# Visual Display Systems

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***Flight & Ground Vehicle Simulation Course – 2017***

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# Introduction: simple displays

- How effective is a standard TV?

# Cognitive Learning

- Good for cognitive learning:
  - CBT
  - CPT

**Virtual Avionics Procedures Trainer**

**USMC CBT**

# Entertainment

- Good for entertainment & games

# Psycho-Motor Skills?

Bad for teaching psycho-motor skills => Tunnel vision!

# Psycho-Motor Skill Training

- Depiction of environment needs accurate:
  - Content
  - Scene geometry
  - 3-D Perspective

# Overall - Many kinds of display


# How we’ll proceed

- Emphasis: Man-machine visual interface – display of synthetic OTW image
- Discussion areas:
  - Vehicle-type constraints
  - Mission/role constraints
  - Performance measurement
  - Available display components & systems
  - Display R&D

# Demands of vehicle type



Four characteristics drive display choice

- Size of viewing volume
    - Single vs. multi-seat operator station or cockpit
- Operator(s) FOV/FOR
- Simulated forces on vehicle & operator
- Compatibility with on-board instruments & sensors

# 1. Viewing Volume

- Single- vs. multi-seat position/cockpit.
  - Single-seat => Easy! DEP of IG = DEP of Display
  - Multi-seat/multi-position => More difficult
  - No-seat?

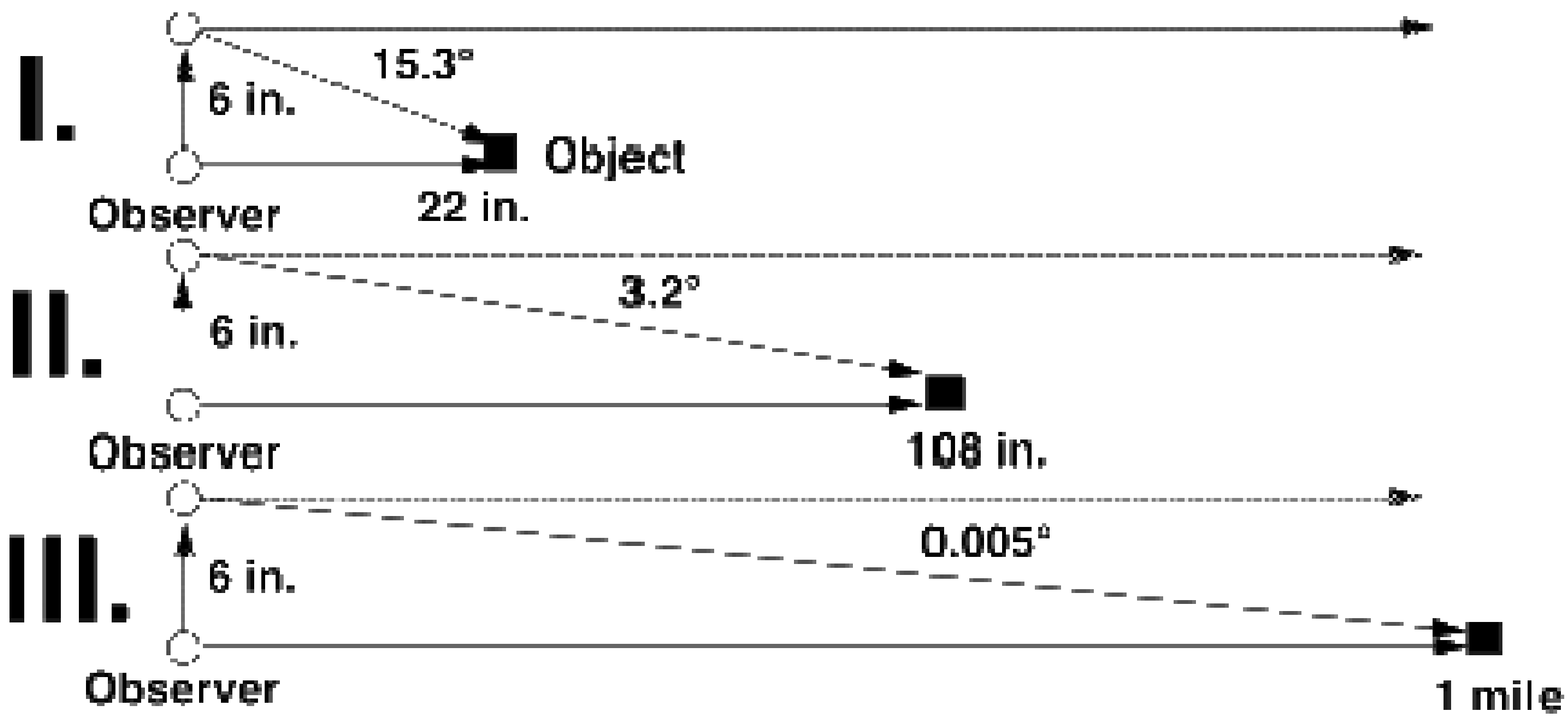
# L-3 Link Predator Mission Aircrew Training System

# Multi-Seat/Multi-DEP

- Separate displays
- Distant display
- Collimation ⟶

- Scene geometry essential, but HOW?

# Optical effect of distance




Angular Deviation of Object with Head Motion
(not to scale)

# Ship's Bridge Simulator

- Objects are distant; screen is distant
- Wide HFOV, but narrow VFOV
  - Numerous juxtaposed display channels

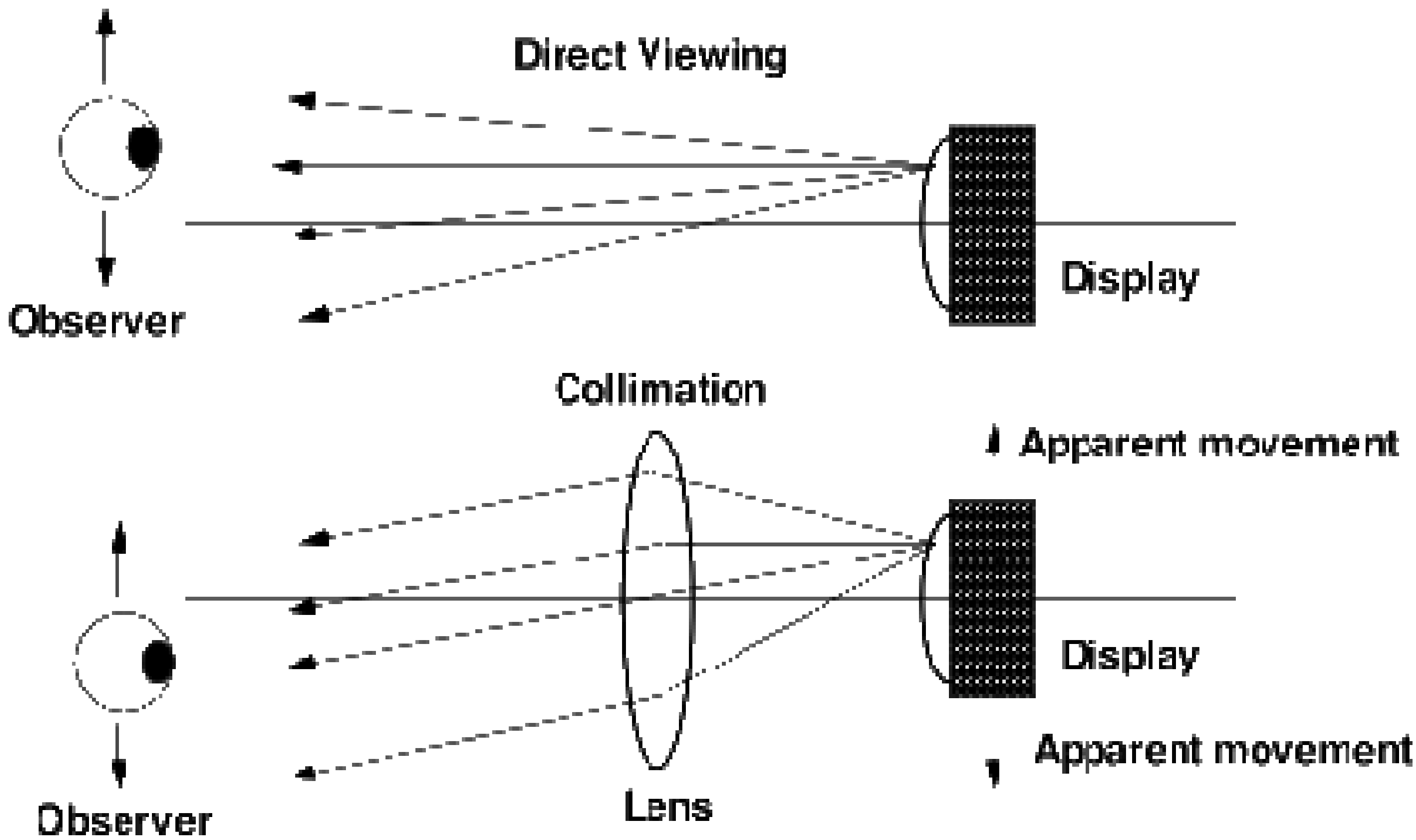
Kongsberg Polaris bridge simulator

- 360º HFOV
- 50 $m^2$
- For Maritime Academy of Asia and the Pacific
- Bataan Philippines

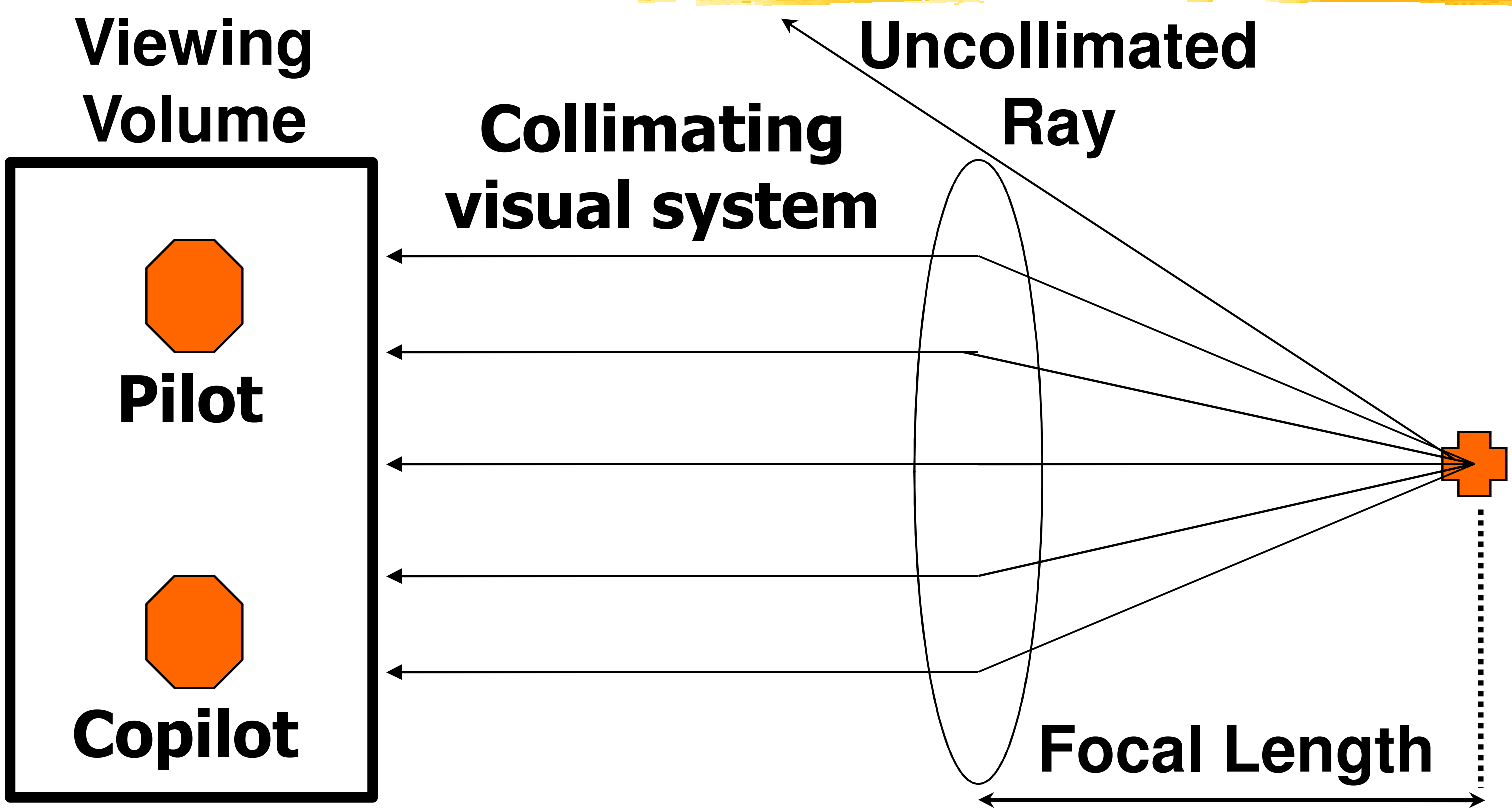
# Principle of collimation

- Certain optical systems inserted between an object/real image and an observer will make light rays leaving the object behave as if coming from farther away, but without depicting a smaller angular size (perceived size related to optical FL)
- A “collimated image” is a special case of a “virtual image”
- How does this work?

