21st Century Aerospace Defense Displays *

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ABSTRACT

Aerospace and defense during the next few years will be dominated by the active matrix liquid crystal display, which became the preferred avionics displays technology in 1992. The trend just begun to replace electromechanical and cathode ray tube technologies with newer flat panel displays will accelerate in the 2000-2010 period as the commercial market continues its move towards digital flat television. Beyond 2010 high definition displays will begin to have a significant impact on fielded air fleets, with ultrahigh definition and even true three-D displays beyond 2020. By 2050 fully immersive cockpits may be anticipated for air and space vehicles and their simulators.

INTRODUCTION

Acquisition reform requires aerospace defense applications in the early 21st century to rely on the commercial marketplace insofar as possible. There are three simultaneous conditions on acquisition reform, all of which are well exemplified by the component technology of displays: (1) integrated display subsystems delivered and bolted into fielded aerospace defense vehicles must work under the full range of documented operational and storage conditions (transport, combat, missions other than war); (2) replacement displays must cost less than those currently in fielded systems to own and operate; and (3) new display capabilities must drive a revolution in aerospace or military affairs. These conditions comprise the principle of acquisition reform—affordability, expressed as minimal cost per mission metric: $/air-tonnage-mile, $/target, $/passenger-mile. Display acquisiton is of strong current concern in both the Congress and DoD.[1]

The principal of "performance specification" is central to the new acquisition paradigm. A performance specification (a) evolves over years through several levels of knowledge (research, manufacturing, fielded) as a display technology variant matures, (b) comprises parameters both generic (life cycle cost, efficacy, visual thrust) and specific (maximum luminance, color coordinates, viewability angles), and (c) varies substantially among classes of application (combat, C4I, support, office). The contrast between the visual thrust provided by fielded electronic displays to aerospace crews and warfighters at the end of the 20th century (1 megapixel) and the ideal capacity of the human visual system (1 gigapixel)—both with 8 bit or higher greyscale per color and full motion video with 60 Hz or higher frame rate—is central to the opportunity of displays to contribute to revolutions in aerospace military affairs. These principles are introduced, discussed and illustrated with roadmaps for aerospace defense displays to acquaint the civil commercial industry with the needs and opportunities in 21st century aerospace defense applications.

PERFORMANCE SPECIFICATIONS

Performance specifications provide guidance to industry for needed products without dictating detailed designs of those products. Such specifications must emanate from government but must also be developed in concert with industry. The problem of establishing performance specifications may be viewed as a time-dependent matrix of Phyla and Levels.[2]

Each 'Phyla' represents a grouping of similar applications. The Phyla for displays should differ but little from those for other electronics technologies. The initial Phyla set might be limited to four: Combat, C4I, Support, and Commercial. The Combat Phyla includes systems that shoot and get shot at. The C4I Phyla includes systems that do not shoot but will get shot at because they direct shooters. The Support

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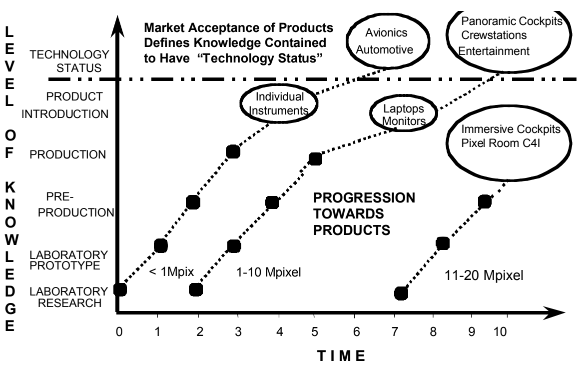
Phyla includes applications removed from the battle zone but necessary to for combat; such systems include logistics chains and may get shot at, especially when they arrive in a battle area to dispense men and equipment.

Each 'Level' represents the status of knowledge as a function of time. The initial Level set might be limited to six: laboratory research, laboratory prototype, pre-production prototype, production, product introduction, technology status (market acceptance of products in fielded aerospace/defense systems). During product introduction the market may barf and the want-to-be technology fails; an example was recent consumer rejection of head-mounted virtual reality displays. A display technology is established by market success in relatively simple applications (small sizes, low information content), then progresses to ever more complex applications (medium to large sizes, high information content). The time dependency of technology evolution through the aforementioned six levels of knowledge is illustrated in below.



