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Glass cockpits — advantages and problems

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Abstract. New trends of construction of information displays used in cockpits of different modern aircrafts are presented. The main attention is paid to the liquid crystal displays as the most commonly used nowadays and still of interest in the future. Other technologies of flat information panels interesting for the future applications are discussed. The results of theoretical works performed at the Institute of Applied Physics MUT and an example of integrated display for gliders designed there are also given.
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1. Introduction

Flat information displays are widely used today in different devices as TV sets, computer monitors, large information panels, etc. Especially, liquid crystal technologies are widely used for different purposes due to a fact that optical properties of liquid crystals can be driven by low electric field [1]. Information displays called LCD (*Liquid Crystal Displays*) are well known example of an application of this feature [2]. Nowadays, about 80 per cent of all information displays in the worldwide market is manufactured in LCD technology. LCDs are quite cheap, low power consuming, and they exhibit excellent optical performance. There are numerous variants of this technology from simple alphanumerical displays with multiplex driving [3] in which TN (*Twisted Nematic*) and STN (*Supertwisted Nematic*) effects are indirectly applied, including colour effects obtained by birefringent foils or dichroic dyes, to large graphical screens in which active matrix driving and advanced electro-optical effects including also MVA (*Multi Vertical Aligned Nematic*) [4] or IPS (*In-Plane Switching*) are used [5]. The latter devices enable real-time information presentations with TV standard.

There are also several other technologies of flat displays, e.g. PDP (*Plasma Display Panels*) [6], OLED (*Organic Light Emission Diodes*) [7] or FED (*Field Emission Displays*) [8] and projecting systems as DMD (*Digital Micromirror Displays*) [9].

In this paper, the recent solutions of information displays designed for aircraft cockpits are presented including the results obtained at the Department of Advanced Technologies and Chemistry, Military University of Technology.

2. Development of aviation displays

Information display or visualisation includes large area of relative different tasks from single indicators, through gauges and graphic real-time screens to virtual reality systems. The number of information displays increases dramatically with the complexity of the system monitored. The splendid example of this trend is a cockpit of any flying object. The lack of information displays in very first aircraft was a real trouble for their pilots. At first, very simple analogue gauges indicating speed, altitude or essential engine parameters were introduced. The number of those gauges was increasing in the next aircraft generations, moreover digital gauges were introduced. In fact, there were much more than one thousand different displays in military and passenger aircraft used twenty years ago, most of them in the cockpit. This situation has been caused by the necessity of independent visualisation of enormous number of engines' parameters (for as many as four or six of them in passenger aircraft, heavy bombers or airlifters), steering systems, flight parameters, weapons, aiming systems and many other. Despite the fact that large amount of those displays is inactive when systems work properly, it is very difficult for a crew to observe them and receive all the necessary information, especially in combat conditions. Therefore it was necessary to improve information systems and make them more effective and user-friendly so, safer for pilots and passengers. This process is of course continuous one, nevertheless there are some main trends, described below. It should be noticed that modification of aircraft systems is quite slow because the best constructions are used more than thirty years.

3. Modern philosophy of aviation displays

The first concept for replacement of electromechanical gauges was CRT lamp, very well known and developed. Unfortunately, its drawbacks were crucial for aviation technology, e.g., large dimensions, especially depth, large mass, vacuum technology and especially electromagnetic noise accompanying its work.

The next step was an attempt to adopt flat panel technologies amongst which LCDs were the first candidate due to the development of technology and mass production, moreover low driving power and so no emission of electromagnetic noise. However, the indirect adoption of LCD flat screens used in TV sets or computer monitors in flying objects is not so simple due to two main reasons: isotropic illumination in the cockpit and very high readout reliability wanted (pilot cannot commit an error readout).

There are two main concepts of an improvement in the information imaging in modern constructions of the cockpits. The first one is to present extended full-colour real-time graphic information with a computer screen standard in one or several flat screens because it is much more effective to look at one or two places instead of many indicators and gauges (this is exactly the origin of the glass cockpit name). Such screens, apart from flight parameters, can present also combat field data including virtual reality systems. To make observation easier, only essential data are displayed in a continuous way. Any alerting information is displayed only if necessary. The important feature of flat digital screens is the possibility of enlarging the presented information, e.g., in alert cases what enables the pilot to see it at once despite usual acoustic signals. One of the main LCD drawbacks, i.e., relatively small viewing angle is not crucial in this case because of close to perpendicular looking geometry and the presence of doubled screens set for a co-pilot. Another LCD disadvantage — limited temperature range of work can be easy diminished by thermostatic systems.