# Light ray behavior

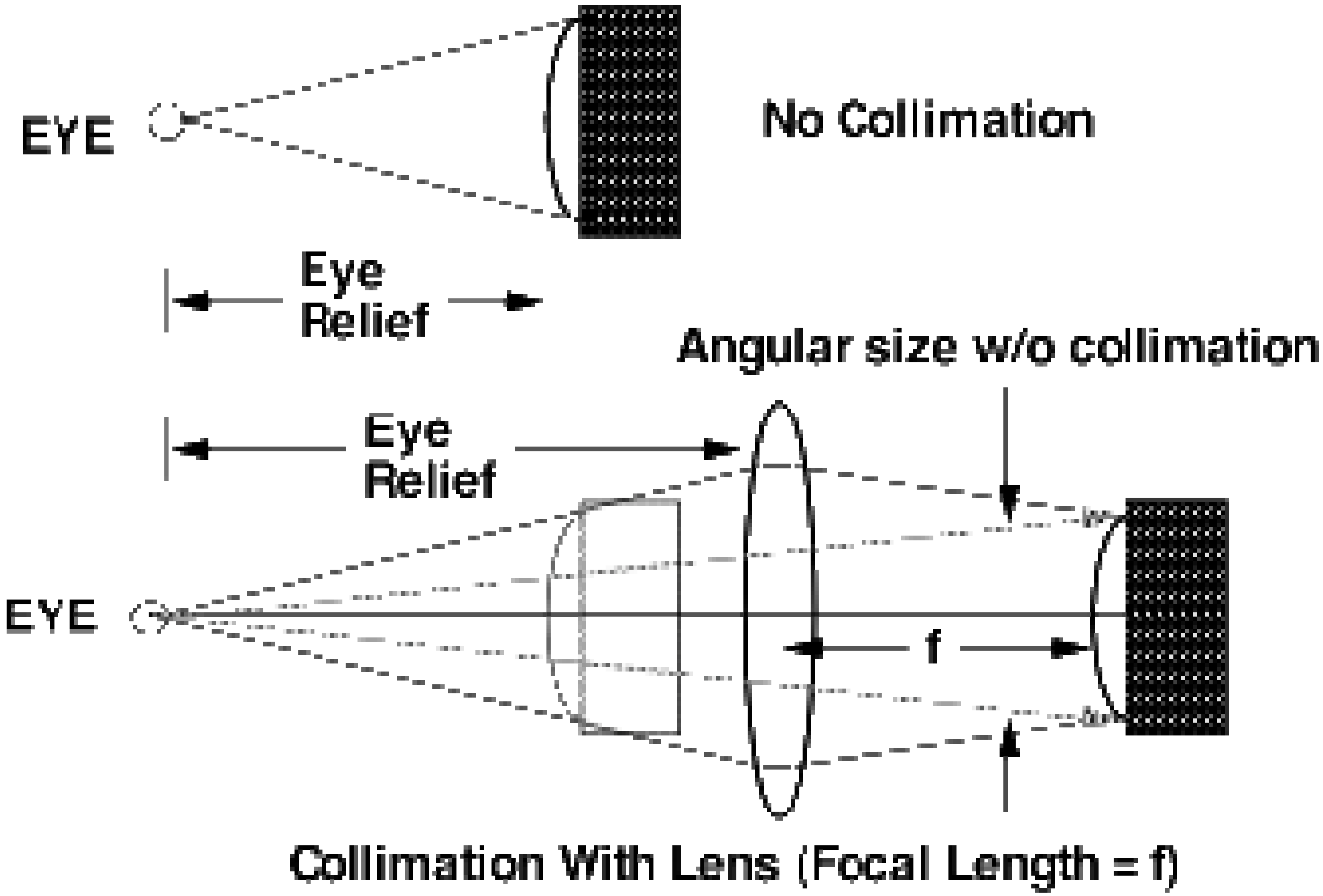


# Pilot & Copilot Viewing




**Object appears directly in front of both pilots**

# Benefit to eye relief

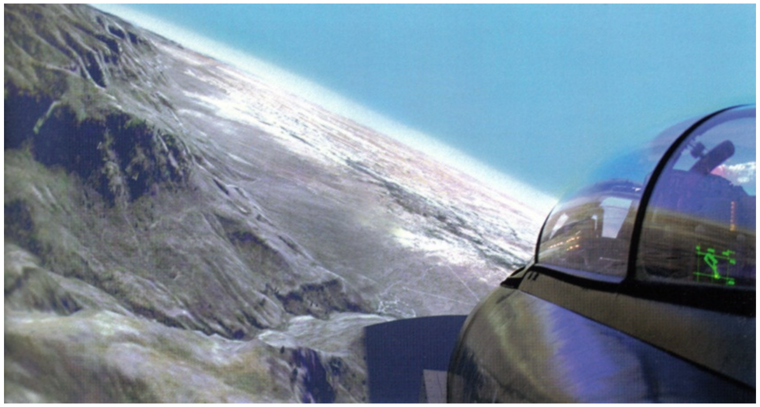


# Collimation characteristics

- Advantages:
  - Magnification ≠ f [fore/aft cockpit position]
  - Angular location ≠ f [sideways movement or lateral displacement]
  - Accommodation & convergence behave as if viewing distant objects in *real* world
- Disadvantages:
  - Other display attributes can suffer
  - Cost, size, and weight of optical system

# 2. Field-Of-View (FOV)

- Different FOV distributions
  - Some more challenging




# Large FOV

- Coping with extended FOVs:
  - Juxtaposed IG & display channels of identical size →
  - A few channels, some subtending large angles and others small angles
  - Head-tracked or head/eye-tracked display channels

Fidelity Flight Simulation LCD Mosaic Wall™

# Large FOV: M1100 Series Humvees


**Humvee variant of CCTT reconfigurable vehicle trainer**

# Small FOVs

Ex: Rockwell Collins XGA & SXGA sight simulators

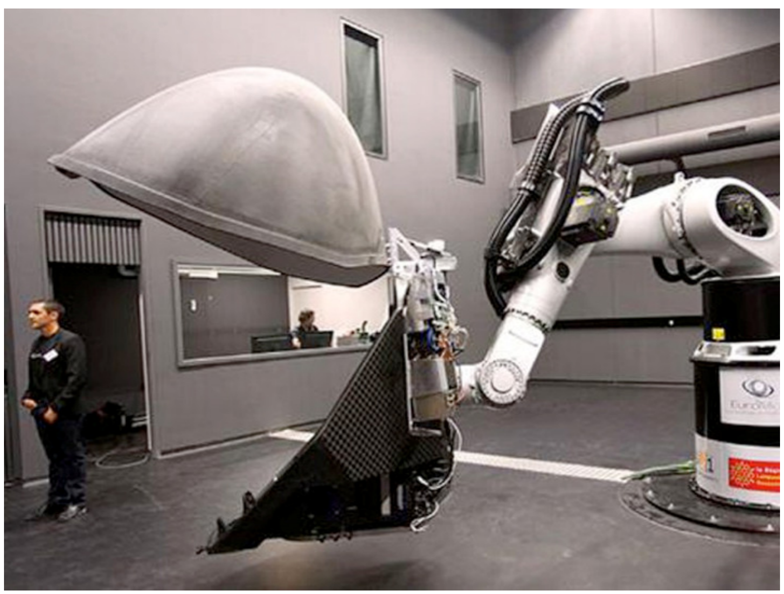
BAE Insyte Periscope Simulator for Royal Netherlands Navy WALRUS Class SCTT

# 3. Operator cueing

- User sensing of vehicle dynamics
  - 6-dof motion requires a display with:
    - Rigidity
    - Sensible weight & inertia (lightweight & compact)
- Possible design solutions
  - Use collimation (for compactness)
  - Innovative materials & optical packaging

# Screen sections on motion

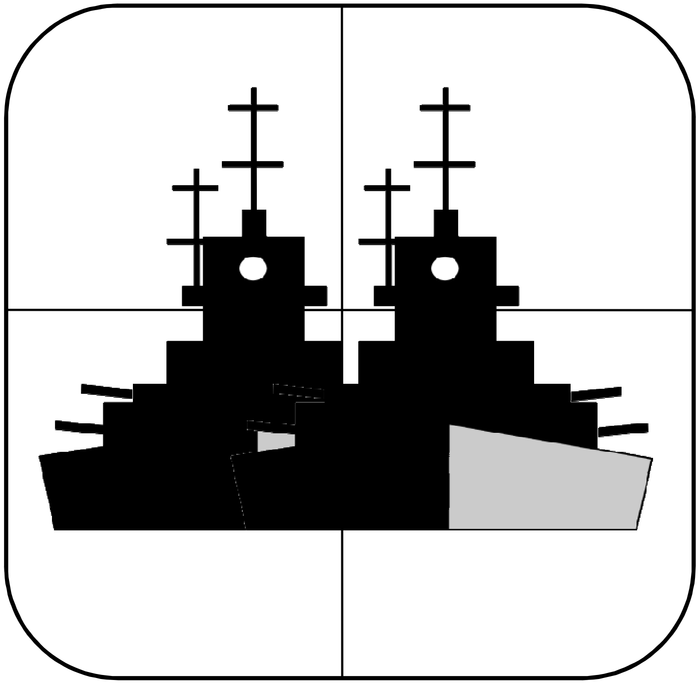
- BEC GMBH/Corp.
  - 2 DLP eyevis projectors
  - $110^{o}$ V x $130^{o}$ H
  - 2560 x 1600 pixels ea.



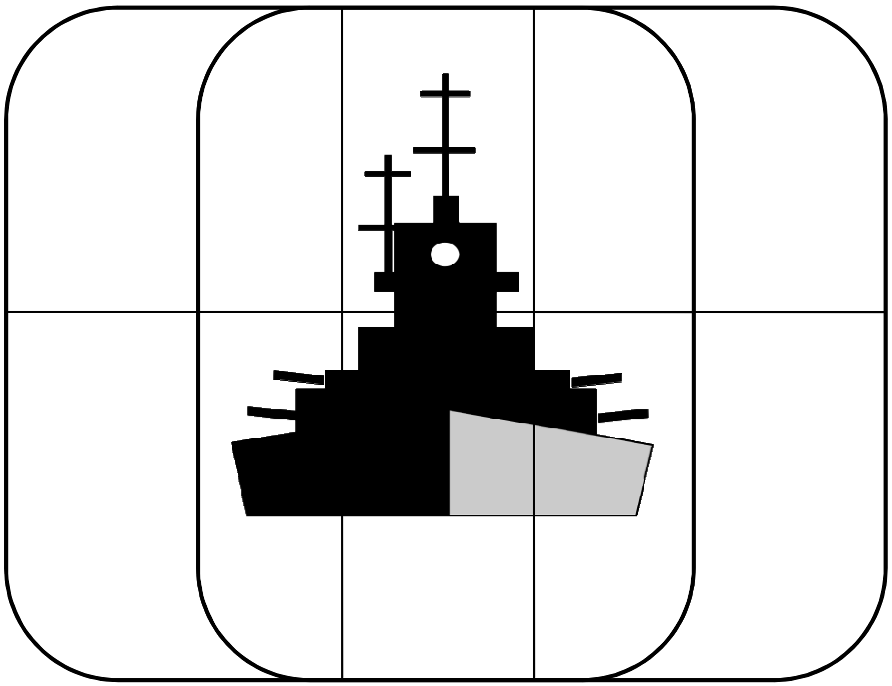
# 4. Cockpit instruments

- Ex: Pilot use of HUD
  - HUD image normally at “infinite” distance
  - Outside scene should be at same optical distance
  - Lack of proper HUD/display correlation causes:
    - Inability to focus HUD and display simultaneously
    - Double imaging
  - Result: Pilot confusion

# Pilot confusion



Focus on HUD Graticule



Focus on OTW Image

# Eliminating confusion

- HUD implementation requires either:
  - Mechanical alteration to yield virtual image at same distance as OTW display ($ or $$$)
  - Collimated OTW display ($$, but VFOV limitations)
  - If OTW imagery is projected onto a screen, the HUD can be removed and its symbology either combined with OTW imagery or projected separately ($).
    - Disadvantage: Unrestricted viewing volume

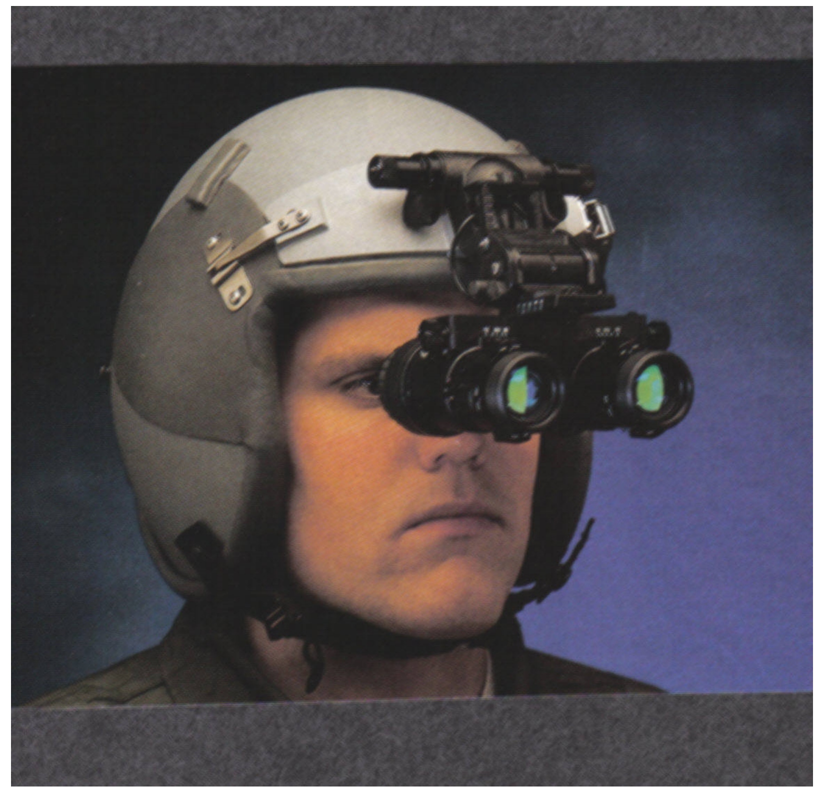
# Ex: TREALITY HudView

- Characteristics
  - Small
  - Split-package
  - Off-axis projection
    - 8-deg H; 15-deg V

**IAI/LAHAV Projected HUD**

# Demands of NVGs

- Need:
  - Good black levels
  - Realistic spectral response
  - Artifacts (light blooming)
- Choices:
  - “Simulate” NVG
  - “Stimulate” actual NVG
  - Many technologies from which to choose
    - Choice affects selection of IG and display system



# Example: “Simulate” NVG

- Dusk from Cinoptics (Netherlands)
  - Ferroelectric LCoS display technology
    - Switching < 100 microsec (vs. 10 msec standard)
  - Resolution: 1280 x1024 pixels
  - Head-tracking necessary
  - Cockpit interior rendered
    - Instrument panel
    - Warning lights on panel
    - Cockpit window outline

# Christie Matrix StIM WQ

- For NVG stimulation
- 1 DarkChip3 DLP
  - Multicolor/IR LEDs
- LED Illumination
  - MTBF > 50,000 hrs
- Brightness: 800 ANSI lumens
- Contrast: 10,000:1 (dynamic)
- Resolution: 2,560 x 1,600 (WQXGA)
- Dual Input: RGB and IR; 60/120 Hz

# 5. Mission-related demands

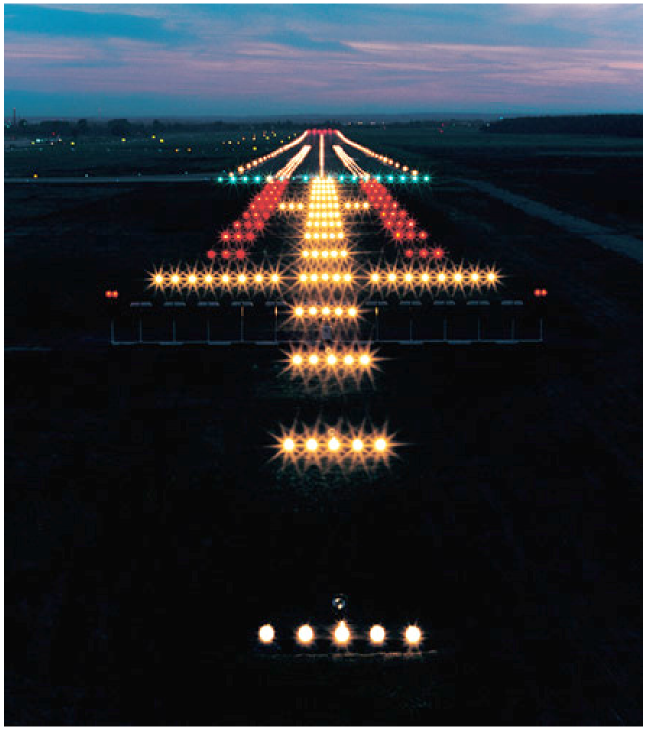
- Mission demands fall into 2 categories:
  - Temporal variations: Weather & time-of-day
  - Discrimination of distant or small objects
- Both categories also impact choice of IG

# Time-of-day requirements

- Day/dusk/night/all weather mission simulation
  - Daylight => full color + gray levels & high brightness
  - Daylight => high refresh rate (to avoid flicker)
    - 60 Hz @ 6 ft.L.
    - Dusk/night can be 30-40 Hz
  - Rendering lights & surfaces

# Raster vs. Calligraphy

- Calligraphy (using CRTs)
  - Exact positioning of lights
    - Linear deflection => More power
  - Brightness via dwell (~ 1μsec)
  - Light point growth via defocus
- Raster (raster or matrix)
  - Raster deflection =>low power
  - Position depends on pixel structure
  - Brightness via pixels (40 nsec/pixel)



# Uses of calligraphic lights

JFK Airport (E&S)

Calligraphy needed for runway edge lights to punch through fog

# Why calligraphy unnecessary?

Matrix spatial light modulator (e.g., LCD, DLP)

- High resolutions available
- Millions of pixels vs 500,000
- Progressive vs 2:1 interlace
- Illuminator of SLM determines brightness (>10x CRT)
- Excess brightness => Good light/surface contrast
- Caution: Need gray scale control at low light levels

# Calligraphy and the FAA

- Calligraphy used to be necessary
- FAA now certifies Level D w/o calligraphy
- Warp & blend achieved with auxiliary electronics

# Electronic Add-Ons

- SLMs need alternative to “raster warping”
  - Electronic corrections enable FOV expansion using juxtaposition of low-cost SLM projectors
    - Edge-blending; color matching; geometry correction
    - Leverages consumer/commercial equipment
  - Examples:
    - RC/SEOS Mercator & DigiBlend
    - ChristieTWIST
    - 3D Perception nBox

# Resolution requirements

- Target acquisition; Judging distance
  - Ideal resolution: Acuity of eye
  - ~1 arc-minute = 1/60th of a degree
- Recall: Johnson Criteria set resolution standards for E/O sensors
  - Criteria often applied to displays in general

# Sample problem

- A low-cost tank trainer uses an HMD as its visual display
- HMD provides binocular color image having:
  - FOV = $40^{o}$ V x $55^{o}$ H
  - 480 lines x 640 pixels/line
- At what range is object “recognizable” as a cow and not an enemy tank?

