Medium

ABCDEFGHIJKLMN
OPQRSTUVWXYZ

abcdefghijklmno
pqrstuvwxyz

Among the sans-serif group there are many different fonts from which to select. Pulton (1965) compared the level of reading comprehension among five different fonts (three different sans-serifs and two fonts with serifs). He found a significantly higher level of comprehension while subjects were using a sans-serif font called Gill-Medium. This font was also ranked first in its level of character discrimination. A careful examination of Figure 4 will indicate that in contrast to the Gill-Medium font, the letters of the other sans-serif fonts are characterized by several "family resemblances." This results in similar appearance and may reduce legibility (compare the "O" and "C"). Likewise, most of the modern sans-serif fonts such as Futura, Avant Garde, and Helvetica also include characters that are too similar to one another, and therefore difficult to distinguish. The sources of similarity between the characters of modern sans-serif fonts are:

1. The standardized or modular appearance of the letters ("P," "R").

2. The effect of mirror images between the upper and lower part of the character ("E," "B," "D").

3. The use of equal radius for different letters ("G," "O," "C") (Craig, 1980; Cheetham and Grimbly, 1964).

It is interesting to note here that most human factors design handbooks advocate the use of sans-serif fonts—emphasizing the characteristics of modern sans-serif fonts as clean and simple fonts. Neglecting, however, the sub-optimal effect of their over-modularity on the legibility and readability. Figure 5 compares sans-serif and serif fonts for a checklist of a wide-body aircraft.

Another font related problem is the use of dot matrix printers. Several airlines employ such printers for documents that are produced by dispatch agents (e.g., flight plan, fuel sheet, and cargo/passenger manifest). This font is very modular, especially in upper case letters. In addition, it is difficult to discriminate between characters because of the dot construction that make up a character and the uneven spacing between dots (see Figure 6). There are also instances in which the print is almost unreadable because of an old ribbon in the printer.

- **Sans-serif fonts are usually more legible than fonts with serifs.**
- **Avoid using a font that has characters that are too similar to one another, as this will reduce the legibility of the print.**
- **Avoid using dot matrix print for critical flight-deck documentation.**

	Circuit breakers	ckd
●	Flt recorder*	on
●	Voice recorder*	tested
	Oxy	on & 100%, spkrs
●	Anti-skid*	tested & norm
	Evacuation signal	armed
	Compasses	ckd
	Lo spd AIL	norm & auto
	Rud trav/pitch feel	on
●	Exterior lts*	on (or off)
	Servo controls	on

	Circuit breakers	ckd
●	Flt recorder*	on
●	Voice recorder*	tested
	Oxy	on & 100%, spkrs
●	Anti-skid*	tested & norm
	Evacuation signal	armed
	Compasses	ckd
	Lo spd AIL	norm & auto
	Rud trav/pitch feel	on
●	Exterior lts*	on (or off)
	Servo controls	on

Figure 5. Serifs vs. sans-serif fonts.

●	Eng start panel*	crank/start abort
	Fire handles	up
●	No smoking*	on
	Emer exit & min cab lts	armed & on
●	Ice protection*	off
●	Window heat*	lo & on
	Radio master sws	on
	Auto flt/nav	ckd
	Inst sws	ckd & norm
	Flt insts & altms*	ckd & set
●	GPWS	tested

●	Eng start panel*	crank/start abort
	Fire handles	up
●	No smoking*	on
	Emer exit & min cab lts	armed & on
●	Ice protection*	off
●	Window heat*	lo & on
	Radio master sws	on
	Auto flt/nav	ckd
	Inst sws	ckd & norm
●	Flt insts & altms*	ckd & set
	GPWS	tested

Figure 6. Dot-matrix vs. laserwriter printing.

3.3. Lower-case vs. UPPER-CASE Characters

There is almost a consensus among researchers that, when other factors are controlled, lower-case characters are more legible than upper-case (Hartley, 1981; Philips, 1979; Tinker, 1963). Poulton (1967) performed an experiment to determine the difference in readers' attention between upper and lower-case in newspaper headings. He reports that lower case headings were located faster than upper case heading. Tinker (1963) tested lower-case and upper-case fonts for legibility and pleasingness. He reported that lower case was read faster and ranked higher in pleasingness.

There are several factors that contribute to the reduced legibility of upper-case words compared with lower-case:

1. Most printed material that we read and use in everyday life is set in lower case.

2. Readability of lower case words is superior; words set in lower-case are perceived at a greater distance, suggesting that the "total word form" and legibility of the elements is important while perceiving words set in lower-case (Tinker, 1963; Smith, Lott, and Cronnell, 1969). Note, however, that when researchers compared the legibility of individual characters, upper-case characters were perceivable at a greater distance.

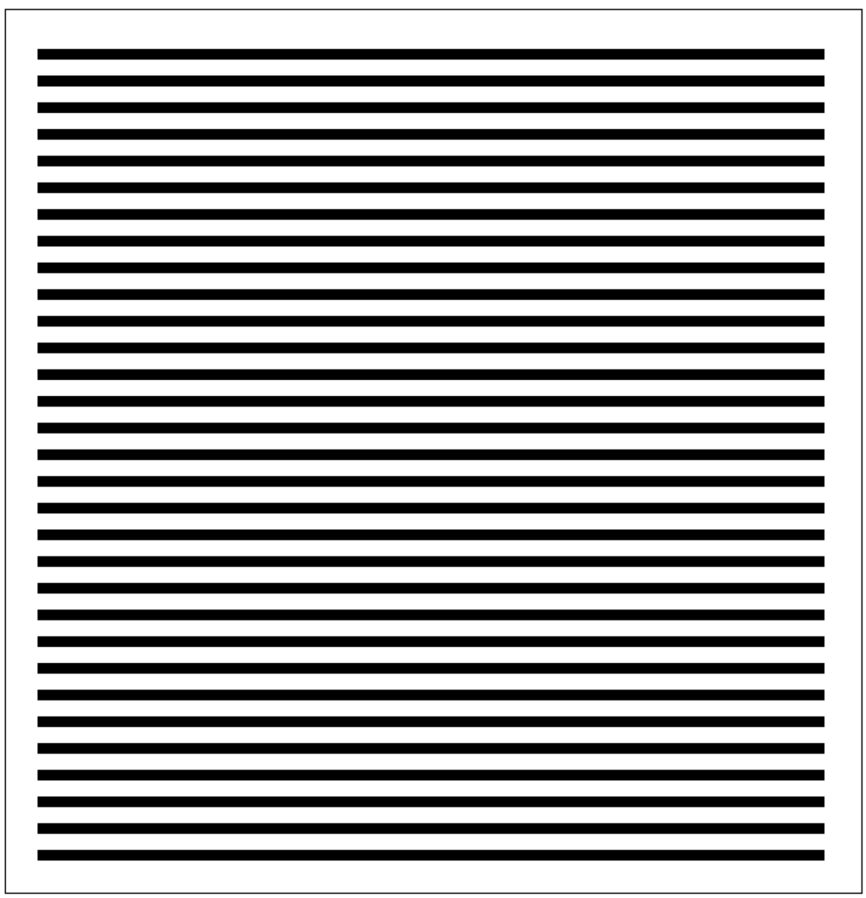


Figure 7. Pattern of stripes (adopted from Wilkens and Nimmo-Smith, 1987).