The second solution is to show the most essential information to the pilot in a continuous way. This task is performed by different methods using so called HUD (*Head-Up Displays*). HUD can be constructed in form of a projection system showing the very basic information (altitude, speed, location, targets, armament, landing parameters etc.) at the transparent screen placed just in front of the pilot's view or can use displays mounted directly at the pilot's helmet. The latter constructions include recently microdisplays with large information capacity (comparable to A4 page of a text) located just in front of one pilot's eye. Those solutions allow for mutual observation of the environment and the display as well as receiving visual information from command or control centres parallel to the classic radio contact. Also in this case LCD technology was the first one adopted and is widely used till now.

Both of those ideas are used simultaneously in modern aircrafts, especially military ones, increasing effectiveness of pilot's "image acquisition" and allowing for immediate and proper decisions during a mission. Despite main information screens, also classic displays and gauges are used, but their role is reduced in a systematic way mainly to show improper work of systems or devices, so the crew should not observe them continuously.

Nowadays, most of aviation displays is manufactured in LCD technology, but recently also joint LCD-DMD projection systems are introduced due to their excellent performance and lower cost. The possibility of an application of other flat display technologies is described later.

All new aircraft constructions are equipped with those panel screen information displays. Moreover, the majority of elder aircraft cockpits are successive upgraded to the modern standard what remarkably improves the pilot's possibility to take the proper decision. The same process concerns helicopters and simple civilian constructions as sport airplanes or gliders, as well as a passenger aircraft in which more or less simple block displays are introduced instead of traditional gauges.

In particular, to improve safety of aviation missions, the special landing information display systems are recently developed. The necessary information is projected by the HUD allowing pilot to see the runaway and all landing information at the same time.

There are also many training systems, which use not only cockpit demonstrators for the respective aircraft, but also include virtual reality solutions using advanced display systems.

4. Examples of modern aviation displays

Some representative examples of currently used modern cockpit information systems are shown below. They have been chosen from a large number of different constructions to show solutions for different aircraft types. In fact, each aircraft used nowadays is equipped with the so-called glass cockpit or at least it will be upgraded in the near future. It is worth mentioning that all those constructions are full-colour systems, what facilitates pilot to distinguish necessary information from the other called "information noise". It is worth mentioning once more that relatively long term of aircraft life enforces the change of cockpit technology rarely, approximately every 10 years.

In Fig. 1, the new glass cockpit of the Space Shuttle made by Honeywell is presented [10]. This is very good example of information imaging system, doubled for pilot and co-pilot, invented for a presentation in real time the enormous information needed for the safety of space missions.

In Fig. 2, the view of a Boeing 777 passenger aircraft manufactured also by Honeywell is presented [11]. In the passenger aircraft, despite technical and flight data, a significant part of necessary information concerns passengers safety and convenience. This example is chosen because it excellently shows the dramatic decrease in the number of displays in comparison with former constructions, e.g., early Boeing 737 cockpit where at least 2000 gauges and indicators were present. In the front panel, five large LCD screens are placed giving necessary information regarding aircraft system

Fig. 1. The view of Honeywell glass cockpit in a space shuttle [10]

Fig. 2. The cockpit of Boeing 777-200 equipped with Honeywell LCD screens [11]

flight parameters, including fly-by-wire system, two of them are doubled for both pilots. There are also several smaller LCD's mainly for text information

In Fig. 3, the comparison between the original Lockheed Martin F-16 fighter cockpit and its new generation designated for F-16 Block 50/52 version (called Jastrząb in Poland) is presented as the excellent example of modern cockpits used in fighters [12]. As one can see, three large screens instead of many conventional gauges are introduced. The front HUD was also improved to be more transparent allowing better view for the pilot. This configuration allows the pilot for effective mission fulfilment.