# Recall: Johnson criteria

| Discrimination Level | TV Lines per minimum dimension |
|---|---|
| Detection | 2 (+1.0/-0.5) |
| Orientation | 2.8 (+0.8/-0.4) |
| Recognition | 8.0 (+1.6/-1.4) |
| Identification | 12.8 (+3.2/-2.8) |

# Problem Solution

- "Recognition" requires 8 raster lines to subtend cow height = 5 ft.
- Center 8 raster lines of HMD subtend:
  - Angle (deg.) = 8 x arctan[(2/480) tan 20$^o$]

    = 0.7$^o$, or 0.0121 radians
- A 5-ft high object subtends 12 milliradians at a range R of:
  - R (ft.) = Height/Angle = 5 ft./0.0121 radian

    = 412 ft. (dangerously close!)

# Changes: FOV & Resolution

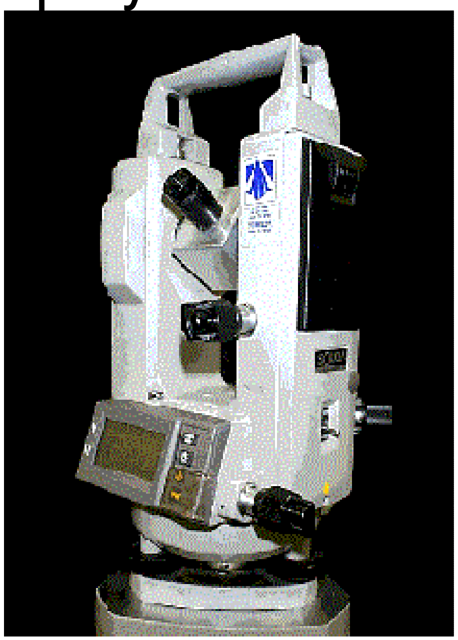
- Reduce HMD FOV to $24^o$ x $32^o$
  - "Recognition" range *increases* to <u>706 ft.</u>
    - Disadvantage - More head-scanning required
- Also increase resolution to 1024 x 1280
  - "Recognition" range *increases* to <u>1,510 ft.</u>
    - Disadvantage - 4x more pixels => greater cost

# Display Measurement

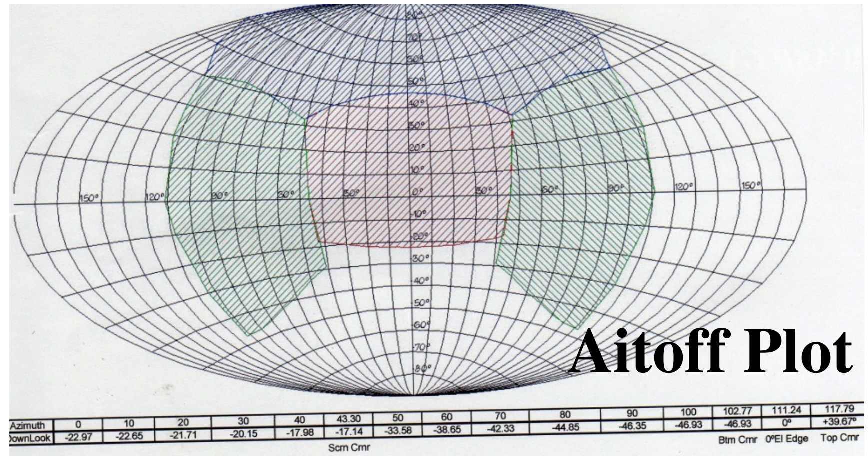
- *Optical* parameters of greatest interest:
  - FOV
  - Brightness & brightness uniformity
  - Contrast
  - Resolution
  - Color & color convergence; NVG “stimulation”
  - Geometry/distortion & Viewing volume
  - Image distance & Eye relief
  - Adjustability / Maintainability
- Also, must worry about motion envelope & rigidity

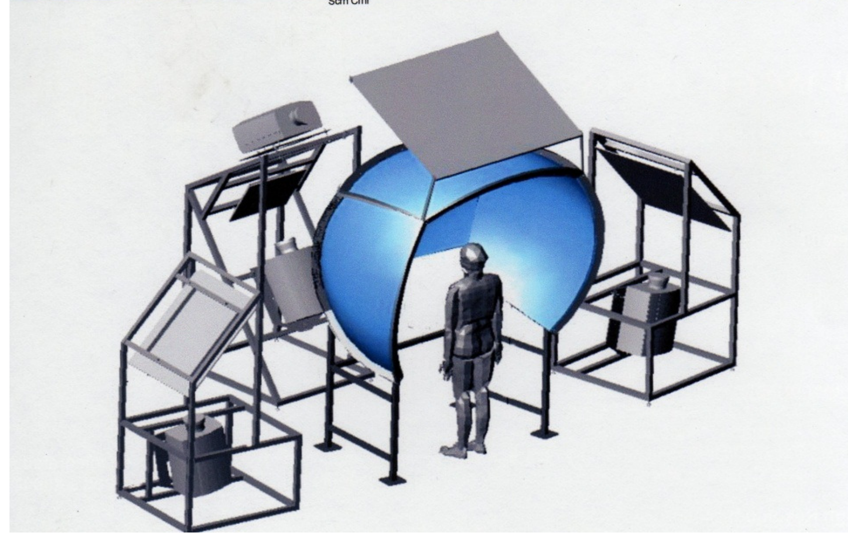
# Field Of View (FOV)

- Field-Of-View (EL; AZ)
  - Use theodolite at DEP
  - Window outline vs. Display Channels







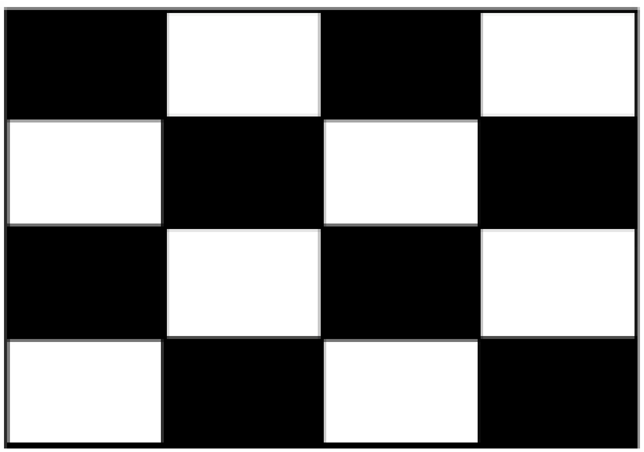



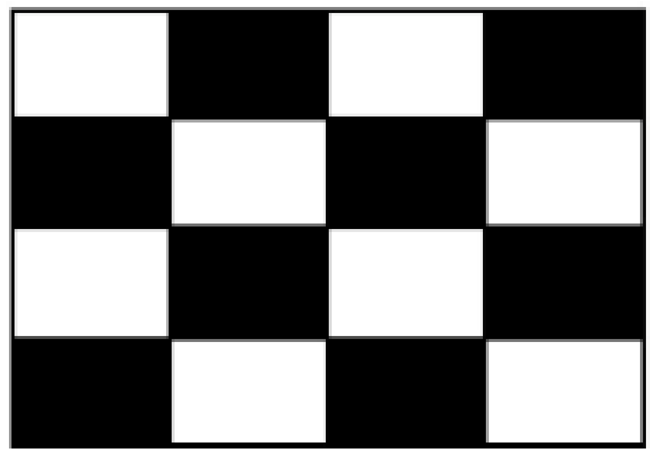
# Luminance

- Brightness
  - Lumen = luminous flux
  - Foot candle = illuminance
  - **Foot Lambert = brightness**
    - Measurable from anywhere
  - Can use an exposure meter in a pinch: L ~ 0.29 x 16 x $f^2$/(ISO x t)
    - L = luminance in ft.L.
    - f = f/stop setting of the lens
    - t = shutter speed (sec.)
    - ISO = film exposure index setting

# Contrast measurement

- Contrast
  - (Imax - Imin)/Imin [e.g., (50-0.2)/0.2 = 249]
  - Black-on-white or white-on-black checkerboard pattern used for measurement
  - Contrast Ratio = Imax/Imin:1