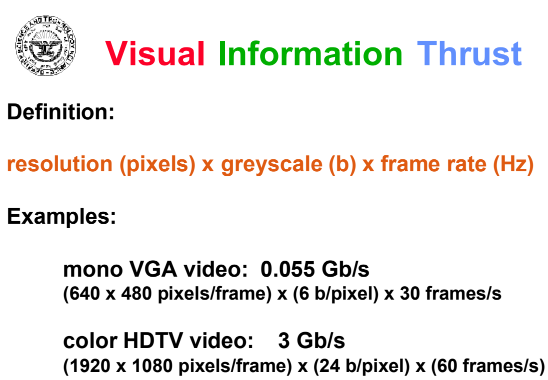
Performance specifications are defined as a vector of time dependent parameters and weights. The weighting function for each parameter is defined for each application Phyla, Level, and year. A fielded combat cockpit in a fixed wing fighter aircraft in 1999 would have parameter values assigned based on measured field performance for the pilot. An ideal performance specification can be defined based on (1) the extrapolation that current limits of human knowledge of how to dig atoms out of the ground and produce displays might one day be removed and (2) the assumption that current understanding of the human visual system is perfect. Thus, for the sunlight readability aspect of an idea aerospace cockpit display one would want over 3,400 nt (1000 fL) and 100:1 luminance contrast ratio (CR), compared to fielded avionic CRTs at about 100 fL and 1.6:1 CR, or fielded avionic AMLCDs at about 200 fL and 10:1 CR.

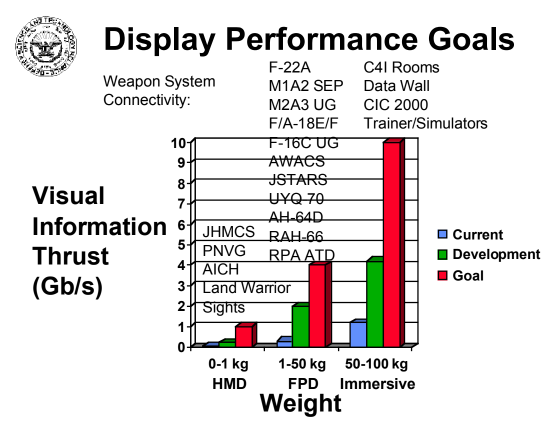
Opportunities to reduce the gaps between fielded and ideal performance specifications provides justification for investment flows (civil and military) to support the display technology revolutions and evolutions depicted in the "Level of Knowledge vs. Time" figure above. DoD programs continually review opportunities for evermore ambitious, needed display applications and plan with this commercial product dynamic in mind.

The number of parameters in a performance specification might be several dozen. Alternatively, one might pick a few generic aggregate parameters that describe the performance in more general terms, including some understandable to non-technical decision makers and to non-display technologists (e.g. to Congress and OSD). Three are suggested: life cycle cost ($LCC, life=10 yrs operation),[3] efficacy (lm/W), and visual information thrust (see below).

VISUAL INFORMATION THRUST

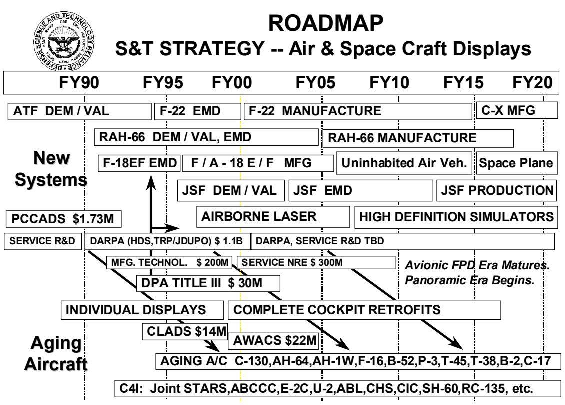
Technology challenges for displays require an aggregate metric relevant to the richness of visual information departing the screen to the user. "Visual Information Thrust," defined and exemplified in below, is hereby introduced and used to categorize aerospace and defense display performance goals.