Figure 4 presents one of the proposed MiG-29 cockpit upgrade made by the cooperation of MiG Aviation Co. and Daimler-Chrysler Aerospace [13]. This solution is not as advanced as F-16 cockpit, nevertheless it is much more functional from the pilot's point of view than the original version.

a) b)

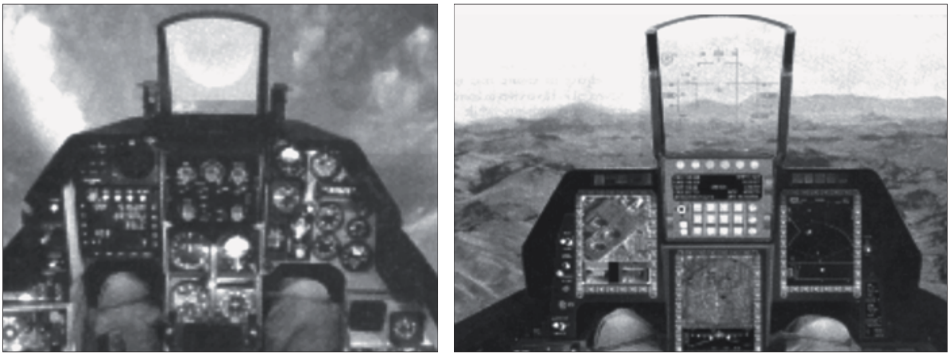

Fig. 3. The classic cockpit of Lockheed Martin F-16 (a) and improved glass cockpit of F-16 Block 50/52 version [12]

Fig. 4. The view of upgraded MiG-29 cockpit [13]

Recently developed Joint Strike Fighter (JSF or F35) projects include demonstrators of the cockpit of this aircraft with multifunction displays shown in Fig. 5 [14]. Lockheed Martin project, the final winner of this competition, uses single Kaiser Electronics 200×500 mm projecting panel in which rear projection system joining small LCD space light modulator and DMD projecting system is applied.

This system seems to be the most useful now and moreover it is cheaper than a large LCD screen. The view of the example of the DMD array is presented in Fig. 6 [15]. In contrary, Boeing has adopted two conventional large (250×200 mm) Harris multifunctional LCD displays and two smaller additional displays in its project. It is worth mentioning that both those systems can be regarded as the most advanced nowadays.

a) b)

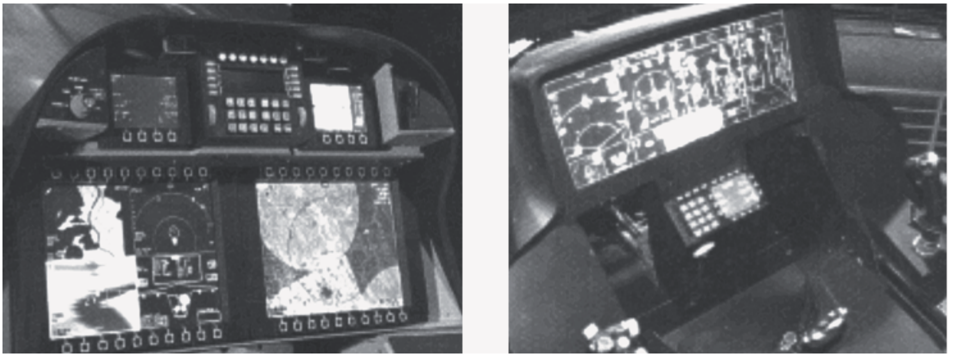

Fig. 5. JSF cockpit demonstrators: a) Boeing project with two multifunctional screens; b) Lockheed Martin single multifunctional panel with rear projection [14]

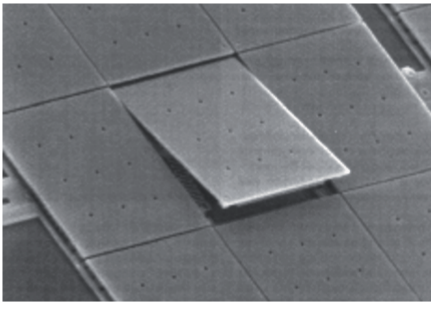

Fig. 6. The view of a part of DMD micromirror array in which single mirrors are deflected electrostatically projecting or no incident light on the screen. The area of a single mirror is about 100 μm^2 [15]

In Fig. 7, the digital pocket map, developed by Kent Display Inc., Honeywell and the Defence Advanced Research Project Agency is shown [16]. This display system can be used in, e.g., in helicopters or downed pilots rescue missions. The downed pilot can found his position located by GPS system and inform a rescue group not only about his coordinates but also a terrain including possible landing area. This particular construction uses a bistable polymer-stabilised cholesteric liquid crystal display being one of new generations of LCDs.