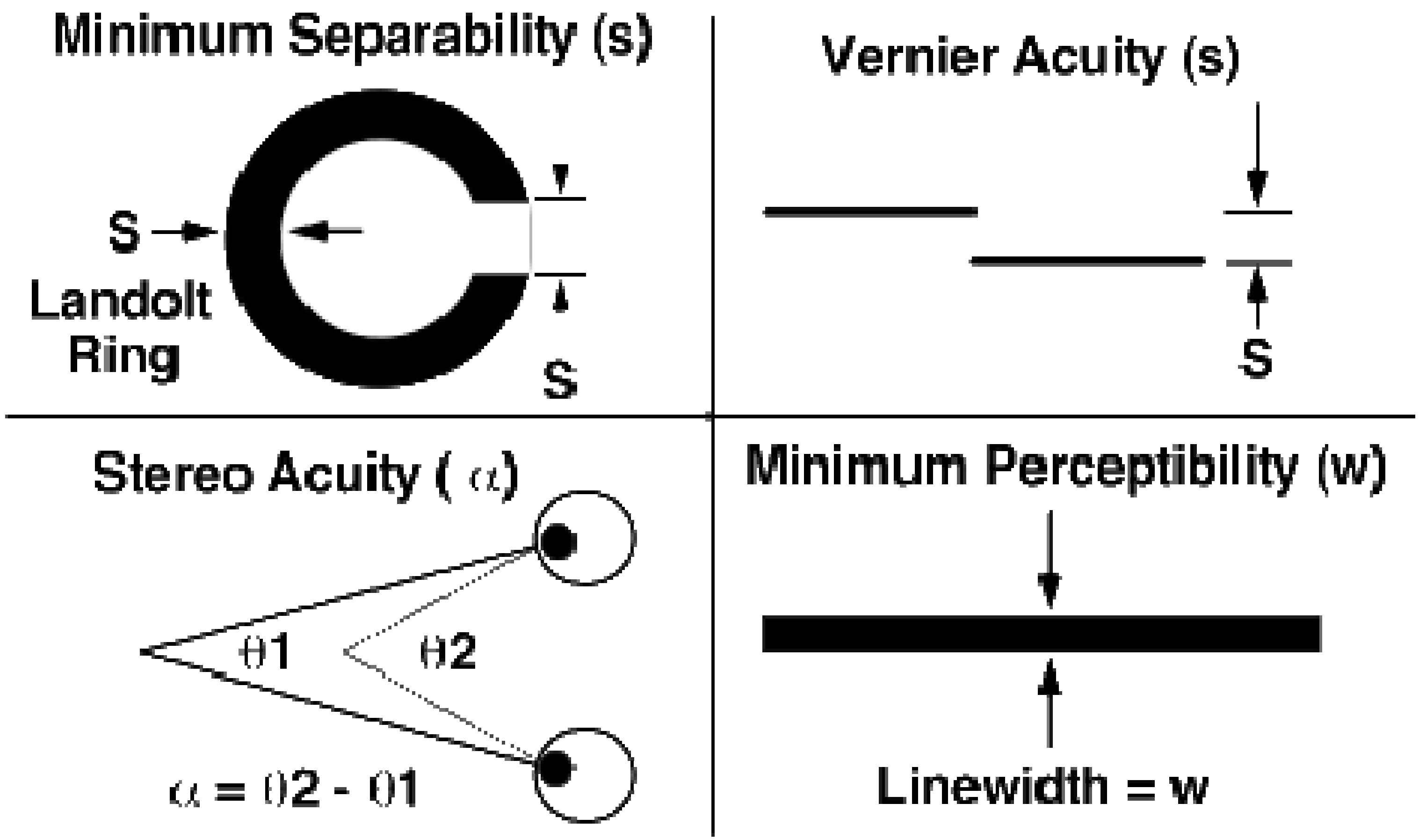




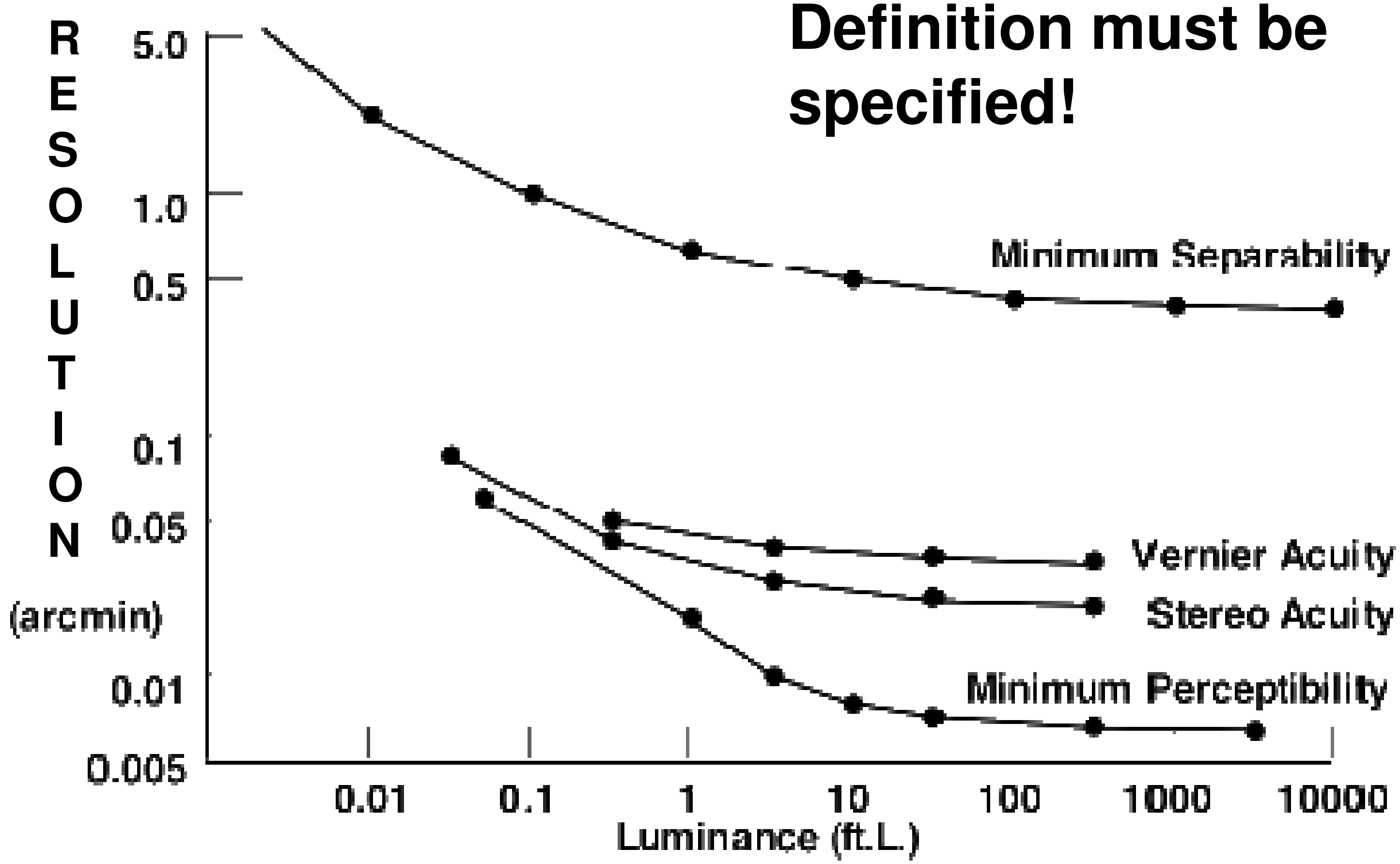
# Resolution measurement

- Resolution is a function of IG video output, cabling, and display characteristics
- Spatial & temporal dependence
  - Vertical ≠ Horizontal
  - Static ≠ Dynamic
- Nomenclature
  - TV Lines; Optical Line Pairs; Pixels (total # or angular subtense); MTF

# Measures of resolution



# Resolution sensitivity



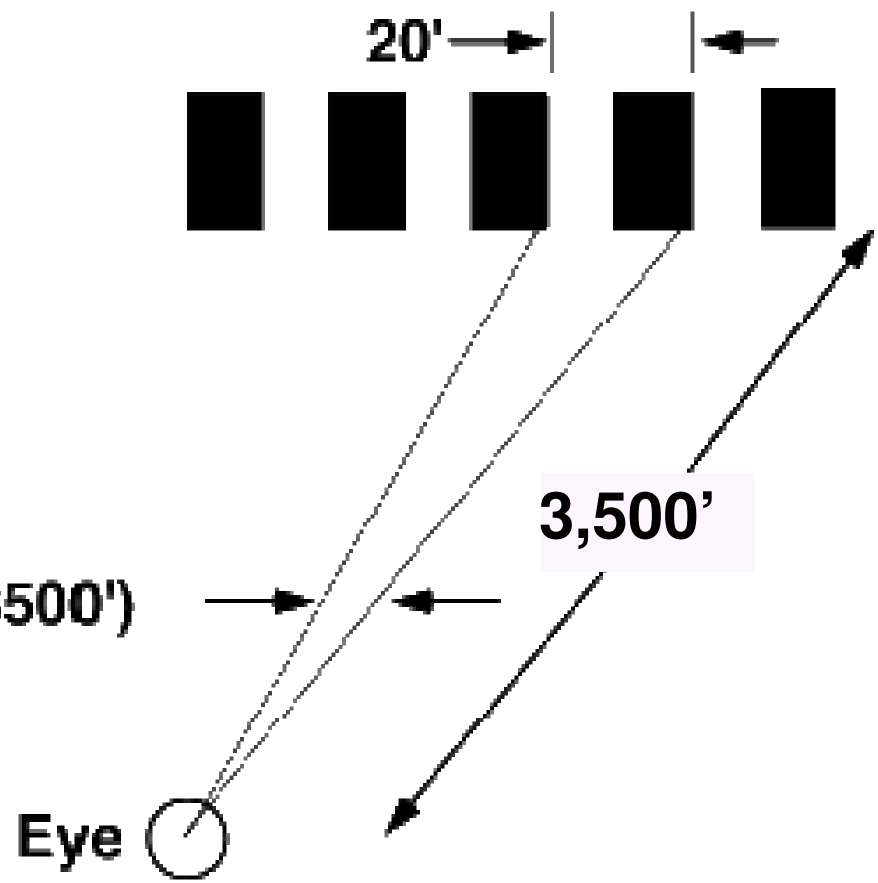

**Definition must be specified!**

# Ex: Static Resolution

**STRIPE PATTERN FOR MEASUREMENT**

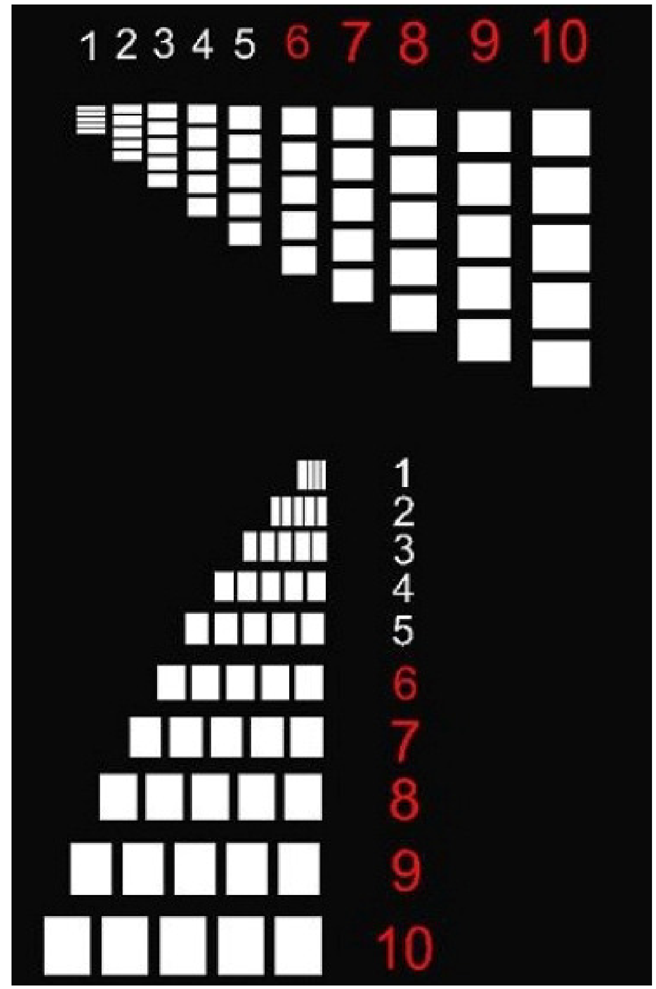
- Often an "operational" definition
- *Minimum Separability*
- In example, 0.33° / OLP

ANGLE = 2 arctan (10' / 3500')
= 0.33°



# Test Pattern for LCoS Smear

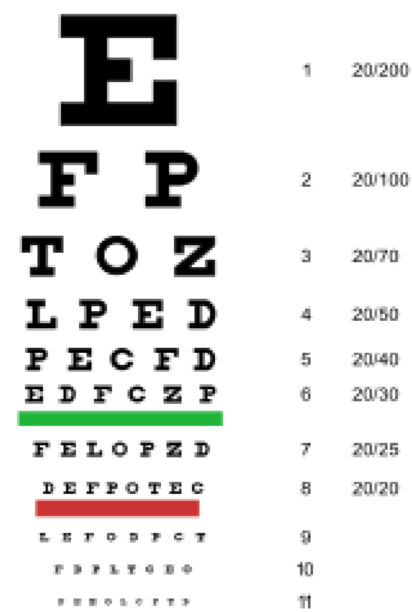
- Ref: FAA, “FSTD Qualification Guidance Bulletin #06-02, LCoS Visual Display System Evaluation”
  - For “dynamic” resolution
  - Numbers correspond to size in arc-minutes of a white bar and its spacing
  - Translate at 10º/sec in pitch & yaw while observing @ 5 arc-minutes. Resolvable => PASS



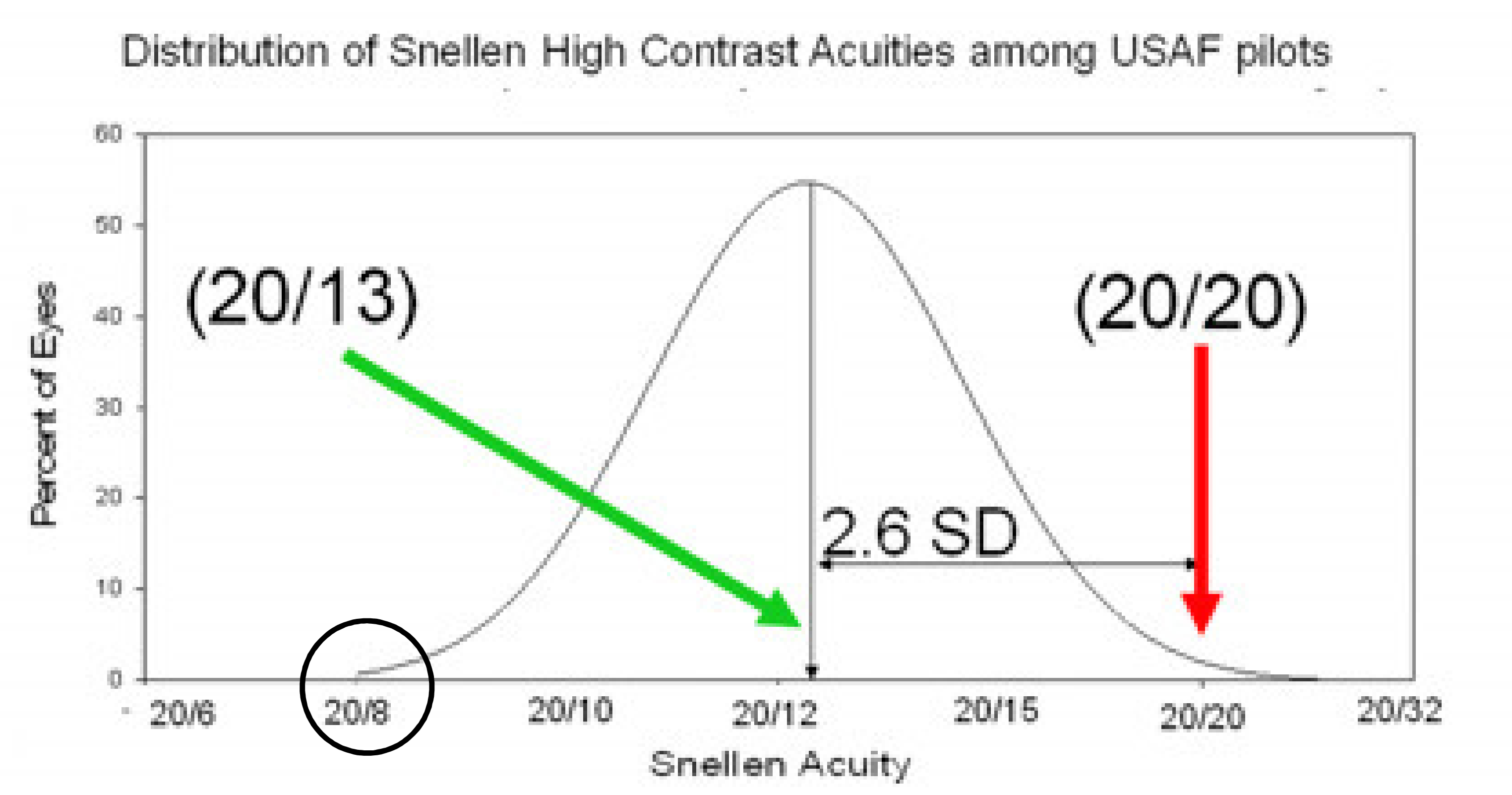
# Snellen resolution metric

- 1 arcmin = 20/20
- Viewing a 3 arcmin image is like viewing a high-resolution scene with uncorrected 20/60 vision

| Pixel size | Resolution |
|---|---|
| 1/2 arcmin | 20/10 |
| 1 arcmin | 20/20 |
| 3 arcmin | 20/60 |
| 5 arcmin | 20/100 |



# Acuity of USAF Pilots



# Modulation Transfer Function

- Modulation = (Imax - Imin)/(Imax + Imin)
  - Same as Michelson's formula for contrast
  - MTF = f(spatial frequency)
  - Modulation just discernible at ~10% MTF

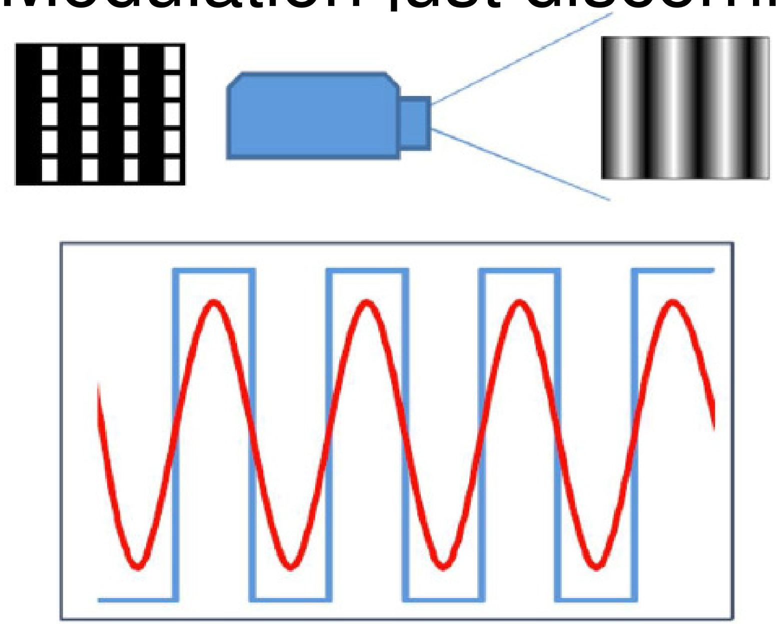


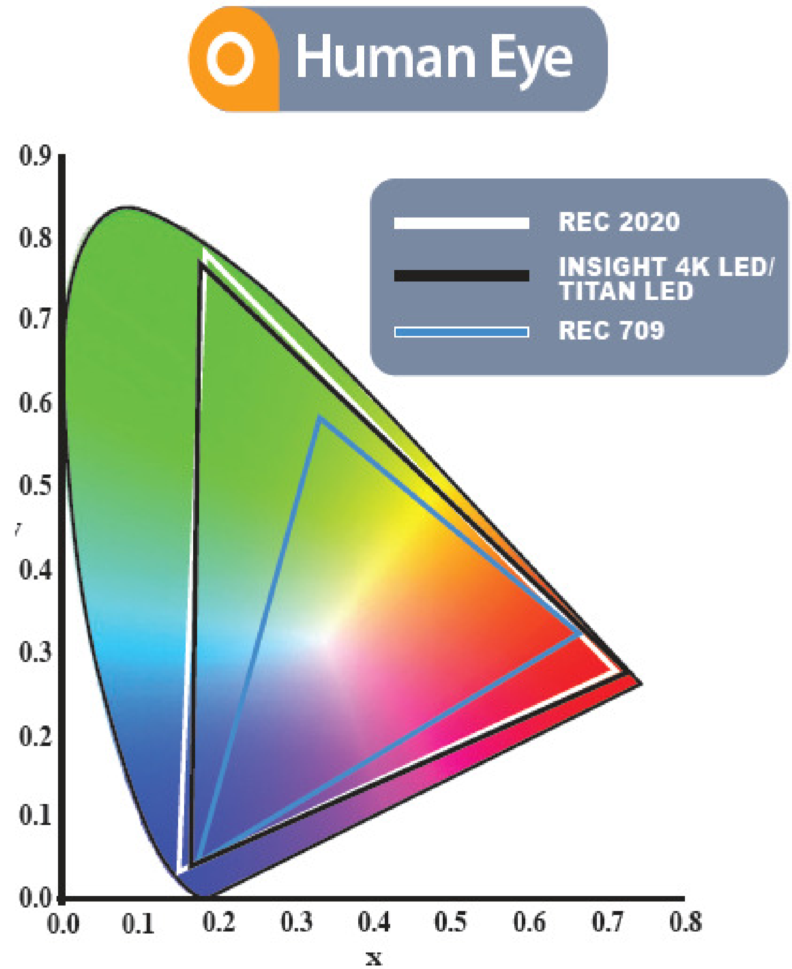
Figure from: Showell, "Developing Standards and Metrics for Projection Screens", IMAGE 2015 Conference, 7-8 July 2015.