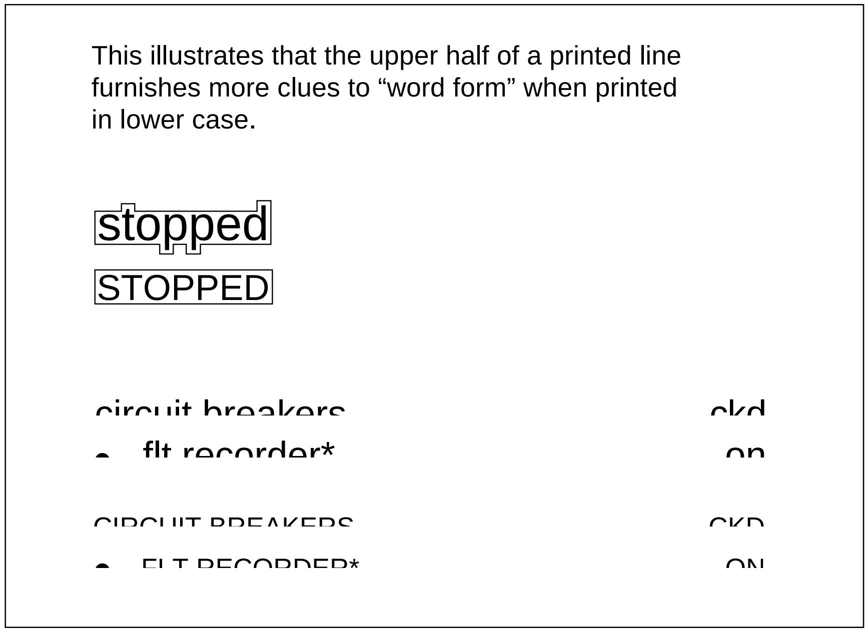


Figure 8. Word form in lower and upper case (adopted from Tinker, 1963).

- **Long chunks of text should be set in lower case.**
- **If upper case is required, the first letter of the word should be made larger in order to enhance the legibility of the word.**

3. DURING READING OF UPPER-CASE WORDS, PERCEPTION OCCURS IN A CHARACTER-BY-CHARACTER ORDER, THEREBY REDUCING THE SPEED OF READING AND READABILITY OF THE ENTIRE WORD.

4. The pattern or shape of a familiar word is stored in the human memory. While reading text, a matching sequence occurs between the observed word and the memory patterns stored in the brain. The more unique the patterns of the word, the easier it is to perform the matching sequence.

5. RESEARCH SUGGESTS THAT SUCCESSIVE LINES OF PRINTED TEXT, COMPOSING A PATTERN OF "STRIPES," MAY INDUCE DISCOMFORT AND ANOMALOUS VISUAL EFFECTS TO THE READERS (SEE FIGURE 7) (WILKINS AND NIMMO-SMITH, 1987). THE LACK OF ASCENDERS AND DESCENDERS MAY FURTHER INTENSIFY THIS EFFECT.

6. Lower-case words consist of characters that have ascenders (the vertical stroke of "d") and descenders ("p," "q"), that contribute to the unique shape and pattern of a word. This makes the lower-case word-form appear more "characteristic." Conversely, an upper-case word appears like a rectangular box with no distinguishable contour (Figure 8).

Another explanation of the superior legibility of lower-case text is the combination of a capital letter and lower-case characters at the beginning of a sentence and/or proper names. Research has shown that visual emphasis given to the first letter of a word will significantly improve the speed of a search. This finding is true for lower-case words as well as for upper-case words combined with a larger first character (Philips, 1979). This can be useful when a documentation designer decides to make a distinction by using typographical features such as lower- and upper-case words and still maintain discriminability and search speed (Circuit, CIRCUIT). It is worth mentioning here that most flight-deck documentation and checklists used today are set in upper case. Figures 9 and 10 are a comparison of lower-case and upper-case format of a checklist.

Figure 9. Checklist of a wide-body airplane set in upper-case.

BEFORE STARTING ENGINES

CIRCUIT BREAKERS .... CKD
- FLT RECORDER* .... ON
- VOICE RECORDER* .... TESTED

OXY .... ON & 100%, SPKRS CKD
- ANTI-SKID* ....TESTED & NORM

EVACUATION SIGNAL.................................. ARMED
COMPASSES ....CKD
ANNUNCIATOR LIGHTS............. TESTED & BRIGHT
LO SPD AIL..NORM & AUTO
RUD TRAV/PITCH FEEL .... ON
- EXTERIOR LTS* ....ON (OR OFF)

SERVO CONTROLS... ON
- ENG START PANEL* .... CRANK/START ABORT

FIRE HANDLES .... up
- NO SMOKING* .... ON

EMER EXIT & MIN CAB LTS..................ARMED & ON
- ICE PROTECTION* .... OFF
- WINDOW HEAT* ....LO & ON

RADIO MASTER SWS.. ON
AUTO FLT/NAV ....CKD
INST SWS .... CKD & NORM
- FLT INSTS & ALTMS* .... CKD & SET

GPWS .... TESTED
- ENG INST/N_1 COMPUTER* .... CKD & TESTED
- GEAR LEVER*...................................... DN, 3 GREEN

OMEGA* ....CKD
FLAP/SLAT LEVER .... W/GAGES
SPEED BRAKES .... RETRACT/DISARMED
FUEL LEVERS .... OFF
- PK BRKS & PRESS*................................. SET & CKD
- RADAR & TRNSPDR* .... STBY
- TRIM CONTROLS* .... SET

MAN DEPRESS VLV ....CLOSED
- ELEC PANEL*... CKD & SET
- BATTERIES*.. NORM

FUEL PANEL .... CKD & SET
- FUEL QUANTITY* .... ___ LBS, CTRS RESET
- HYD PANEL* .... CKD & SET

OIL QUANTITY*... ___ QTS
- APU* ....CKD

FIRE & SMOKE DETECTION......................... TESTED
- AIR COND & PRESS*................................ CKD & SET
- RAM AIR INLET SWITCH* .... NORM CLOSE
- VENT PNL* .... CKD/BLOWER OFF

TEST PANEL ....NORM & OFF
PROBE HEAT .... CKD & OFF

Figure 10. Checklist of a wide-body airplane set in lower-case.