Figure 8 presents the example of special landing information systems using HUD with front projection, which remarkably improves the safety of this dangerous manoeuvre [17, 18]. The pilot can observe the real runway and in the same time and place respective information from aircraft database and control centre. All necessary actions and decisions, especially for a given airport can be trained using the respective simulator.

Fig. 7. An example of digital LCD map, especially useful in rescue mission to find downed pilots [16]

a) b)

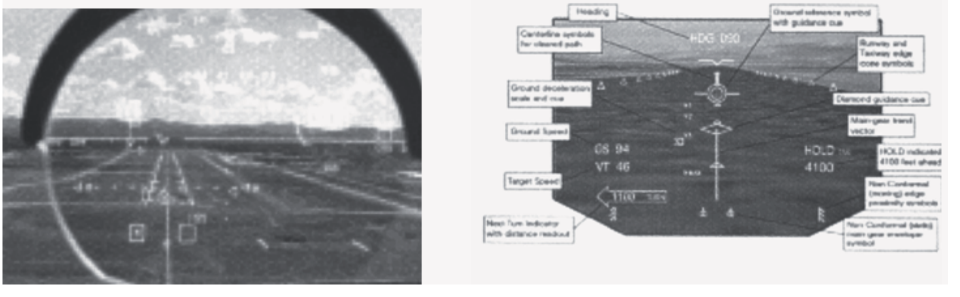

Fig. 8. Landing safety systems projected at cockpit HUD: a) Honeywell Corp. designed for Gulfstream [17]; b) Flight Dynamics simulator for pilot training [18]

5. MUT results

The scientific team of the Liquid Crystal Group of the Department of Advanced Technologies and Chemistry, Military University of Technology, has working on information displays for aircraft and gliders for several years. Due to the lack of an active matrix technology it is not possible to manufacture purely Polish graphic LCDs. However, the solution of such a task is possible in cooperation with flat screen factories recently opened in Poland as LG in Mława.

However, in some cases, especially for small sport or disposal aircraft, helicopters and gliders, there is no need of an application of devices with large information capacity. In Fig. 9, the example of the demonstrator of the integrated TN LCD display is presented. This display shows essential flight parameters as ground speed (upper and central part of the display), rising speed (left), and altitude (right) in as digital as graphic mode.

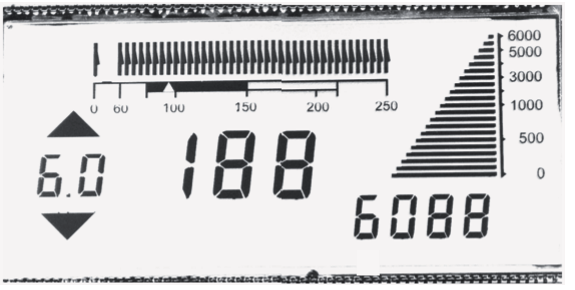

Fig. 9. The view of MUT integrated display for gliders

This device has been originally developed for Polish PS-5 glider, but it can be easily redesigned for other gliders, motogliders, and small aircraft. The graphic information allows for easy orientation if landing speed is within a permissible range (underlined at the display). The construction of the imaging system allows us to use conventional sensors used in gliders. There is also the possibility of introducing the information concerning essential engine parameters in this system.

The second direction of studies in our group is the optimization of LCD technology for displays working in special conditions. The analysis of the display parameters is based only on experimental results therefore it is very difficult, expensive and time-consuming to optimize the mathematical model of a light propagation through the LCD. Such an analysis has been done for LCD working in transmissive and reflective modes and the respective software has been worked out. The aim of this analysis was to determine the effect of external light on the display optical parameters, such as contrast ratio (CR) and brightness what is crucial for avionic applications. The negative mode of display work has been chosen, because this mode enables us to obtain colour imaging in a simple way, e.g., by an application of the colour filter.

Because many properties of display elements can affect the final optical parameters, the analysis can be performed only by using the numerical simulation of the display. It is possible if we have use a proper application of a theory of light propagation through the anisotropic media. Such a theory should take into account the following phenomena and factors:

— multiple light reflection between the display layers;
— different directions of the ordinary and extraordinary wave vectors;
— real direction of the light electric vector, which is not perpendicular to the wave vector for extraordinary wave;
— dichroic properties of the LC.