# MTF degradation

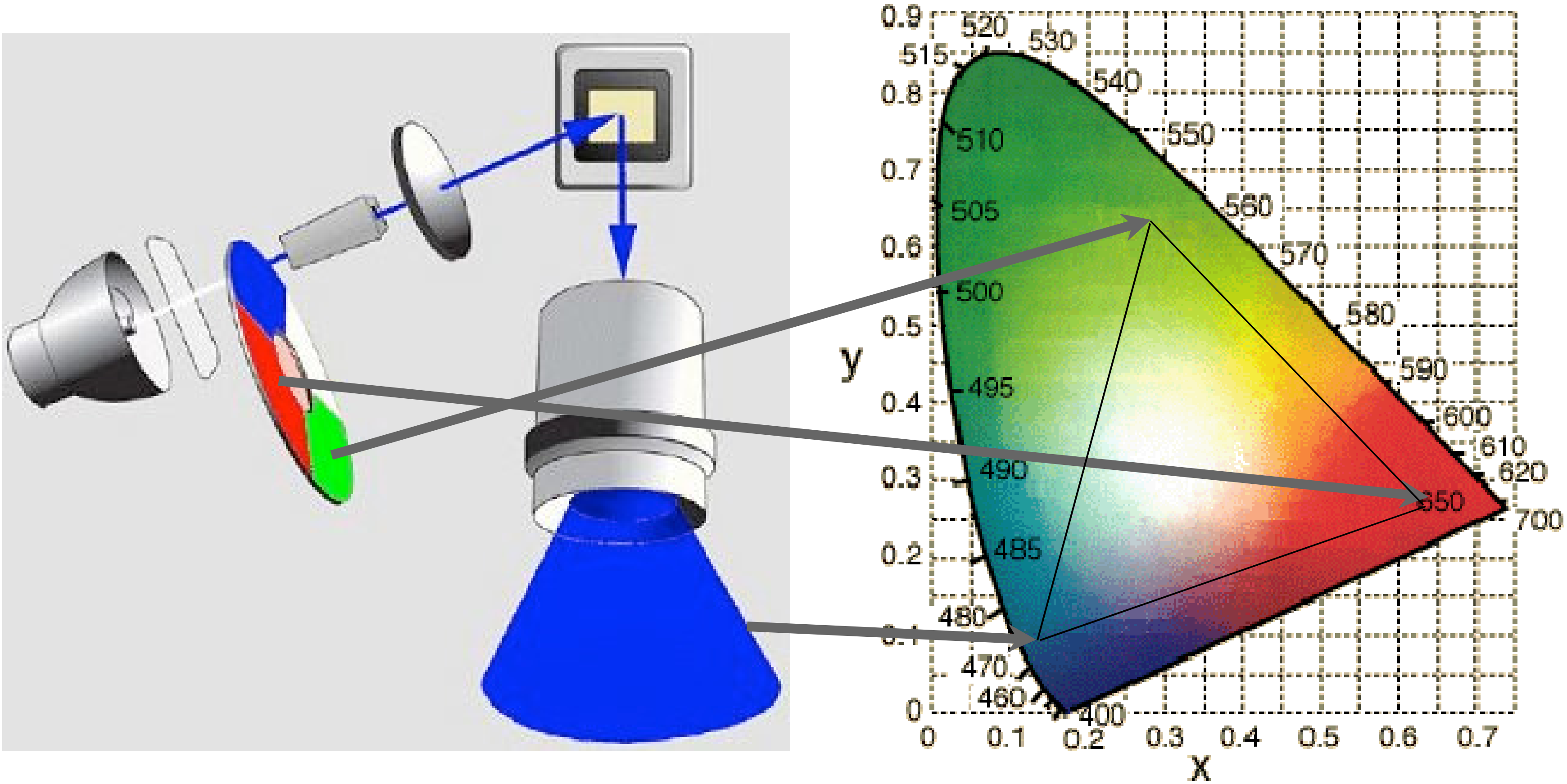
- What does MTF = 0.5 at 1 lp/arcmin mean?
  - Answer: Image detail of 1 lp/arcmin at full intensity modulation (1) is seen as having reduced modulation (0.5) => Contrast less, too
- Possible causes
  - CIG trade-off: e.g., anti-aliasing
  - Display limitations – e.g., lens roll-off
  - Cabling – Acts as LPF if too long

# Color & Color Convergence

- Color
  - Measured with a patchwork of colors
  - Plot on a Kelly Chart
  - REC 709 - HDTV std
- Color Convergence
  - Affects color purity and resolution
  - Spatial/temporal variation common in CRTs; not SLMs

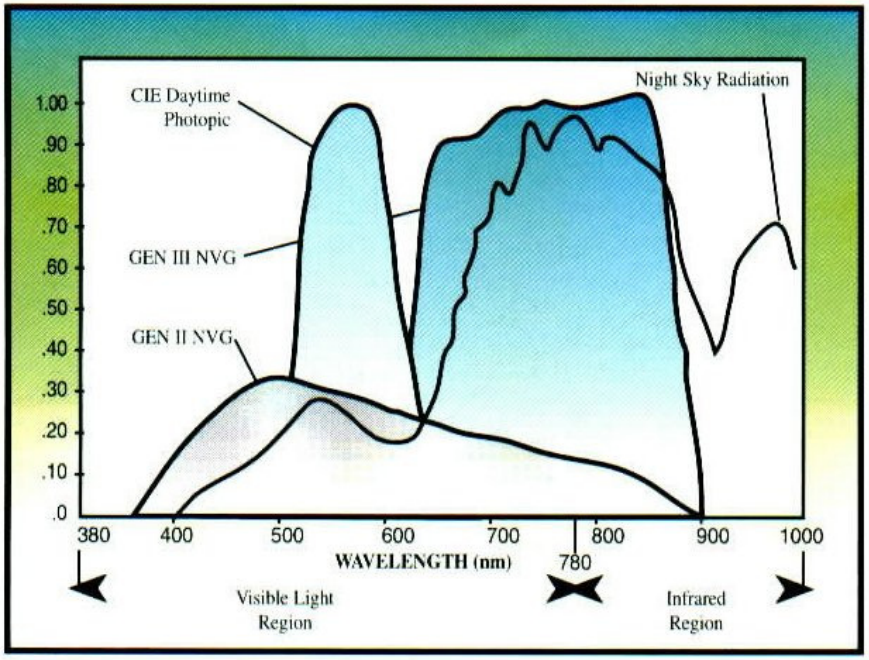


# Sequential Color



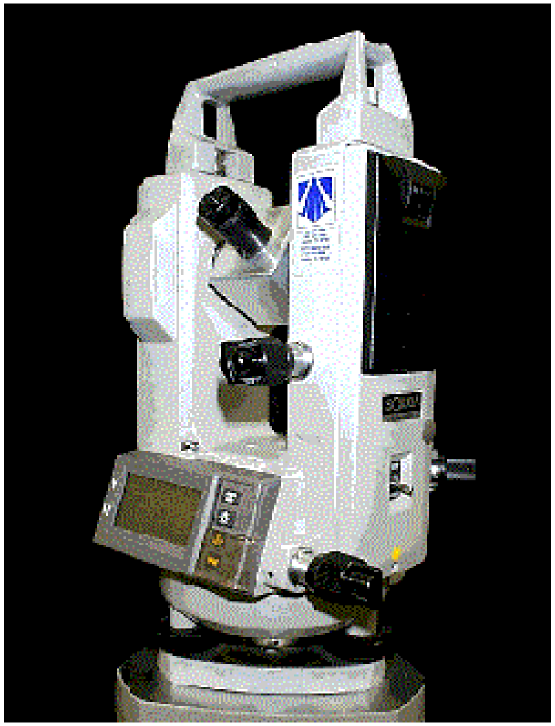
# NVG Stimulation

- Represents another set of constraints on color performance
- Must simultaneously optimize both night visual scene and NVG scene arising from night sky and lunar illumination
  - Wavelength bands don't overlap!

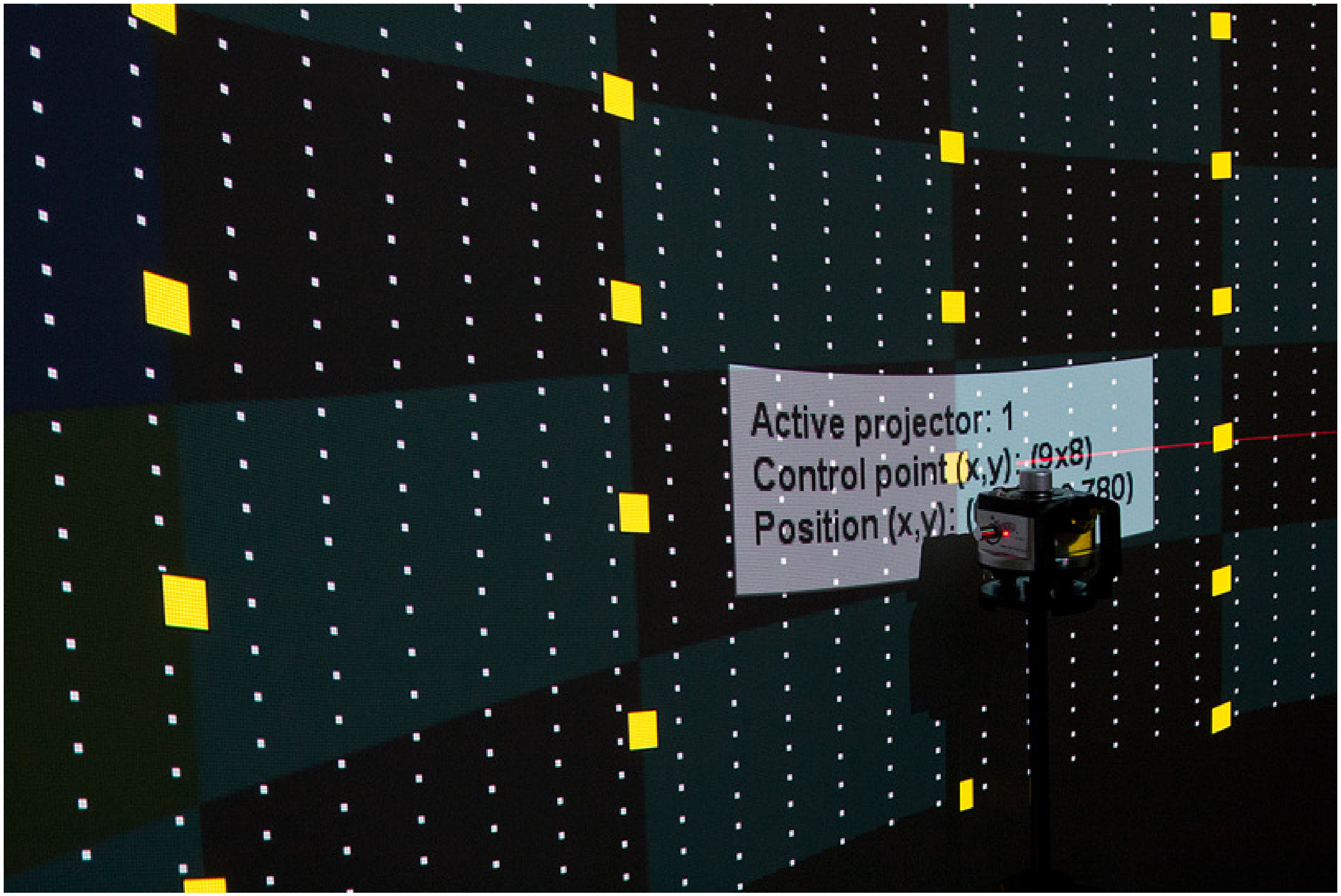


# Geometry measurement

- Geometry
  - Judge distance, speed, & height
  - Measured with grid test pattern & theodolite at reference eye point
  - Absolute error < $3^o$
    - Rel. geometry: +/-$1^o$ per $5^o$ spacing
    - Curved screens => more correction
  - Viewing volume = Region of "acceptable distortion"
    - Smaller components lower cost, but at expense of viewing volume

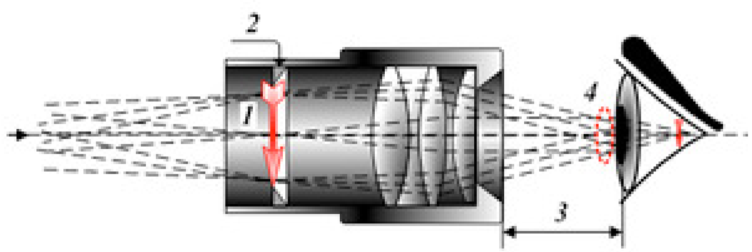


# Geometry Correction



# Image Distance & Eye Relief

- Measured with Vergence Meter
  - Milliradians; Meters; Diopters (1/m)
  - Ex: 4 mrad = 17.5 m = 0.057 D
  - Standard vergence errors:
    - Horizontal: 0.1 to -0.05 Diopters
    - Vertical: -7.5 to +7.5 mrad
- Eye relief = Distance to nearest optical element

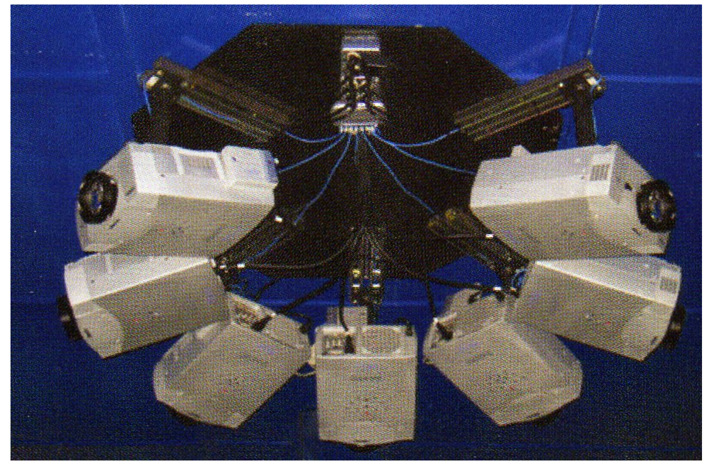



# Adjustability

- Imagery suffers if time-consuming adjustment inhibits tuning for peak performance.
- Type & range of adjustments important
- Standard display adjustments include:
  - Brightness, color, geometry, black level, and channel blending
  - Means of calibration

# Control of multiple displays

- Goal: Enhanced performance
  - Ease of use –> alignment often
  - Ease of use –> reduced labor time & costs
- Remote adjustment units widely available
  - Generally digital
  - One unit controls all
- Ex: Barco* xRACU
  - Controls 12 (or 32) projectors
  - Color, brightness, contrast, etc.