Before Starting Engines

- Circuit breakers .... ckd
- ● Flt recorder* .... on
- ● Voice recorder* .... tested
- Oxy .... on & 100%, spkrs ckd
- ● Anti-skid* .... tested & norm
- Evacuation signal .... armed
- Compasses .... ckd
- Annunciator lights.............. tested & bright
- Lo spd AIL .... norm & auto
- Rud trav/pitch feel .... on
- ● Exterior lts* .... on (or off)
- Servo controls .... on
- ● Eng start panel* .... crank/start abort
- Fire handles .... up
- ● No smoking* .... on
- Emer exit & min cab lts .... armed & on
- ● Ice protection* .... off
- ● Window heat* .... lo & on
- Radio master sws................................. on
- Auto flt/nav .... ckd
- Inst sws .... ckd & norm
- ● Flt insts & altms* .... ckd & set
- GPWS .... tested
- ● Eng inst/N_1 computer* .... ckd & tested
- ● Gear lever* .... dn, 3 green
- ● Omega* .... ckd
- Flap/slat lever .... w/gages
- Speed brakes .... retract/disarmed
- Fuel levers .... off
- ● Pk brks & press* .... set & ckd
- ● Radar & trnspdr* .... stby
- ● Trim controls* .... set
- Man depress vlv .... closed
- ● Elec panel* .... ckd & set
- ● Batteries* .... norm
- ● Fuel panel .... ckd & set
- Fuel quantity* .... ___ lbs, ctrs reset
- ● Hyd panel* .... ckd & set
- ● Oil quantity* .... ___ qts
- ● APU* .... ckd

CIRCUIT BREAKERS ....
- Flt recorder* .... on
- Voice recorder* ....
  Oxy ....
- Anti-skid* ....
  Evacuation signal ....

12 Point Helvetica
(x height = .125 ;1 point = 1/100 of an inch)

CIRCUIT BREAKERS CKD
- Flt recorder* .... on
- Voice recorder* ....
  Oxy ....
- Anti-skid* ....
  Evacuation signal ....

11 Point Helvetica
(x height = .110 ;1 point = 1/100 of an inch)

CIRCUIT BREAKERS .... CKD
- Flt recorder* .... on
- Voice recorder* ....
  Oxy ....
- Anti-skid* ....
  Evacuation signal ....
  Annunciator lights . tested

10 Point Helvetica
(x height = .094 ;1 point = 1/100 of an inch)

CIRCUIT BREAKERS .... CKD
- Flt recorder* .... on
- Voice recorder* ....
  Oxy ....
- Anti-skid* ....
  Evacuation signal ....
  Annunciator lights .... tested
  Lo spd AIL ..... norm & auto

9 Point Helvetica
(x height = .081 ;1 point = 1/100 of an inch)

3.4 Font Height (Typesize)

Measurement. When specifying the height of a font and spacing (both vertically and horizontally), the designer should be aware that there are several scales and methods of measurement. The traditional printer's "point" used for typesize-height equals 1/100 of an inch; however, when it is used to measure distance between lines, words, etc., a point is approximately equal to 1/72 of an inch. This can be confusing. Another area of confusion is the method of measurement. Lower-case letters can be measured in two different methods. One is the overall size of the character, measured from the bottom of the descender (p) to the top of the ascender (d). The other is the actual height of a character that lacks ascenders or descenders ("o," "r," "x"); this measurement is called the "x height" of a font. The designer should also note that while a "point" on a Macintosh computer is exactly 1/72 of an inch, a "point" on a professional typesetter is slightly less than 1/72 of an inch (L. E. Gifford, personal communication, February, 1992).

Font height vs. viewing condition. Most of the information in the literature regarding font height is presented in graphs. These graphs usually indicate the relationship between character height, viewing distance, illumination level, stroke width, and visual acuity (Woodson, 1981; Howett, 1983). The graph in Figure 11 depicts the recommended relationship between character height and viewing distance for different illumination levels and alphanumeric status (static, dynamic). Although this graph was designed for labels on instrument panels, it also can be used as a guide for character size (Woodson and Conover, 1964). When using this graph to determine the height of a lower-case character, the distinction between the overall typesize and "x" height should be considered.

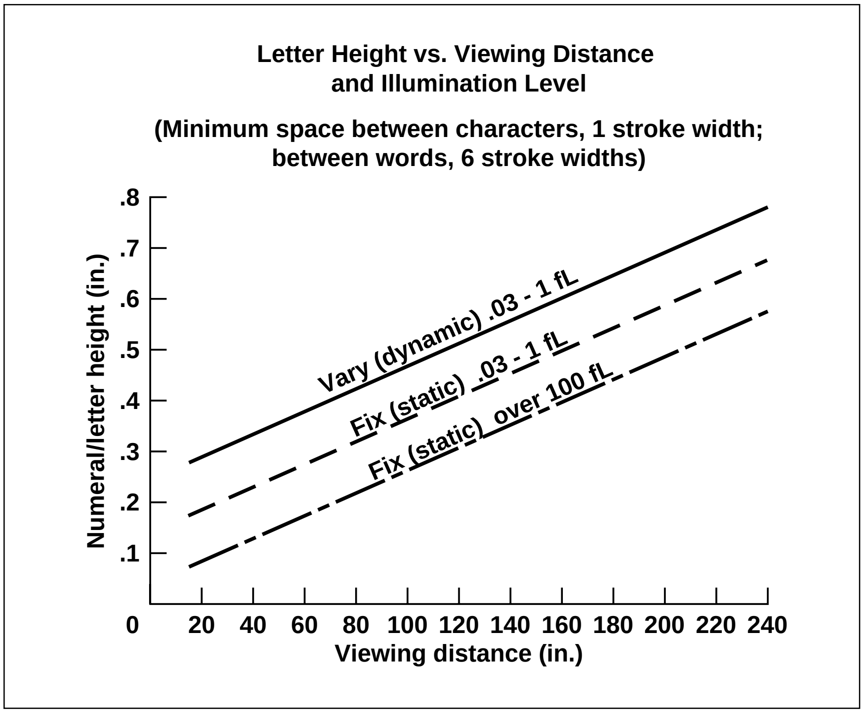


Figure 11. Letter height (adopted from Woodson et. al. 1964).

Two variables are manipulated in Figure 11: viewing distance and illumination levels. The normal reading distance is about 16-24 inches from the eye. However, this is dependent on cockpit layout, company procedures, and personal preference. It is not uncommon to see checklists and approach plates mounted on the yoke clip, placed on the forward panel, or on a clip below the side window. In all these cases the distance from the eye to the print may vary considerably. The other variable, luminance, is defined as the amount of light (per unit) reflected from the surface. This unit is measured in foot lambert (fL). The minimum recommended level of luminance in Boeing's cockpits is 0.2 fL. (R. J. Braune, personal communication, January 1989). Thus, for these cockpits the entry to the graph in figure 11, will be on the dashed line.

In addition to the above, other graphs are available to determine character height. These graphs are presented in Figures 12 and 13. The designer should be conservative in using the data from these graphs since no information regarding the subject group is presented. Furthermore, there are no available data to indicate whether the information presented in these graphs (Kubakawa, 1969; Sanders and McCormick, 1987; Woodson, 1981), was constructed from experimental data or simply by calculations of the visual angle.