Using this theory, the special software has been developed [19-22]. Additionally, the set-up for measurements of the display optical parameters was constructed making possible to verify the theoretical predictions by experimental results. Those steps enabled the numerical optimization procedure of LCD properties.

Then, optical parameters of LCD have been calculated by a developed computer program knowing the optical parameters for all layers used to construct such a display. Chosen hypothetical parameters obtained from this program for LCDs are presented below.

In the considered problem, the planar nematic LC layer has been analyzed. This layer had a twisted texture with a twist angle equal to 90 degree — TN effect. The studied layer was 6 μm thick. In the first step we assumed ideal polarizer and analyzer and we calculated spectral characteristics of transmission and reflection coefficients of LC layer for the first and the second minimum of transmission (optical path $\Delta nd = 0.48$ and $\Delta nd = 1.12$, respecively, where Δn is the optical anisotropy and d is the liquid crystal thickness) as a function of an error of mutual arrangement of optical polarizer and analyzer axes. The negative mode of TN effect — an angle between polarizer and analyzer axes equal to 0 degree — was assumed. The obtained results, presented in Fig. 10, show the influence of this error on transmission and reflection coefficients of the LC layer and shift of a wavelength from a minimal value of these coefficients. In the other words, the influence of an error of mutual arrangement of the optical axis of polarizer and analyzer on the optical matching point of a LC layer was determined.

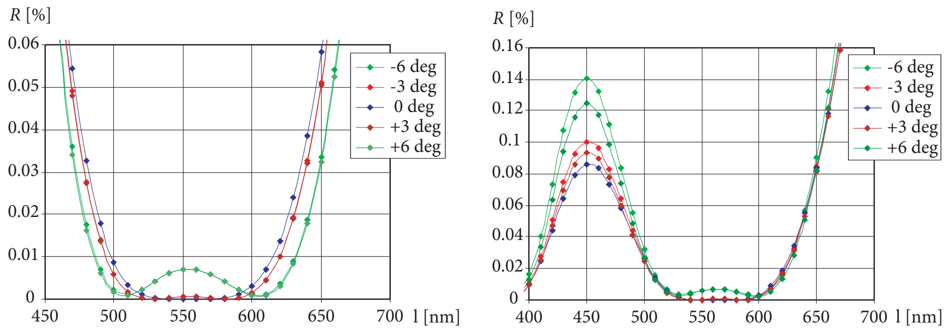

Fig. 10. Spectral characteristics of transmission and reflection coefficient of planar TN layer for negative mode and ideal polarizers obtained for two optical matching points: the first and the second minimum as a function of the arrangement error of polarizer and analyzer optical axes alignment for negative LCD mode

The characteristics presented above show that even small mutual rotation of polarizer and analyzer optical axes can make large changes of the optical properties of the LCD. These results have been obtained for standard glass (700 μm thick, refractive index of 1.52), polarizers with transmission coefficient equal to 80% and 0.01% (for two polarizes with optical axes mutual parallel and perpendicular, respectively), conductive transparent indium-tin oxide (ITO) layer 25-nm thick, refractive index of 1.85 and TN layer as above. Two cases have been analyzed:

with or without antireflective layer placed onto display surface and matched for wavelength of 550 nm. To calculate the contrast ratio, the spectral characteristics of the A-type light source and daily human eye sensitivity have been used.

Therefore, having clean-room technological line as presented in Fig 11 and wanting to construct LCD of proper performance, one should determine possible errors which can occur during the construction process and estimate a range of the parameters (e.g. contrast ratio) of the display obtained in this process. Certainly, the precision of mutual arrangement of polarizer and analyzer optical axes is only one of a lot of phenomena affecting final display parameters. The optimization procedure should be finally described, e.g., taking into account the technological possibilities, the materials available and user expectations.

Fig. 11. LCD technology line inside the clean-room, Military University of Technology, Warsaw, Poland

6. Other flat screen technologies

As it has been said, there are several other technologies to construct flat information screen. The question is — are they interesting from aviation point of view?