# Corrections for dome screen

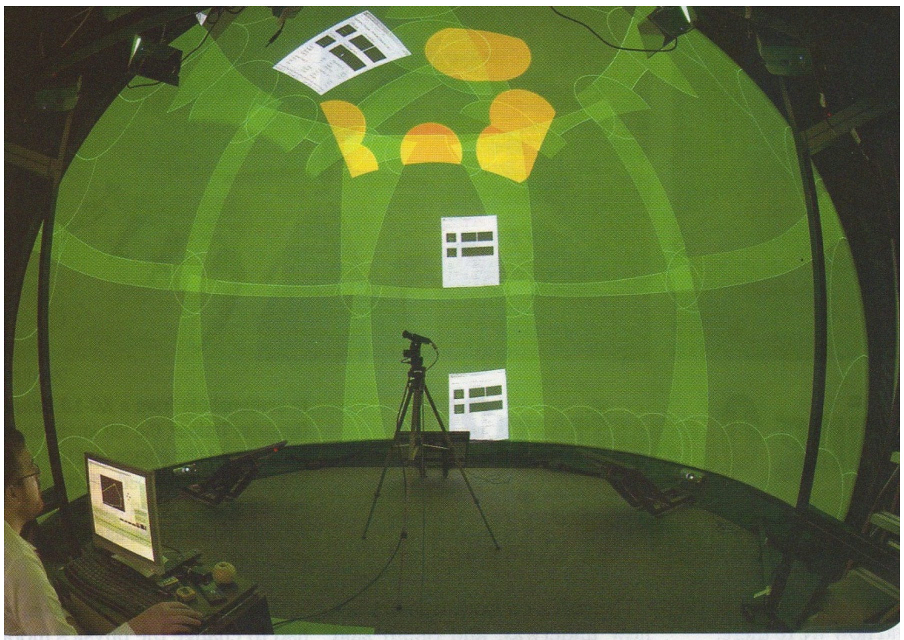
Image needed for pilot

Image warped for display

ref: Beechey, et.al., “Development of the AH-1Z Full Flight Simulator for the US Marine Corps”, AHS 67th Annual Forum (Virginia Beach VA) 3-5 May 2011 – Figure 22.

# Example of alignment

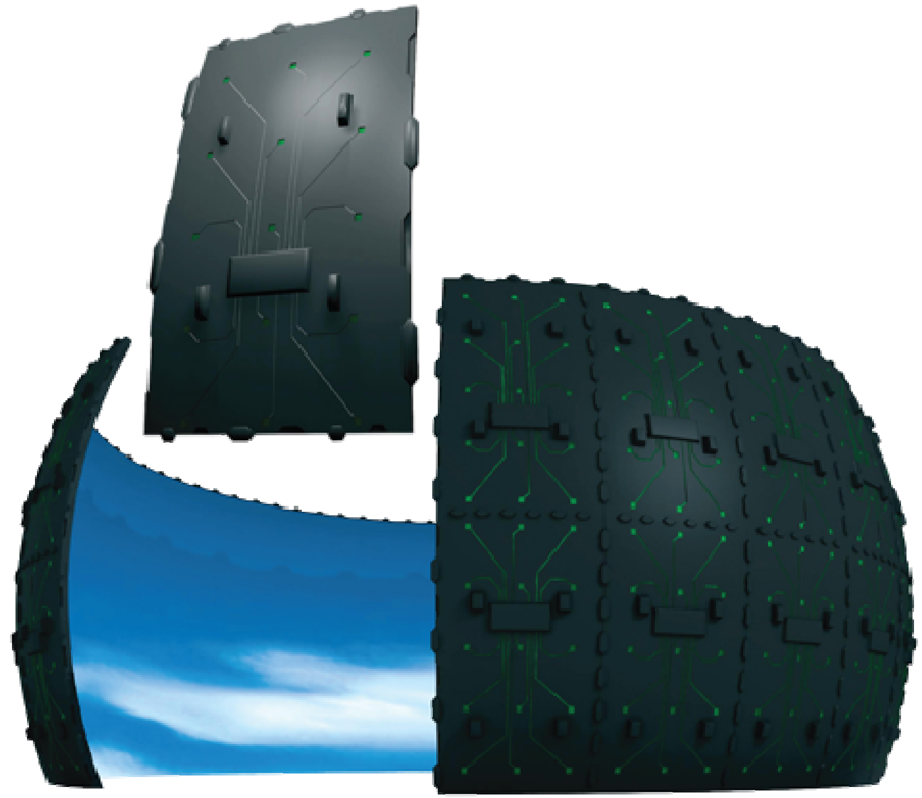
**Before** | **After**



**JTAC Virtual Trainer Dome at AFRL (Electric Picture)**

# Ex: Auto-Alignment

- Modular screen
  - Embedded sensors communicate with nBox display processor to adjust geometry, edge blending, and color automatically
  - Available in spherical; conical; cylindrical; flat



**3D perception's**
*Aurora smart screen*

# Technology Classification

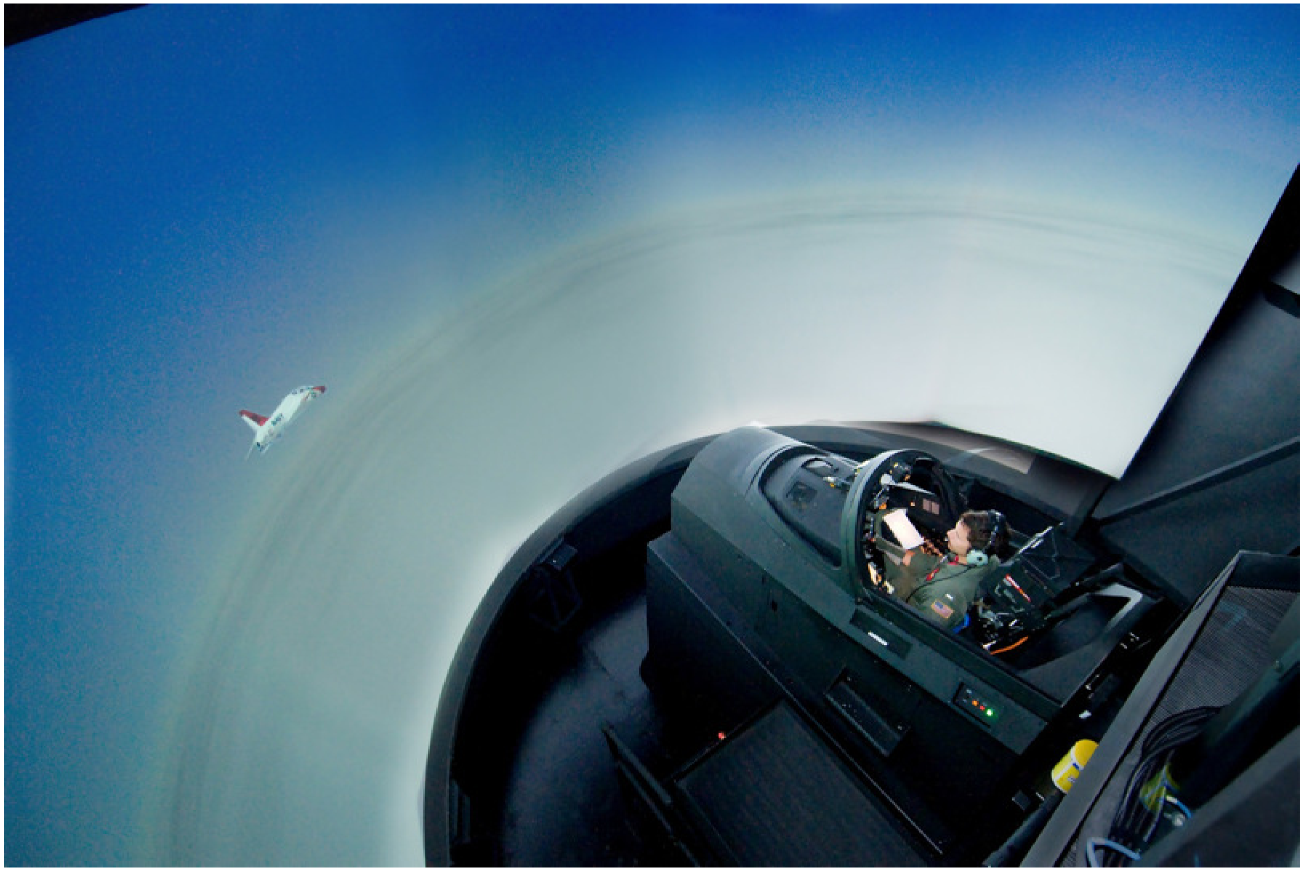
- Types of display currently in use:
  - *Screen front-projection, or monitor viewing (real images)*
  - Screen rear-projection (real images)
  - Monitor- or projector-driven collimation (virtual images)
  - Target-tracked AOI
  - Head- or head/eye-tracked AOI
    - Includes Head-Mounted Displays (HMDs)

# TREALITY (Barco) SEER

- Small Environment Enhanced Reality
  - Constant eye relief over entire FOV
  - Seamless spherical projection surface
  - 4, 5, or 8 channels

# T-45C Simulator @ NAS Kingsville TX

FOV: 180º using 5 x BARCO* Sim 7 projectors



# Barco* Sim 7Q HC LCoS Projector

Resolution: QXGA (2048 x 1536)
using 0.82” LCoS @ 4:3 aspec

Dynamic Range up to 20,000,000:

- Contrast Ratio up to 40,000:1

Luminance: Up to 2,800 lumens

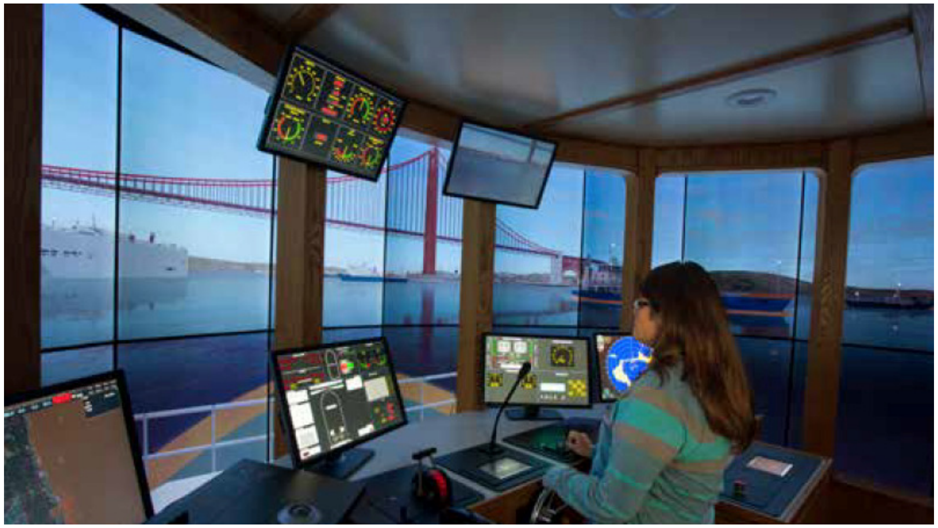
- 380 Watt UHP Lamp
- Suitable for Gen 4 NVGs
  - Twin irises for frame time & ft.L.

Latency: ~2 msec

Weight: 60 lbs. + lens

# SUNY Maritime College

- From “Electric Picture” Display Systems
  - Trains future tugboat captains
  - (38) x Samsung 55” UD Series video wall displays stacked in pairs => 270º arc at bow
  - (2) x 65” MD Series displays for stern view

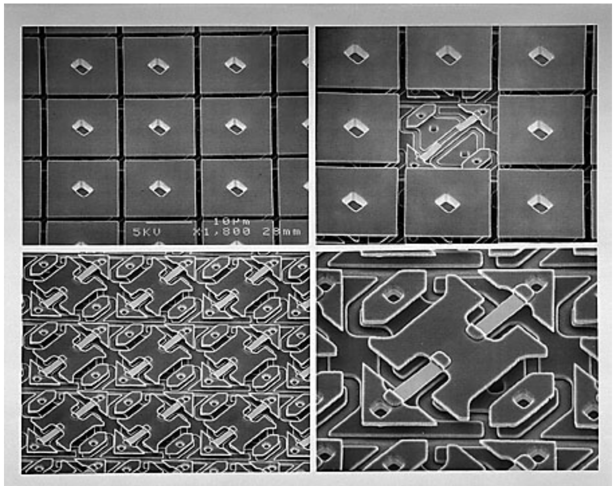


# JTAC MiniDome

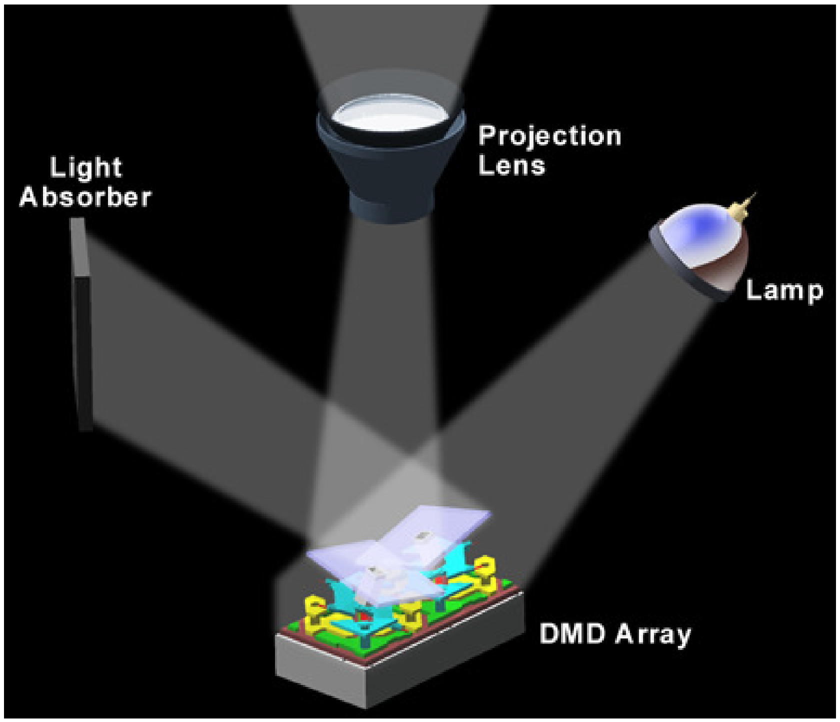
- Product of *Immersive Display Solutions*
- Ex: ImmersiveDome 500C with integrated light-block enclosure
  - Collapsible; fabric
  - 5.0 m diameter
  - Multiple DLP projectors