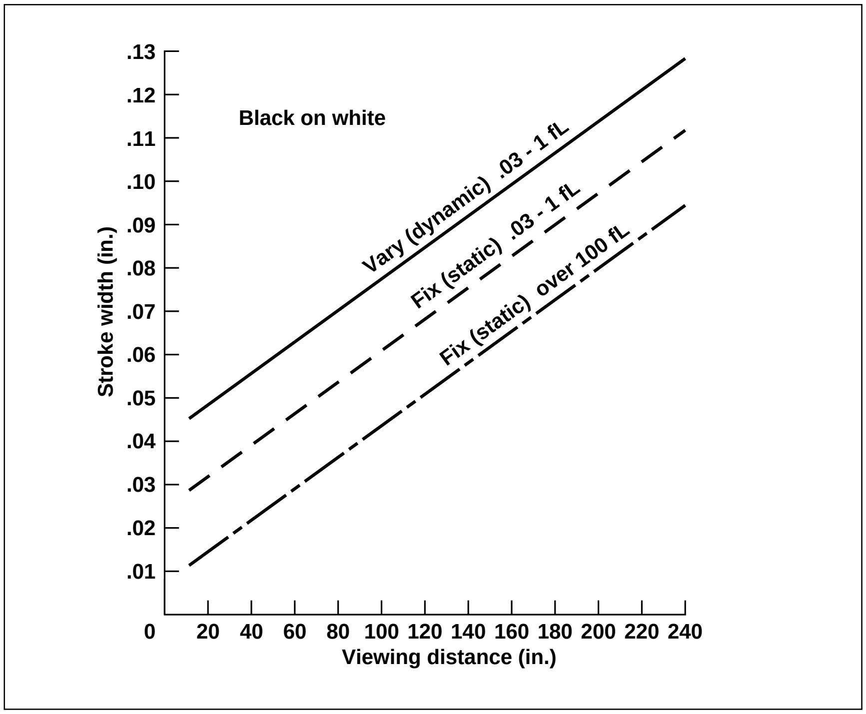


Figure 12. Stroke width vs. viewing distance and illumination level (adopted from Woodson, 1981).

Luminance level. This factor, as mentioned above, affects legibility. The minimum luminance level reflected from the paper can drop to 0.16 fL when no direct light is on the document. de Ree (1991) conducted an experiment to evaluate different layout formats for emergency checklists. He reported that search time is significantly slower in dark flight conditions and stated that "perhaps the intensity of the reading lights on the flight deck has to be increased to improve this situation" (p. 165).

The table presented in Figure 14 was developed for designing labels for instrument panels at a viewing distance of 28 inches. In cases where the viewing distance is not 28 inches, the table allows for a linear conversion to different viewing distances (Heglin, 1973).

Recommendation for font height in the literature. Grether and Baker (1972) provided several recommendations for checklist typesize in a chapter titled "Design Recommendations for Decals, Check Lists, and Labels" (pp. 107-108). They recommend that for a viewing distance of 28 inches or less, and for illuminance below 1.0 fL, the font height should be at least 0.20 inch. When the illuminance is above 1.0 fL, the font height can be reduced to 0.10 inch. These data are what the NTSB referred to in their analysis of the Air New Orleans BAe-3101 accident (cited in the introduction of this report) (NTSB, 1988).

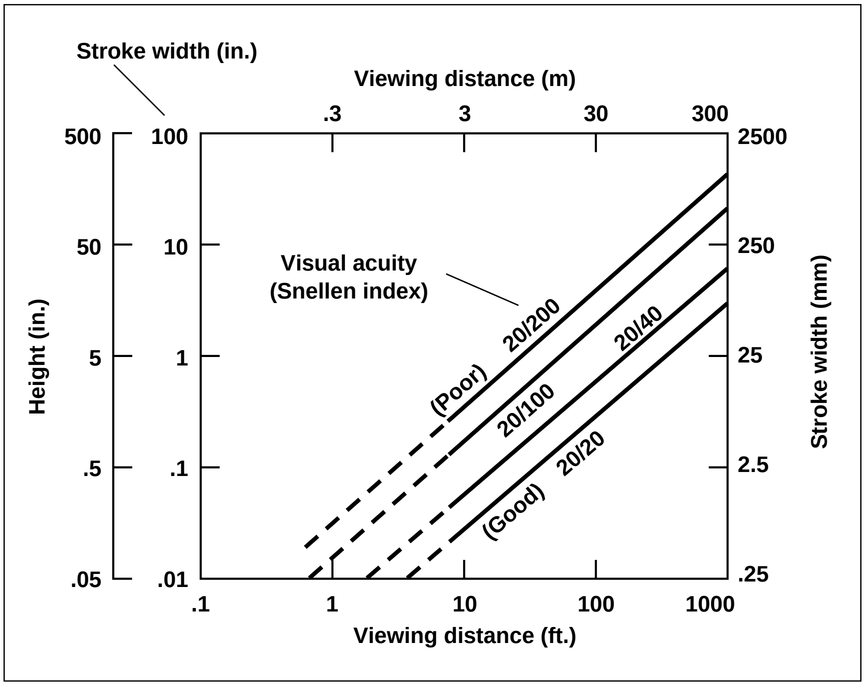


Figure 13. Height vs. viewing distance and visual acuity (adopted from Woodson, 1981).

This recommendation, however, must be assessed with the following in mind:

1. The recommendation regarding checklists is coupled with labels and decals, which are used differently on the flight deck (labels are fixed to the panel).

2. This recommendation assumes the use of upper-case characters.

3. There is no mention of color or contrast level.

4. The recommendation is based on a height vs. viewing distance graph and not on an empirical experiment (W. F. Grether, personal communications, 1988).

While evaluating typesize for optimum reading, Tinker (1963) experimented with typesizes that ranged from 0.08 to 0.14 inches, all set in lower-case roman. He reported that a 0.11 inch typesize was read significantly faster than 0.10 inch. The majority of the readers judged the 0.11 inch typesize as the most legible.

To summarize, it appears from the above graphs and tables that a font size between 0.14 and 0.20 inches is suitable for checklists and other critical documentation used on the flight deck. However, for practical reasons of limited space on a single page (in case of a checklist) and simply because of increased volume (in case of manuals), this range (0.14-0.20) may not be efficient (Turner and Huntley, 1991). Again, one must not forget that any determination of suitable font height must be combined with accompanying typographical factors such as horizontal spacing, line width, vibration levels, color, etc., before any final judgement concerning the legibility of any typesize can be extracted. How far can the designer go in reducing the font size of important flight documentation? The answer is based on the specifics of each case. What is clear, from reviewing checklists, manuals, and these data, is that a font size below 0.10 inch for any important flight-deck document is not recommended.