FED displays exhibit, till now, one main disadvantage — high driving voltage (so mentioned electromagnetic noise), however, less than those of CRT. Recently, this drawback has been significantly reduced but economical factors (existing factories using other technologies) probably exclude this technology.

PDP is now the most important alternative for LCD's but in spite of excellent image features it has the valuable disadvantage — power consumption which is for today at least two times larger than for LCDs. In case of 30" panel, the power consumption is slightly lower than 1 kWatt what is unbearable in the aircraft cockpit.

OLED systems are regarded as the most interesting for display systems for at least 10 years, but the introduction of the real devices is delayed.

In the authors opinion, mixed systems containing LCD space light modulator and using projecting system, e.g. DMD type are the most prospective during at least the next 10 years. The detailed discussion of the present and future status of flat display technologies is given in the next paragraph

7. Discussion

According to the experience, flat information screens are the best solution for the information display in the cockpit of a modern aircraft. This statement is connected with small depth of those devices, low weight, low energy consumption, absence of electromagnetic noises, and extremely ergonomic data presentation.

On the other hand, several kinds of such screens give the perfect performance of the obtained information image. So, the question is: what technology should be the most effective for flying ships?

In Table 1, the display technologies for special defence market are presented.

As one can see, three main technologies CRT, LCD, and LED are used nowadays, however, FED and OLED are also of interest.

TABLE 1

Display technologies in defence systems (2002/3)

<table>
<tr><th colspan="2">Technology</th><th colspan="2">Percent of DoD display</th></tr>
<tr><td colspan="2">CRT</td><td colspan="2">38.2%</td></tr>
<tr><td rowspan="3">LCD</td><td>Active-matrix</td><td>26.9%</td><td rowspan="3">36.1%</td></tr>
<tr><td>Passive-matrix</td><td>5.6%</td></tr>
<tr><td>Dichroic</td><td>3.6%</td></tr>
<tr><td colspan="2">Liquid Crystal on Silicon (LCoS)</td><td colspan="2">1.7%</td></tr>
<tr><td colspan="2">Inorganic electroluminescent</td><td colspan="2">2.0%</td></tr>
<tr><td colspan="2">Inorganic LED</td><td colspan="2">12.4%</td></tr>
<tr><td colspan="2">PDP</td><td colspan="2">1.9%</td></tr>
<tr><td colspan="2">Electromechnical (EM)</td><td colspan="2">7.0%</td></tr>
<tr><td colspan="2">DMD</td><td colspan="2">0.1%</td></tr>
<tr><td colspan="2">Incandescent</td><td colspan="2">0.5%</td></tr>
</table>

In fact, this comparison regards all military applications of information display while as it have been said above the cockpits of flying ships have the special requirements. Below, the main advantages and drawbacks of existing technologies are briefly discussed.

Field Emission Displays are vacuum fluorescent devices that work on the principle of cold cathode emission. Electrons emitted from a cathode are accelerated through the vacuum to strike a phosphor light emitting element. The phosphors used in CRTs can also be used in FEDs. The colour gamut for both technologies can be identical. Contrary to the electron thermoemissive generation in CRTs, FED produces electrons by tunnelling from the emitter surface into vacuum due to a large electric field.

FEDs have many advantages in comparison with CRT and other display technologies. The weight and thickness of an FED display is less than $1/10^{th}$ that of CRT. FEDs consume very low power. FEDs unlike LCDs do not have any viewing angle issues and there is no change in display performance when viewed at any angle, horizontal or vertical. FEDs can withstand a wide temperature range from –45 to +85.

Organic Light Emitting Displays are based on the electroluminescence in organic materials reported for the first time in 1963. Nowadays, organic light emitting displays are splitted into organic LED = OLED, and polymer LED = PLED. At one level OLEDs and PLEDs are quite similar. Both employ the ITO as a transparent conductive layer and the hole injector material. Both use low work function metals as cathode electron-injecting materials, and both have organic stack thickness of about 140 nm.

The OLED has an evaporated thin film stack covered with 15-20-nm buffer layer or hole injecting layer, e.g., copper phthalocyanine, followed by a hole transport layer of 50-60 nm, e.g. naphtha-phenyl benzidene. The emitting layer is formed of 35-40 nm of Alq_3 doped with an organic dye, e.g., coumarin 540. An undoped Alq_3 layer of 35-40 nm is used as an electron transport layer and buffer layer, isolating the emitting layer from the metal cathode.