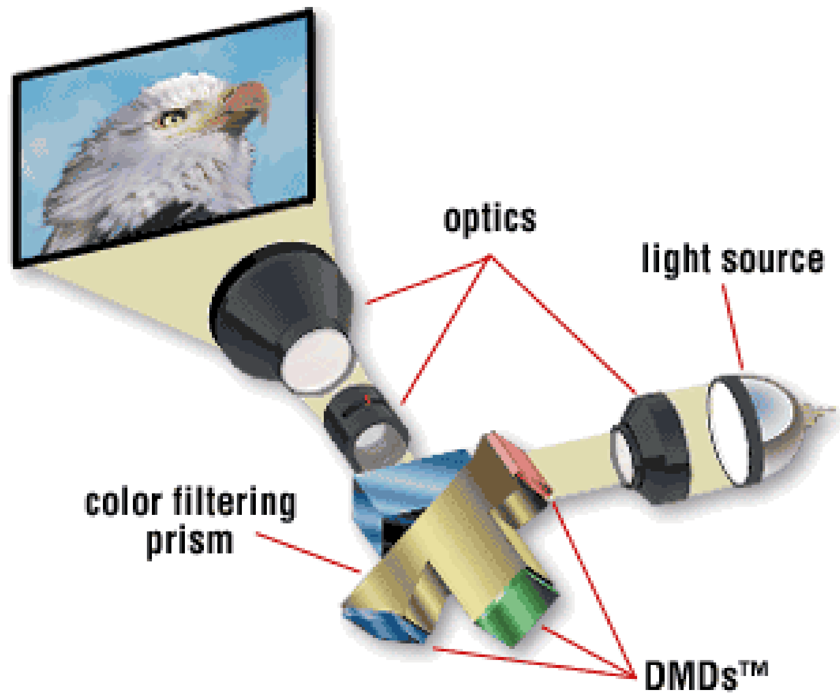
# DLP Light Valves

- Arrays of small micro-mirrors
  - Reflective semiconductor light switches
- Obtaining full-color
  - 3 DLPs (RGB) + optical blending
  - 1 DLP + color-wheel
  - 1 DLP + multi-color LEDs
- Gray-scale modulation
  - PWM; Ratio of ON/OFF time
- Mirror Array up to 2560 x 1600

# DLP modulation (3 panels)



# Ex: 3D Perception F80

- Dual Lamp, 3-chip DLP
  - 1920 x 1200 (WUXGA)
  - Contrast = 15,000:1
  - 8,500 ANSI lumens
  - Weight: 57 lbs
  - Latency: < 23 msec
  - Warping, blending & color-matching via CompactUTM

# Ex: E-Vision 8000 Series from Digital Projection

- Single DLP: WUXGA (1920 x 1200 pixels)
- Brightness = 8,000 ANSI lumens
- Sequential Color Management
- 6-segment RGBCWY color wheel => Max lumens
- 6-segment RGBCMY => Optimized colors
- Swappable color wheels

# Barco (projectiondesign): FL35, F50, & F70 Trade-offs

- All single-chip DLP

| Parameter | FL35 | F50 | F70 |
|---|---|---|---|
| Light Source | LED | 350W UHP | Laser phosphor |
| Brightness (max) | 1,000 lumens | 5,000 lumens | 5,000 lumens |
| Lifetime (hrs) | Up to 100,000 | Up to 2,000 | Up to 60,000 |
| Resolution | 2560 x 1600 | 2560 x 1600 | Up to 4K UHD |

# SLM Aging - Symptoms

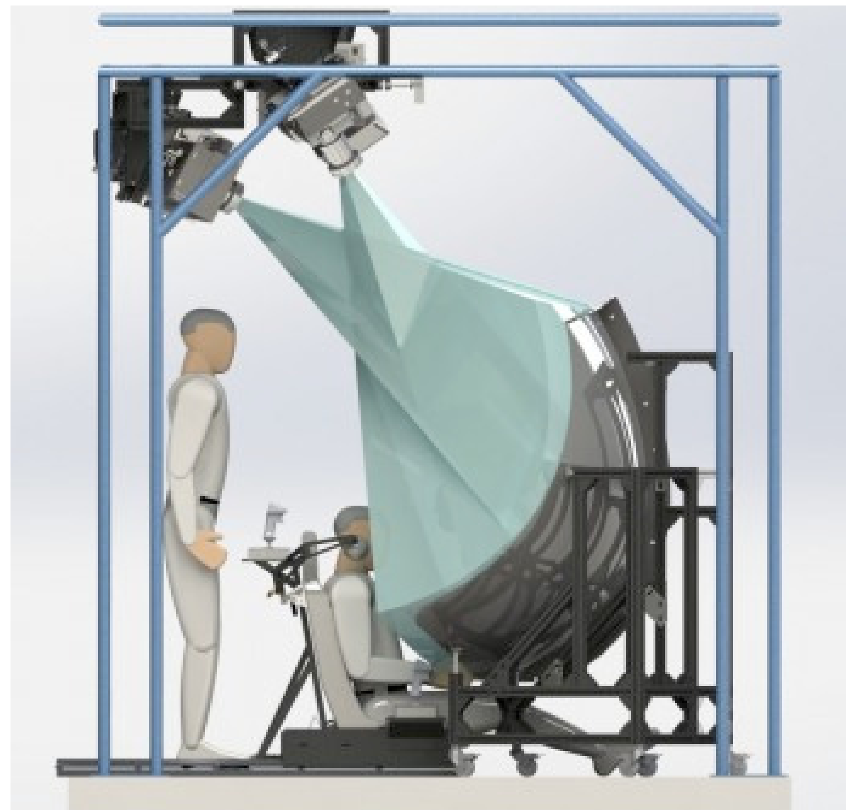
- Example: NADS - Night Scene
  - Aging effect of UV radiation

UHP Lamp + LCDs

LEDs + DLP

# Christie DualView Display

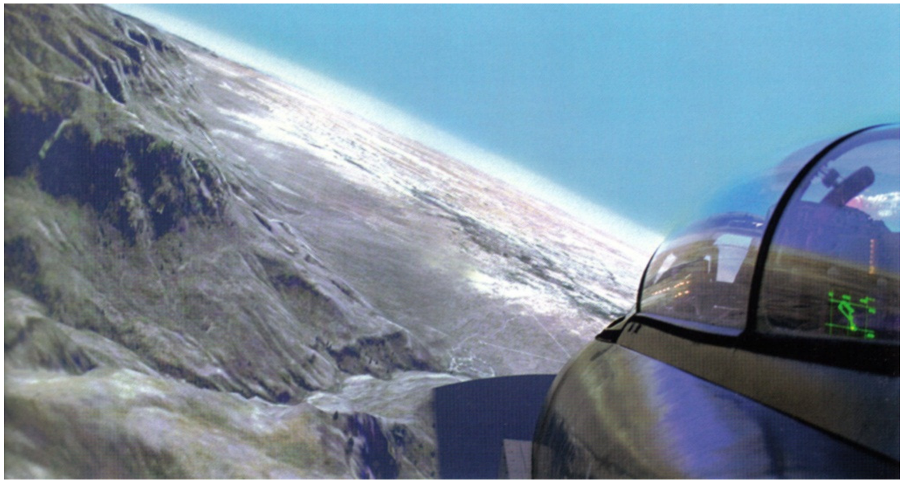
- I/ITSEC 2012 demo for underwater RPV control
  - Collaborative training
- 4 blended projectors
  - Electronic shutters
  - EP & Projectors toggled at 120 Hz
  - 9.2 Mpixels/EP
- Dual EP => Distortion = 0



# AVIOR Laser Projection System

- Product of Rheinmetall Defence Electronics GmbH starting in 2000
  - Initial sales for Tornado & MiG-29K simulators
  - Level D cert. on Lufthansa A-340 FFS in March 2007
  - XGA, SXGA, or UXGA (1600 x 1200) @ 60 Hz
  - One or two channels/laser source
  - Projection head & laser separable by up to 30 m
  - On Navy F-18 simulators
    - To support NVG, uses R,G,B, and IR wavelengths

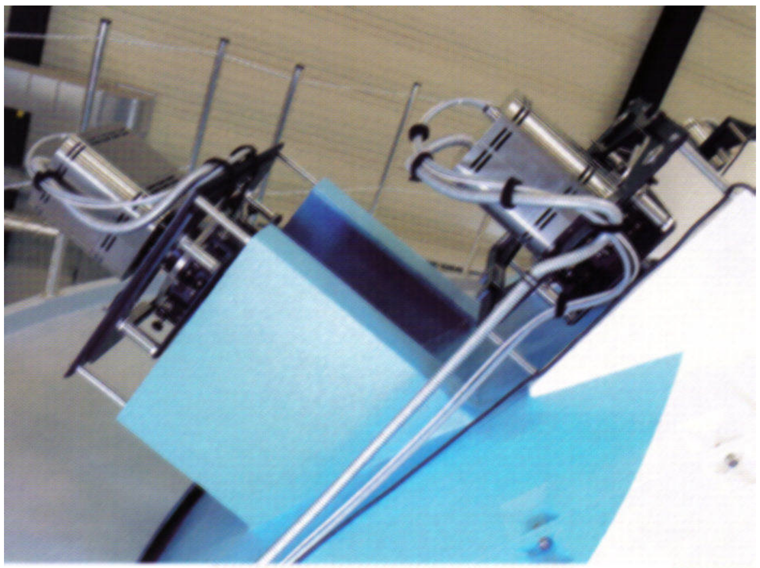
# AVIOR laser scene projection



Daylight scene

Night landing scene

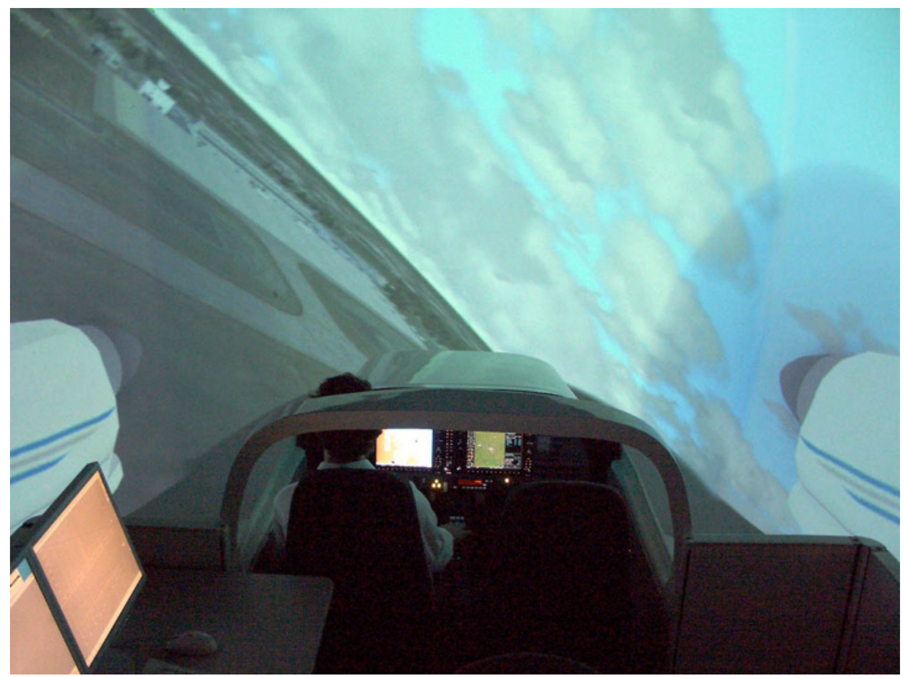
# AVIOR laser projector



Laser Head (~8 kg)