- **When specifying font height or accessing graphs to determine the size of a lower-case character, the distinction between "x" height and overall size should be made.**
- **As a general recommendation, the "x" height of a font used for important flight-deck documentation should not be below 0.10 inch.**

NUMERAL/LETTER HEIGHT FOR 28-INCH VIEWING DISTANCE
For other viewing distances, multiply the value by [*distance (in inches)/28*].

	HEIGHT OF NUMERALS AND LETTERS (IN.)	
	Low luminance (down to 0.03 fL)	High luminance (1.0 fL and above)
Critical markings – position variable (numerals on counters and settable or moving scales)	0.20 to 0.30	0.12 to 0.20
Critical markings – position fixed (numerals on fixed scales, control and switch markings, emergency instructions, etc.)	0.15 to 0.30	0.10 to 0.20
Noncritical markings (instrument identification labels, routine instructions, any marking required only for initial familiarization)	0.05 to 0.20	0.05 to 0.20

Figure 14. (adopted from Howett, 1983).

3.5. Stroke Width and Height-to-Width Ratio

- **The recommended height-to-width ratio of a font that is viewed in front of the observer is 5:3.**

Stroke widths affect the ability of the eye to differentiate between the stroke of the character ("I") and the space inside the character ("E," F"). The width of a stroke is a function of height of the character. Most human factors data books recommend the use of a height-to-width ratio of 5:3 (Heglin, 1973; Sanders and McCormick, 1987; Woodson, 1981).

The reader should note that this recommended ratio is applicable only when the document is in front of the observer (a 90 degrees angle between the line-of-sight and the document). Fixed display, such as a mechanical checklist (which is mounted on a panel in the cockpit), may not be located in front of the pilot. Therefore, in designing a display that is viewed from an unfavorable viewing angle (which may artificially reduce the *apparent* width of the character), a different height-to-width ratio (e.g., 5:4) should be considered in order to increase the *actual* width of the character (Heglin,1973).

3.6. Horizontal and Vertical Spacing

The vertical and horizontal spacing between characters affects the legibility and readability of the text especially when the font height is small. Increasing the vertical spacing between lines reduces the probability of adverse visual effect from the "pattern of stripes" (Figure 8). Wilkins and Nimmo-Smith research (1987) suggests that "judgements of the clarity of text... are critically dependent on the spacing of the lines, more so than the overall density of lettering on the page. As a result, the clarity of text can potentially be increased at no extra cost by increasing the separation between the lines slightly and decreasing slightly the mean horizontal spacing between the centers of letters, within the limits of conventional typography" (p. 1718). In addition, the "opening" of an appropriate vertical space between lines reduces the chance of optical bridging between adjacent lines—a critical factor for the design of any list-type documentation. The recommended vertical space between lines is 25-33 percent of the overall size of the font (Tinker, 1963; Woodson, 1981). The horizontal space between characters should not be less than one stroke width. As for word spacing, the gap between characters should be large enough to allow grouping of words. This is achieved when the word space is 25 percent of the overall height, and, again, not less than one stroke width (Hartley, 1985; Woodson, 1981). Figures 15 and 16 are variation on horizontal and vertical spacing.

- **The vertical spacing between lines should not be smaller than 25-33% of the overall size of the font.**
- **The horizontal spacing between characters should be 25% of the overall size and not less than one stroke width.**

Circuit breakers .... ckd
● Flt recorder* .... on
● Voice recorder* .... tested
Oxy .... on & 100%, spkrs ckd
● Anti-skid* .... tested & norm
Evacuation signal .... armed
Compasses .... ckd
Annunciator lights...... tested & bright

Lo spd AIL .... norm & auto
Rud trav/pitch feel .... on
● Exterior lts*....................... on (or off)
Servo controls .... on
● Eng start panel*...... crank/start abort
Fire handles .... up
● No smoking*................................ on
Emer exit & min cab lts . armed & on
● Ice protection* .... off
● Window heat* .... lo & on

Optimal

Radio master sws......................... on
Auto flt/nav .... ckd
Inst sws .... ckd & norm
● Flt insts & altms* .... ckd & set
GPWS .... tested

Figure 15. Variations—Vertical Spacing.

Circuit breakers .... ckd
● Flt recorder* .... on
● Voice recorder* .... tested
Oxy .... on & 100%, spkrs ckd
● Anti-skid* .... tested & norm
Evacuation signal .... armed
Compasses.................................. ckd
Annunciator lights .... tested & bright
Lo spd AIL .... norm & auto

Rud trav/pitch feel .... on
● Exterior lts* .... on (or off)
Servo controls .... on
● Eng start panel*...... crank/start abort
Fire handles .... up
● No smoking* .... on
Emer exit & min cab lts . armed & on
● Ice protection* .... off

Optimal

● Window heat* .... lo & on
Radio master sws .... on
Auto flt/nav .... ckd
Inst sws .... ckd & norm
● Flt insts & altms*............ ckd & set
GPWS .... tested

Figure 16. Variations—Horizontal Spacing.

3.7. Line Length

Line length is an important factor for flight-deck documentation because the designer will always try to minimize the size of checklists, manuals, and other documentation. A traditional checklist layout is very similar to an index list or table of contents. A common problem with these layouts is the large gap between the entry and the corresponding information (Challenge <-......-> Response). The wider the gap, the greater the chance that the reader will make a mistake through perceptual misalignment (Wright, 1981). Although most airlines try to minimize this gap in order to fit two checklist columns on one page, some checklists cover the entire width of an 8.5 by 11 inch piece of paper. This makes them more prone to such misalignment. For additional information about the effect of different line length on the legibility of print see Tinker (1963, pp. 77-87). Figure 17 compares column size for a checklist of a wide-body aircraft.

●	No smoking*	on
	Emer exit & min cab lts	armed & on
●	Ice protection*	off
●	Window heat*	lo & on
	Radio master sws	on
	Auto flt/nav	ckd
	Inst sws	ckd & norm
●	Flt insts & altms*	ckd & set
	GPWS	tested
●	Eng inst/N_1 computer*	ckd & tested
●	Gear lever*	dn, 3 green

	Circuit breakers	ckd
●	Flt recorder*	on
●	Voice recorder*	tested
	Oxy	on & 100%, spkrs ckd
●	Anti-skid*	tested & norm
	Evacuation signal	armed
	Compasses	ckd
	Annunciator lights	tested & bright
	Lo spd AIL	norm & auto
	Rud trav/pitch feel	on
●	Exterior lts*	on (or off)
	Flap/slat lever	w/gages
	Speed brakes	retract/disarmed
	Fuel levers	off
●	Pk brks & press*	set & ckd
●	Radar & trnspdr*	stby
●	Trim controls*	set
	Man depress vlv	closed
●	Elec panel*	ckd & set
●	Batteries*	norm
●	Fuel panel	ckd & set
	Fuel quantity*	___ lbs, ctrs reset

Figure 17. Comparison of column size.