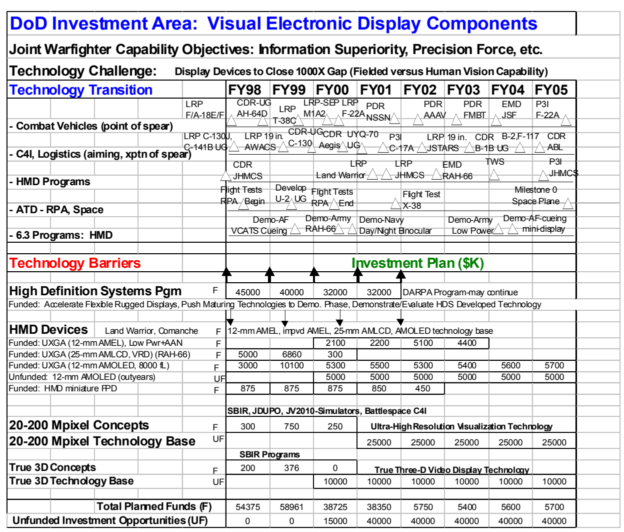
ROADMAPS

Aerospace Systems—20 Year View. Aircraft and other military displays are developed according to weapon system needs. A roadmap may be used to relate DoD S&T investments to systems. The roadmap for aerospace vehicles to 2020 is illustrated in below. The S&T program is undertaken to support existing fleets as well as revolutionary new weapon systems.[4] The center piece of the DoD S&T display investment strategy is the DARPA High Definition Systems program. Related programs translate the technology to manufacturing. Such manufacturing technology efforts the past six years have included two for AMLCD (OIS, dpiX), three for FED (Raytheon, Candescent, Micron), and two in EL (Planar). Non-recurring engineering (NRE) investments by service acquisition organizations integrate the new display technology into aircraft. Examples of the affordable maintenance of an operational status for aging aircraft with flat panel displays and other new display technologies include C-141, AH-64D, H-46, H-1, P-3, U-2,T-38,T-45, F-16, C-17, Space Shuttle & AWACS. Examples of new aircraft include the F-22A Raptor, RAH-66 Comanche, Joint Primary Aircraft Trainer System (JPATS), F/A-18E/F Super Hornet & AAAV. Every fleet is converting to new, flat panel displays: older technologies used for avionics displays not only have less capability to provide aircrew with needed in-flight information, they are increasingly not available at any price. The vanishing vendor syndrome (VVS) for avionics-grade electromechanical and cathode ray tube technologies has forced acquisition organizations one by one, system by system, to re-prioritize available funding to display NRE re-design and re-procurement efforts to maintain dispatch rates and readiness.



Aerospace & Defense Systems—5 Year View. Display science and technology has received significant funding from DoD during the past decade, with some $1.3B having been invested via a Congressionally-directed five year High Definition Systems (HDS) program from FY1989-1993 and via the National Flat Panel Display Initiative (NFPDI) from FY1994-2001. The term "HDS" has continued in common use to describe the DARPA investments even though a variety of some 10 separate, focused programs have made up the $1.3B, including support for the United States Displays Consortium (USDC) and Phosphor Technology Center of Excellence (PTCOE). These display S&T investment programs are, and should continue as, DARPA-led with support from all services. Additional sums have been invested via the DoC NIST Advanced Technology Program (ATP) and other, special programs placed by Congress in service budgets. The current emphases in the HDS program are flexible displays, ruggedized commercial, pushing maturing technologies to demonstration phase, and focused demonstration/evaluations.

An example detailed roadmap to 2005 is illustrated below. The long bars in the 2020 roadmap now begin to show the detail of system milestones which provide a continual series of transition opportunities for displays. Planned DoD S&T investments to overcome technology barriers to system applications are shown as funded lines labeled "F". These sums are in the Presidents Budget for FY2000. The amount shown for the current fiscal year, FY1999, is about $60M. The total DoD display investment in the FY1999 National Defense Act is greater: about $111M. The difference represents programs placed by Congress in accounts connected mostly to systems offices. Great technology barriers remain (see previous and succeeding sections). Three example areas that might be selected for emphasis during the next five years are labeled unfunded, "UF", below: (1) ultra-high resolution visualization technology; (2) true-3D; (3) miniature active matrix organic light emitting diode.