The popular PLED structure uses a layer of polyethylene dioxythiophene (PEDOT) as hole transport material. This can be spin cast from a solution to a thickness of about 70 nm. The PPV layer is formed by polymerizing a spin cast film of precursor material. The total thickness is of about 140 nm.

OLEDs and PLEDs are good candidates for display application. They have high brightness, high contrast, high efficiency, fast response (in the microsecond range), wide viewing angle, and easy grey scale control.

The greatest problem with OLEDs is the incompatibility of materials with conventional photolithography for pattering emitters and electrodes. The device materials, including the cathodes, are also very sensitive to moisture and oxygen, so extremely good sealing systems are required.

In Table 2, the input parameters assumed for comparison of the above technologies are gathered. Table 3 presents the properties of different kinds of displays. The comparison of the displays is possible by an application of the coefficient (score) describing the fulfilment degree of the requirements scaled from 0 to 100.

TABLE 2

Display required parameters

Attributes	Target
Operating temperature range	–40°C to +85°C
Backlight	None
Colour performance, colour depth	SMPTE 170-1994 coordinates 6 bit/subpixel minimum
Viewing cone	160 degrees
Contrast ratio	300:1 minimum
Luminance Sunlight viewability	400 cd/m^2 20:1 min CR ≅ 3000FC
Temperature stability (–40 to +85°C)	80% min. of 25°C performance
Video response time	Video capable across operating temperature range
Array size (colour)	VGA
Lifetime	10 000 hours to ½ life
Residual image	5 seconds max. after 2 hour dwell
Technology maturity/availability	Mass production
Cost	5-10 USD/sq. inch of display screen (module cost)

The LCD (active matrix) is the closest to full colour ¼ VGA or greater resolution display for special application. Beyond, the near term FED technology may see application if the residual image issue can be solved or minimised, reasonable luminance and display life is obtainable.

The main problem of EL technology is full colour capability (there are the problems with good blue phosphor). The OLED technology has been introduced for mass production very recently.

One should remember that PDP exhibits now much power consumption than LCD, e.g., for 30" panel the power consumption for these technologies is ~400 and 200 Watts, respectively.

8. Conclusions

1. The general tendency of improving cockpit information systems in modern aircraft consists in a reduction of the number of gauges and indicators, especially electromagnetic ones.
2. Large multifunctional integrated flat screens are introduced instead of single gauges.

Table 3

The comparison of main flat screen technologies [23]

	LCD		TFEL		FED		OLED	
Attributes	actual	score	actual	score	actual	score	actual	score
Operating temperature range	–30, +65	75	–40,+85	100	–40, +85	100	–40, +85	100
Backlight	YES	0	none	100	none	100	none	100
Colour performance, colour depth	< OK	80 100	< OK	50 100	< OK	90 100	< OK	90 100
Viewing cone	120°	70	160°	100	160°	100	160°	100
Contrast ratio	150	70	OK	100	OK	100	OK	100
Luminance Sunlight viewability	350 15:1	90 80	200 <	50 80	300	80 20	300	80 80
Temperature stability (–40 to +85°C)	40%	50	OK	100	OK	100	<	40
Video response time	–10°C	30	OK	100	OK	100	Ok.	100
Array size (color)	Ok	100	OK	100	OK	100	Ok	100
Lifetime	Ok.	100	Ok	100	<	50	<	50
Residual image	OK	100	Ok	100	<	10	<	40
Technology maturity/ availability	OK	100	<	80	<	60	<	40
Cost		80		40		40		80

3. The essential flight and combat information is displayed in front of the pilot's view at transparent HUDs or at displays mounted at the pilot's helmet.
4. Data is presented in form of digital or graphic information, which is more readable than classic analogue gauges.
5. LCD technology is now preferred, also integrated with micromirror projecting systems.
6. It is possible in Poland to develop and manufacture simple alpha-numerical and graphical integrated aviation displays in LCD technology.
7. The possibilities of the authors' laboratory regarding the optimization procedures of LCD are presented and the significance of such procedures in display construction process is underlined. It is important especially for special LCDs, where each single percent of the luminance or contrast ratio is important. Three elements are needed to do the complete optimization procedure (even complicated one): the correct mathematical model of a light propagation through the display, the software calculating display parameters basing on this model and measurement set-up to verify theoretical results.