3.8. Face (Italic, Bold) and Underline

- **Avoid using long strings of text set in italics.**
- **Use primarily one or two typefaces for emphasis.**

Several experiments discuss the effects of different type faces on legibility. In one experiment preformed by Tinker (1965), italic face was read 2.7 per cent slower than roman lower-case (with an equal "x"- height). Furthermore, 96% of the 224 subjects who participated in this study judged that italic is less legible than a regular roman font (see Figure 18). Bold face was read at the same reading speed as lower-case text. However, the majority of the subjects (70%) commented about the unpleasingness of the text as compared to plain roman font. Results of another experiment (Antersijn and de Ree, 1989) indicated "that bold and medium face do not differ in readability, even under low illumination" (p. 291); suggesting that there is no apparent advantage in printing long chunks of text in bold face. Nevertheless, bold face can be safely and advantageously used for contrast and emphasis. Although faces can highlight a specific item on a document, over usage of this typographical technique can be inefficient. EMPLOYING too *many* **faces** for ***contrast*** , **emphasis**, and ATTENTION-*seeking* **may** be **CONFUSING** and can ***dramatically*** *reduce* the *legibility*, and *readability* of the PRINTED matter (Hartley, 1981).

- *No smoking* .... on*
  Emer exit & min cab lts .. armed & on
- *Ice protection*.............................. off*
- *Window heat* .... lo & on*
  Radio master sws .... on
  Auto flt/nav................................. ckd
  Inst sws........................... ckd & norm
- *Flt insts & altms*................ ckd & set*
  GPWS.................................... tested
- *Eng inst/N_1 computer* .. ckd & tested*
- *Gear lever* .... dn, 3 green*
- *Omega* .... ckd*
  Flap/slat lever .... w/gages
  Speed brakes .... retract/disarmed

- No smoking* .... on
  Emer exit & min cab lts .. armed & on
- Ice protection*.............................. off
- Window heat* .... lo & on
  Radio master sws .... on
  Auto flt/nav.................................. ckd
  Inst sws.......................... ckd & norm
- Flt insts & altms*............... ckd & set
  GPWS................................... tested
- Eng inst/N_1 computer* . ckd & tested
- Gear lever* .... dn, 3 green
- Omega* .... ckd
  Flap/slat lever .... w/gages
  Speed brakes .... retract/disarmed

Figure 18. Italic vs. Non-Italic face.

- **Use black characters over a white background for most cockpit documentation.**

- **Avoid using white charac ters over a black back ground in normal line op erations. However, if this is desired:**

1. **Use minimum amount of text.**
2. **Use relatively large typesize.**
3. **Use sans-serif to minimize the loss of legibility.**

STAB TRIM FAILURE

3.9. Contrast

Woodson (1981) recommends the use of dark characters over a light background for normal illumination conditions. However, when the observer must maintain a dark adaption condition, Woodson recommends a light character over a dark background. To evaluate this condition, Tinker (1965) manipulated and measured the following variables in a laboratory experiment: speed of reading, subject's preference, eye movement measurements, recognizability in the peripheral vision, and discriminability at a distance (when looking straight ahead). For all the above dependent measures, the definite advantage of black print on a white background was proven. Black over white is also recognized at a larger angle from the line-of-sight. This is important in the cockpit environment as documents cannot always be held in optimal viewing angles. Nevertheless, white over black may provide a good method to emphasize a title (such as a name of an emergency checklist).

3.10. Color Coding

A character and its background may differ in the amount of light they reflect and color. Howett (1983) reported that when the character and its background are viewed from a short distance, more visual difference can be reinforced by using large luminance differences than by employing large chromatic (color) differences. In other words, the contrast is more important than color differences in determining visibility of the characters. For example, red and blue have considerable color contrast, yet very small luminance contrast.

Some airlines use color coding to distinguish between different checklists in the flight manual. Black print over white background is used for the normal checklists and performance graphs, black over yellow for the abnormal checklists, and black over light red for the emergency checklists. If one wishes to employ color in flight-deck documentation, Figure 19 presents the recommended color contrasts. Yellow characters over black, and blue over white are probably the best choice of color contrast.

Tinker (1963) performed several experiments to determine the effect of color contrast on legibility. In a test to investigate the perception of different colored numerals at a glance, black characters over yellow background showed the best results. Tinker gives the following recommendations regarding the use of dark characters over colored background:

1. The reflection percentage of the background should be at least 70 percent.

2. The luminance ratio between the character and the background should be about 1:8.

3. The typesize should be 0.10 inch or greater.

The human peripheral vision is limited in color sensitivity. Figure 20 shows that some colors are recognized at a greater angle away from the line-of-sight than others. When a pilot uses colored document during night operations, certain colored ambient lighting (usually red or green) will effect the color of the print and/or its background. The data presented in Figure 21 indicates the effect of colored light on colored objects (Kybakawa, 1969).

Conditions	Characters	Background
Average or higher levels and quality of illumination	Black	White
	Black	Yellow
	White	Black
	Dark blue	White
	White	Dark red, green, and brown
	Black	Orange
	Dark green and red	White
	White	Dark gray
	Black	Light gray
Poor level and quality of illumination	Black	White
	White	Black
	Black	Yellow
	Dark blue	White
	Black	Orange
	Dark red and green	White
Dark adaptation required	White	Black
	Yellow	Black
	Orange	Black
	Red*	Black
	Blue and Green	Black

*Low-level red light is required to maintain the lowest dark adaptation level.

Figure 19. Suggested color contrast (adopted from Woodson, 1981).

- **Black over white or yellow are recommended for cockpit documentation.**
- **Avoid using black over dark red, green, and blue.**

Colors have a psychological effect on human beings, mainly because we associate certain colors with past experiences. Some colors convey the feeling of warmth, while others appear cold (Woodson, 1981, cited from U.S. Navy Shipboard Color Coordination Manual, NAVESEA 0929-002-7010). The color red is usually associated with danger, green with normal, and amber with caution; and so are the colors of indicators in the cockpit (Federal Aviation Regulation 25.1322). For example, black characters over a yellow background, will always be associated with caution for most military pilots (diagonal yellow and black stripes are used in many military cockpits to indicate caution conditions).