TECHNOLOGY CHALLENGES

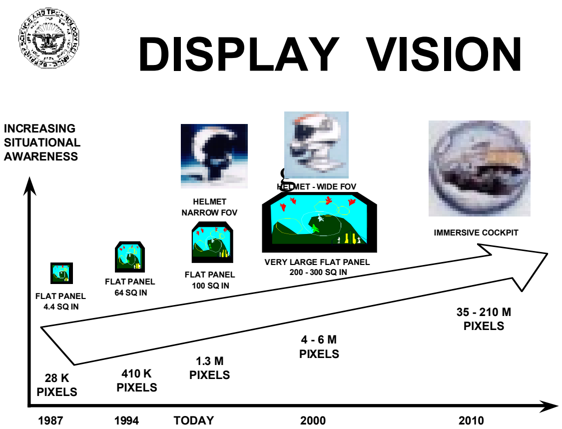
Grand Challenge. The grand challenge to all display technologies in all applications is to close the 1000X gap between the capacity of the human visual system and currently available products in everyday use. Simple 20-20 vision is over 100X the resolution of current technology. In wide intensity range situations (sunlight, infrared imagery, stars against dark sky) objects as small as 25 arcseconds can be easily resolved by most persons. A person can look around in 4π steradians with no scene generation latency. An ideal electronic display would, thus, generate some 10^9 pixels at 24 bits per pixel and full motion video (60Hz or more), a visual information thrust of 1.6 Tb/s. Present commercial and military fielded display are usually less than HDTV, a visual information thrust of "just" 3.0 Gb/s. A typical current fielded application is color VGA, a visual information thrust of just 0.4 Gb/s. The capacity of the human visual system is about 4000X that provided by standard NTSC TV, or 16000X that of RS-170 mono FLIR. An additional grand challenge is to provide true 3-D display with multi-perspective look-around without headwear.

Military Aerospace Display Challenge—Surfing

The aerospace/defense display challenge is to leverage the commercial market to the maximum extent possible. Surfing is an apt analogy, with the commercial market represented by waves of technologies and products (high energy & funding levels) and aerospace/defense as the surfer applying relative small amounts of energy (funding) to ride to shore (achieve a low volume albeit tough performance parameter application). An overall goal is to rely on commercial display technologies of the future rather than the past to significantly reduce life cycle costs.

DoD science and technology (S&T) organizations recognize a responsibility to the warfighter, the maintainer, and the taxpayer. Bringing military FPDs into the DoD inventory serves the warfighter by providing a more mission-capable piece of equipment to reduce workloads while improving situational awareness and combat kills. The depot workload is reduced along with the need for spares due mean time between failure (MTBF) rates for FPD some 30-100 times lower than the out-going technologies, thus addressing the vanishing vendor syndrome (VVS) for current military EM and CRT displays. The taxpayer is served by decreasing DoD life cycle cost expenditures, even ultimately reducing the projected number of persons, platforms, and combat vehicle sizes necessary to achieve availability and sortie rates sufficient to provide the defense capabilities required by national military objectives.

Aerospace Display Challenge. Aerospace and defense applications grow daily and now include general and corporate aviation as well as military, commercial and space craft cockpits and cabins. Even so, AMLCDs have been in aerospace applications only about 10 years since the introduction of the Toshiba 2.5 x 2.5 inch square 3ATI for TCAS collision avoidance and have now grown to the 7.8 x 7.8 inch in the F-22 Raptor cockpit and the 16 inch in aerospace cabin crewstations. It is now time to move these larger displays to the cockpit and to prepare for panoramic cockpits and ultrahigh resolution simulators. Goals include the capability to put pixels on the head, vehicle/console, or wall according to the following timeframe (full color & video in all cases): 4-6M, 10M, and 35-210M by 2000, 2005, and 2010, respectively. The chart below summarizes this aerospace defense display technology vision.



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