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REFERENCES

[1] P. Yeh and C. Gu, *Optics of Liquid Crystal Displays*, New York, Wiley, 1999.

[2] J. A. Castellano, *Handbook of Display Technology*, San Diego Academic Press, 1992.

[3] P. Yeh, *Optical properties of general twisted-nematic liquid-crystal displays*, J. Soc. Inf. Display, 5, 3, 1997, 289-291.

[4] Y. Koike and K. Okamoto, *Super high quality MVA-TFT liquid crystal displays*, Fujitsu Sci. Tech. J., 35, 2, 1999, 221-228.

[5] J. J-. Lyu, J. Sohn, H. Y. Kim, and S. H. Lee, *Recent trends on patterned vertical alignment (PVA) and fringe-field switching (FFS) liquid crystal displays for liquid crystal television applications*, IEEE/OSA Journal of Display Technology, 3, 4, 2007, 404-412.

[6] J. H. Souk, *Flat panel display world in 2012*, SID Conference Record of the International Display Research Conference, 2006, 3-5.

[7] C. Hayes, *Slimmer and thinner make OLED a winner*, Electron. Prod. Des., 28, 7, 2007, 29-31.

[8] O. Yamada, Y. Sato, and M. Uchidoi, *Progress of FPD technology*, ABU Technical Review, 228, 2007, 3-9.

[9] D. Dudley, W. Duncan, and J. Slaughter, *Emerging Digital Micromirror Device (DMD) applications*, Proc. SPIE, 4985, 2003, 44-55.

[10] *Honeywell Advertisement*, Aviat. Week Space Tec., June 26 2000, S6.

[11] D. M. North, *Finding common ground in envelope protection*, Aviat. Week Space Tec., 28, 2000, 66.

[12] M. Gerzanics, *Advanced F-16: a pilot's perspective*, Flight International, 18-24 July, 2000, 103-104.

[13] M. A. Taverna, *Russian-German feud imperils MiG venture*, Aviat. Week Space Tec., June 19, 2000, 47-48.

[14] *Pilot's perspective*, Flight International, Suppl. 5 September, 2000, 37-40.

[15] W. B. Scott, *Sandia expands envelope of MEMS devices*, Aviat. Week Space Tec., June 12, 2000, 57-59.

[16] P. J. Parmalee, *Military aims to reap benefit of long-life E-book*, Aviation Week & Space Technology, August 21, 2000, 73-75.

[17] *Honeywell Advertisement*, Aviation Week & Space Technology, June 26, 2000, S8.

[18] Aviat. Week Space Tec., August 14, 2000, 50.

[19] J. Zieliński and M. Olifierczuk, *Colour liquid crystal display — problems and optimization procedure*, Mol. Cryst. Liq. Cryst., 2006, 454, 395/[797]-413/[815].

[20] J. Zieliński and M. Olifierczuk, *Liquid crystal displays: the visualization problems with the observation under sun illumination*, Proc. SPIE, 2005, 5947, 5947V1-5947V1.

[21] M. Olifierczuk and J. Zieliński, *The contrast ratio in reflective liquid crystal display with a nematic phase*, J. Opt. Technol., 72, 9, 2005, 20-27.

[22] M. Olifierczuk and J. Zieliński, *Two-parameter optimization procedure for a TN display*, J. Soc. Inf. Display, 12, 2, 2004, 135-142.

[23] M. R. Vincent, *A comparison of high information content flat panel displays for automotive applications ISSN0099-0966X/99/3001-0180*, Proc of SID, 1999.

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Kokpity szklane — zalety i problemy

Streszczenie. Przedstawiono nowe kierunki konstrukcji wyświetlaczy informacyjnych do kokpitów współczesnych samolotów. Główny nacisk położono na wyświetlacze ciekłokrystaliczne jako najbardziej obecnie rozpowszechnione i perspektywiczne. Przedyskutowano inne technologie płaskich ekranów, interesujące z punktu widzenia przyszłych zastosowań. Przedstawiono również wyniki prac teoretycznych oraz przykład zintegrowanego wyświetlacza dla szybowca skonstruowanego w Instytucie Fizyki Technicznej WAT.

Słowa kluczowe: Wyświetlacze ciekłokrystaliczne, zobrazowanie informacji, kokpity, samoloty
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