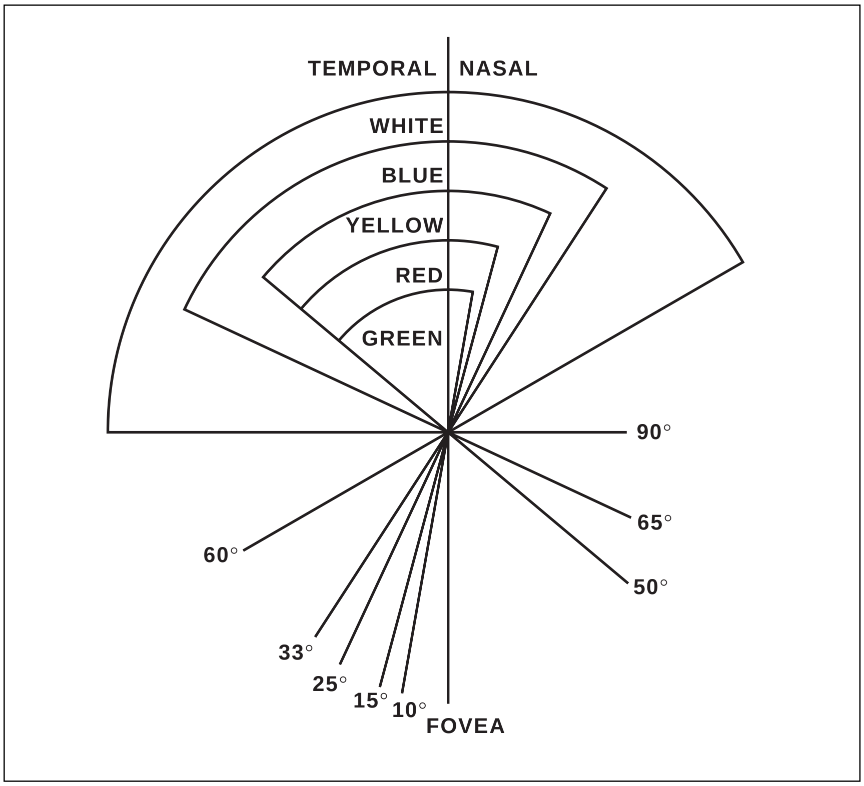


Figure 20. Recognition of color as function of angular displacement from line-of-sight (Adopted from Heglin, 1973).

EFFECT OF COLORED LIGHT ON COLORED OBJECTS				
Object color	Red Light	Blue Light	Green Light	Yellow light
White	LIght Pink	Very Light Blue	Very Light Green	Very Light Yellow
Black	Reddish Black	Blue Black	Greenish Black	Orange Black
Red	Brilliant Red	Dark Bluish Red	Yellowish Red	Bright Red
Light Blue	Reddish Blue	Bright Blue	Greenish Blue	Light Reddish Blue
Dark Blue	Dark Reddish Purple	Brilliant Blue	Dark Greenish Blue	Light Reddish Purple
Green	Olive Green	Green Blue	Brilliant Green	Yellow Green
Yellow	Red Orange	Light Reddish Brown	Light Greenish Yellow	Brilliant Light Orange
Red Orange	Brown Red	Bluish Brown	Dark Olive Brown	Brownish Orange

Figure 21. The effect of colored light on colored objects (adopted from Kubakawa, 1969).

3.11. The Cumulative Effect of Improper Typography

For a given printed document, it is obvious that the combination of two or more non-optimal or marginal conditions will have a greater effect on legibility and/or readability. Therefore, when specifying the graphical appearance of flight-deck documentation, the designer must be careful in combining several non-optimal conditions (white print over black background, italic and bold faces, colors, small typesize, etc.). Such combinations will tend to reduce the overall efficiency of using the document (see Figure 22). Tinker (1963) conducted several experiments to determine to what extent these combinations could be predicted. He found a progressive loss of legibility due to multiple non-optimal conditions such as decrease in typesize, increase in line length, changes in font type, etc. However, his findings indicate that the combined effect of non-optimal conditions cannot be predicted by merely adding the effect of each sub-optimal condition.

• *Flt recorder* .... on*
• *Voice recorder* .... tested*
Oxy .... on & 100%, spkrs ckd
• *Anti-skid* .... tested & norm*
Evacuation signal .... armed
Compasses .... ckd
Annunciator lights .... tested & bright
Lo spd AIL .... norm & auto
Rud trav/pitch feel .... on

Servo controls .... on
• Eng start panel* .... crank/start abort
Fire handles .... up
• No smoking* .... on

• Flt recorder* .... on
• Voice recorder* .... tested
Oxy .... on & 100%, spkrs ckd
• Anti-skid* .... tested & norm
Evacuation signal .... armed
Compasses .... ckd
Annunciator lights .... tested & bright

Figure 22. The combined effect of several sub-optimal typographical conditions.

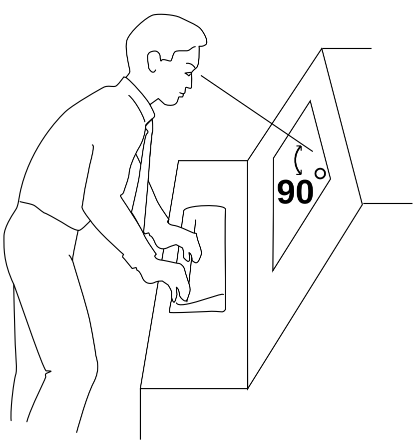
4. Several Environmental Conditions Influencing Reading

- **Use anti-glare plastic to laminate documents.**

4.1. Glare

Several quick reference handbooks (QRH) and checklists used by several airlines and some military units are laminated to protect them from wear and tear. Others are inserted into a plastic casing and are pulled out only when a new revision is issued. In choosing a plastic cover or lamination, an anti-glare plastic that diffuses the light is recommended; otherwise, some rays from the light source will be reflected to the pilot's eyes. This is commonly observed in a dim cockpit when the pilot-light is directed to a document covered with glossy plastic. Tinker (1963) conducted several experiments to find the effect of surface glare on reading. He tested with three types of surface reflection (22.9%, 85.8% and 95.1%). The results showed a significant reduction in reading speed of the high glossy material (95.1% reflection). Furthermore, 75% of the subjects (sample size was 224), preferred the non-glossy paper.

Other types of glare are common during night operation. When the printed matter is lit by a direct light (such as a flashlight or pilot-light) and the pilot's eyes shift between the document and the dark window or panels, the eyes must constantly readapt to different levels of luminance. Severe differences in luminance between the document in-front of the observer (the critical vision) and the surroundings (peripheral vision), can lead to a reduction in visual discrimination, reading speed, and comfort. Furthermore, any strong light source (direct-sunlight, radar scope) that is not shielded from the field of vision, will cause disability glare. As the light source gets closer to the line-of-sight an increased reduction in visual efficiency will be experienced (Sanders and McCormick, 1987).



4.2. Slope and Angular Alignment for Reading

Optimum reading conditions are achieved when the printed copy is held flat and the plane of the copy is at 90 degrees to the line-of-sight. In this condition, the printed alphanumerics are seen at their exact form. As the printed copy is tipped away, the geometric form of the alphanumeric (width-height ratio) is distorted. Several experiments were conducted to investigate the reduction in legibility due to this factor. One experiment revealed that a document with a typesize of 0.10 inch aligned at 105, 120, and 135 degrees from the line-of-sight, retarded reading speed by 1.5, 5.3, 9.8 percent respectively (Tinker, 1963, cited from Skordhal, 1958).

When the printed matter was held at 90 degrees to the line-of-sight, but the lines of text were at angle (tilted to the side), a retardant in speed of reading and a reduction in visibility of the alphanumeric character occurred. One explanation for this is that when the printed document is tilted away the eyes have to move obliquely from one fixation pause to another along the line of text. This strains additional eye muscles and makes this practice of reading more difficult.

- **Ensure that the quality of the print and the paper is well above normal standards—poor quality of print and paper will effect legibility and readability.**

4.3. The Quality of Paper and Print

The thickness of the material, i.e., the paper on which the document is written, can also affect the legibility of print. It is not uncommon to see pilots hold their checklist card between the eyes and the window. It is therefore recommended that documentation should be printed on a thick opaque paper. This will prevent the print on the other side of the document from showing through and blurring the print on the front.

The visual impression of printed matter plays an important role in the attraction and motivation of the pilot to read and use it (Hawkins, 1987). The layout of the document and the organization of the procedures in the aircraft operating manual is an important factor in minimizing search time to locate emergency procedures (Degani and Wiener, in progress; de Ree, 1991; Flight Safety Focus, 1985). Another important factor is the quality of the actual print that comes out from the print shop. The print should be clear and the boundaries between strokes and spaces should be sharp and distinguishable (for a bad example, see the BAe 3101 checklist in Figure 1). Likewise, several checklists obtained by the author from one major U.S carrier appeared to be degraded as the result of several copier machine iterations; vertical spacing between characters was reduced, and strokes discrimination was poor. It was difficult to read the checklist.

- **The designer must assess the age groups of the pilots that will be using the documentation and take a very conservative approach in assessing information obtained from graphs and data books.**

4.4. The Effect of Pilot's Age on Reading

There is a 50% reduction in retinal illumination at the age of 50 years compared to 20. This reduction in the level of retinal illumination also plays a role in slowing the rate as well as the level of dark adaptation. The thickness of the eye's lenses is the major cause of farsightedness among the middle aged and elderly. As the lens thickens, it becomes yellow and reduces the transmission of blue light through it. Thus, older people have more difficulty in differentiating between colors. This effect is mainly seen in the blue-green and red regions of the hue, and therefore should be considered in designing a colored document (Sanders and McCormick, 1987; Tinker, 1965). These effects will only be amplified while reading critical text under adverse environmental conditions in the cockpit. It should be noted here, that in all the tables and figures in the proceeding sections, there is no indication of the age group of the subjects. As some of the data were prepared for the military, the reader may very well assume that in most cases the subjects employed in these studies were young recruits.

5. Final Note

It will probably take a decade or two until most commercial airplanes in the U.S. will fall into the category of "paper-less cockpits." These future cockpits will have electronic checklists and electronic libraries containing most of the information that is now in print (O'Lone, 1990, November 5; Riley, 1990). Meanwhile, paper (manuals, checklists, dispatch papers) will dominate as a form of presentation for this type of information on the flight deck. Nevertheless, there is almost no applied research on how to present flight-deck documentation in the most efficent manner. The author believes that this is a clear gauge to the lack of attention given to these devices by most high risk industries (nuclear power, process control, military, maritime, and more). It is puzzling to note this deficiency in flight-deck documentation of several major U.S. airlines.

This report was intended to fill an existing "vacuum" of information concerning typographical and graphical aspects of flight-deck documentation. The author hopes that NTSB recommendation A-88-72, will lead human factors specialists to investigate these issues and provide specific guidelines and answers concerning optimal methods of presenting critical documentation. Similar issues pertaining to computer generated displays such as electonic checklist and electronic library systems should also be investigated. If proper typographical and graphical display design will not be implemented, then it is possible that the same problem of hard-to-read displays may perpetuate into these new systems.

6. List of Design Recommendations

This section lists together all the design recommendations from the previous sub-sections. These recommendations are not specifications. They only form a baseline, which is based exclusively on the author's subjective interpretation of the data. Each recommendation should be carefully evaluated by the designer based on the type of documentation, usage, criticality, and the target population. The recommendations are listed according to the order of sections in this report (sub-section numbers are given in parenthesis):

1. Sans-serif fonts are usually more legible than fonts with serifs. (3.2)

2. Avoid using a font that has characters that are too similar to one another, as this will reduce the legibility of the print. (3.2)

3. Avoid using dot matrix print for critical flight-deck documentation. (3.2)

4. Long chunks of text should be set in lower case. (3.3)

5. If upper case is required, the first letter of the word should be made larger in order to enhance the legibility of the word. (3.3)

6. When specifying font height, or accessing graphs to determine the size of a lower-case character, the distinction between "x" height and overall size should be made. (3.4)

7. As a general recommendation, the "x" height of a font used for important flight-deck documentation should not be below 0.10 inch. (3.4)

8. The recommended height-to-width ratio of a font that is viewed in front of the observer is 5:3. (3.5)

9. The vertical spacing between lines should not be smaller than 25-33% of the overall size of the font. (3.6)

10. The horizontal spacing between characters should be 25% of the overall size and not less than one stroke width. (3.6)

11. Avoid using long strings of text set in italics. (3.8)

12. Use primarily one or two typefaces for emphasis. (3.8)

13. Use black characters over a white background for most cockpit documentation. (3.9)

14. Avoid using white characters over a black background in normal line operations (3.9). However, if this is desired:
    1. Use minimum amount of text.
    2. Use relatively large typesize.
    3. Use sans-serif to minimize the loss of legibility.

15. Black over white or yellow are recommended for cockpit documentation. (3.10)

16. Avoid using black over dark red, green, and blue. (3.10)

17. Use anti-glare plastic to laminate documents. (4.1)

18. Ensure that the quality of the print and the paper is well above normal standards. Poor quality of the print will effect legibility and readability. (4.3)

19. The designer must assess the age groups of the pilots that will be using the documentation, and take a very conservative approach in assessing information obtained from graphs and data books. (4.4)

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13. ABSTRACT ***(Maximum 200 words)***

Many types of paper documentation are employed on the flight-deck. They range from a simple checklist card to a bulky Aircraft Flight Manual (AFM). Some of these documentation have typographical and graphical deficiencies; yet, many cockpit tasks such as conducting checklists, way-point entry, limitations and performance calculations, and many more, require the use of these documents. Moreover, during emergency and abnormal situations, the flight crews' effectiveness in combating the situation is highly dependent on such documentation; accessing and reading procedures has a significant impact on flight safety. Although flight-deck documentation are an important (and sometimes critical) form of display in the modern cockpit, there is a dearth of information on how to effectively design these displays.

The object of this report is to provide a summary of the available literature regarding the design and typographical aspects of printed matter. The report attempts "to bridge" the gap between basic research about typography, and the kind of information needed by designers of flight-deck documentation. The report focuses on typographical factors such as typefaces, character height, use of lower- and upper-case characters, line length, and spacing. Some graphical aspects such as layout, color coding, fonts and character contrast are also discussed. In addition, several aspects of cockpit reading conditions such as glare, angular alignment, and paper quality are addressed. Finally, a list of recommendations for the graphical design of flight-deck documentation is provided.

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