AVIOR VisIR
(400-700 nm OTW; 820 nm IR

# Diamond DA-42 Level 6 FTD

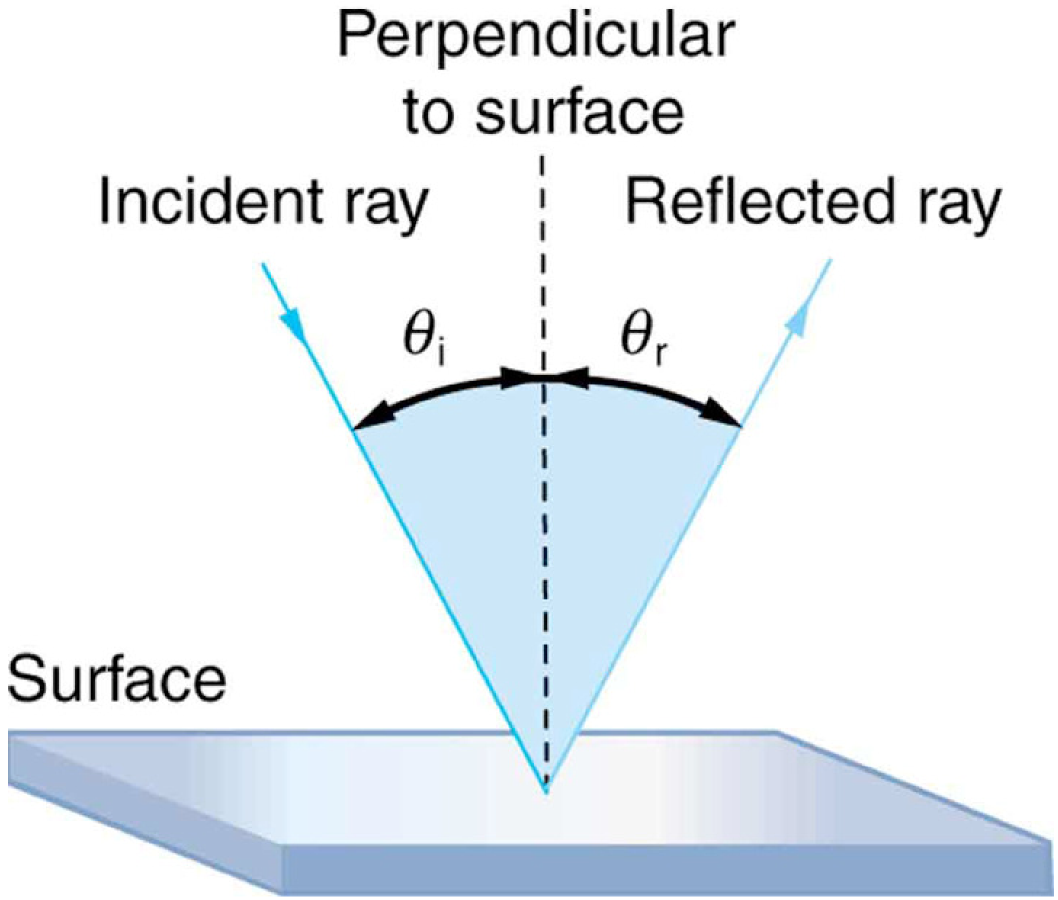



**Pictures courtesy: Frasca**

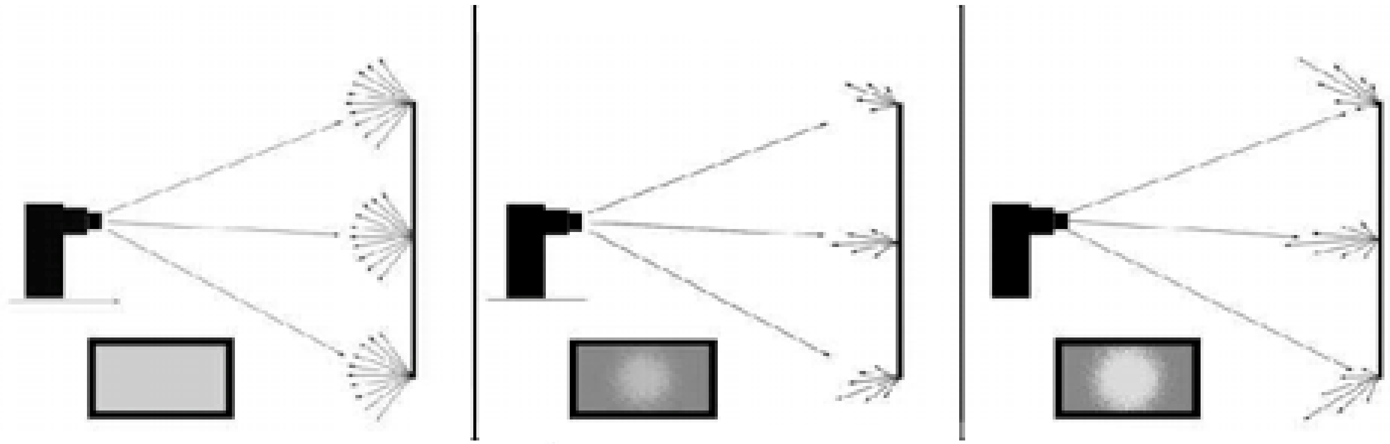
# Visual system for LM

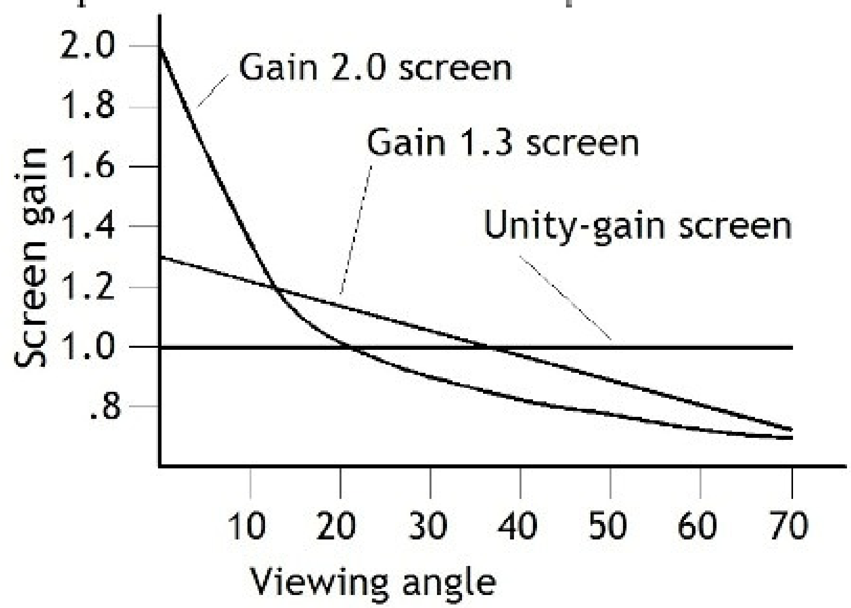
- System designed by Display Solutions
  - FOV = 150º x 55º on "tilted" cylindrical screen
  - 3 x DLP channels (3-D perception) that are geometry-corrected, blended, and color-matched

# Law of Reflection

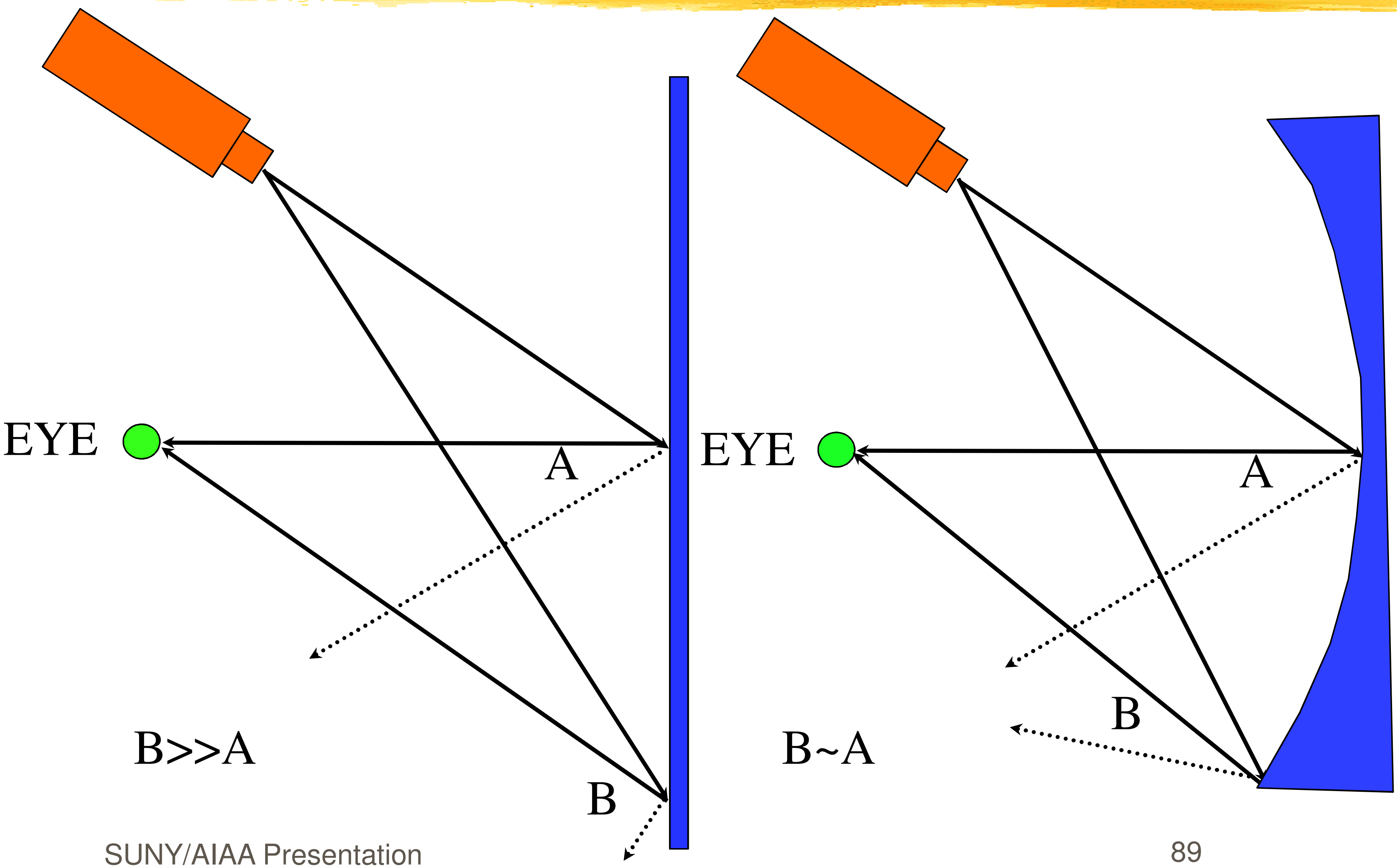


# Impact of Screen Gain





# Cylindrical vs. Spherical

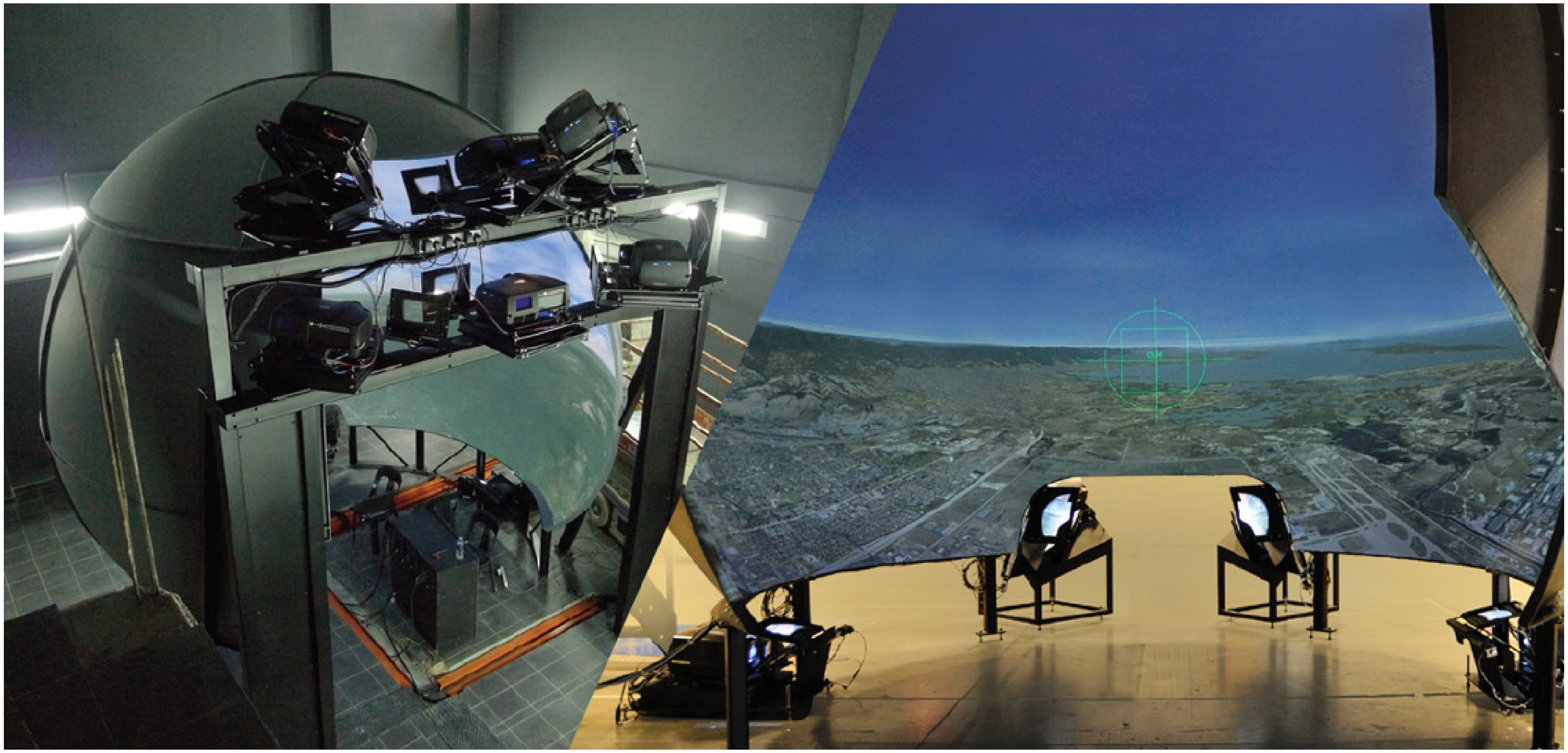


# Christie SEP Display

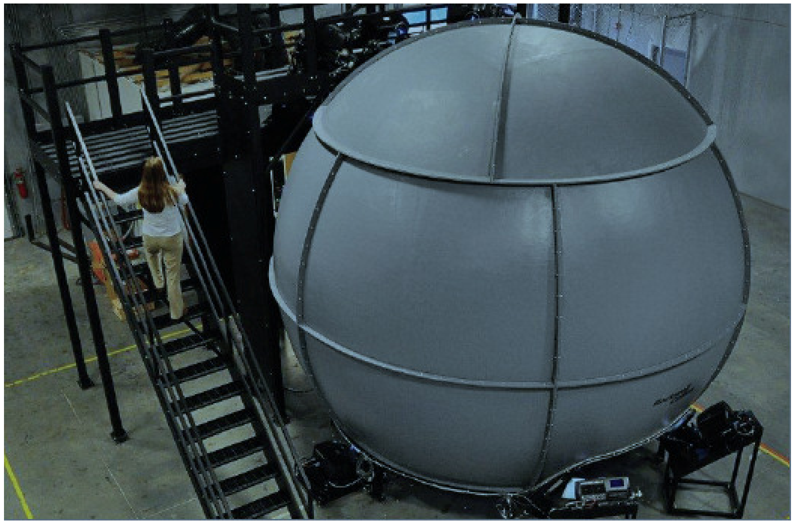
6 Projectors; 9 million pixels; spherical screen

# SpectraView

- Rockwell Collins front-projection display
  - Scalable: single seat, tandem; side-by-side



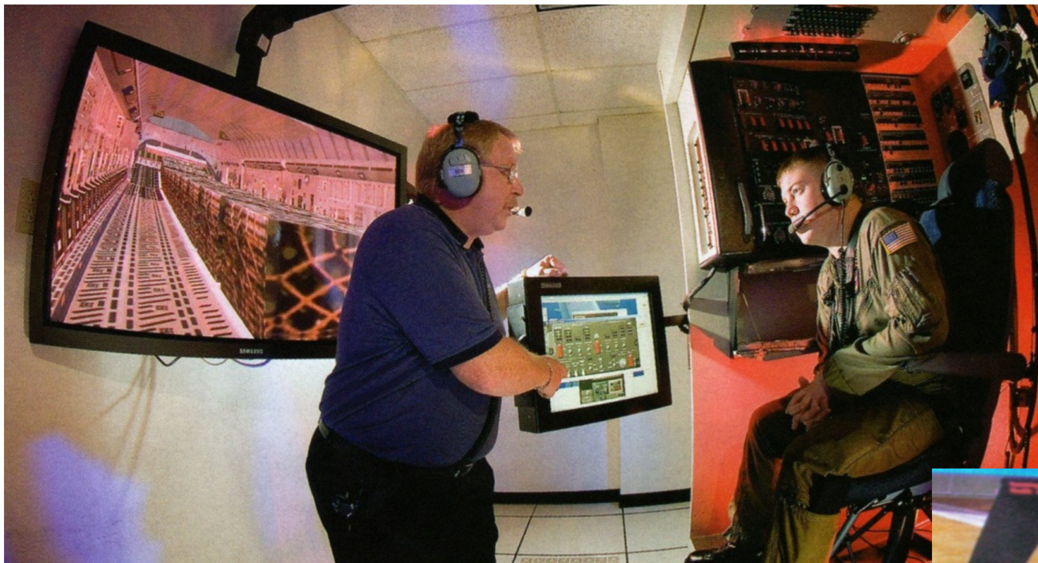
# SpectraView Performance



- FOV: Up to 320°H and 140°V
- Resolution: Up to 4 arcmin

| Dome Radius | FOV (H x V) | Channels | Projector |
|---|---|---|---|
| 1.8m | 270° x 115° | 9+HUD | 2015HC QXGA |
| 1.8m | 240° x 120° | 8+HUD | 2015HC QXGA |
| 2.0m | 180° x 45° | 3 | LCoS SXGA+ |
| 2.5m | 210° x 60° | 3+HUD | 2015HC QXGA |
| 1.8m | 220° x 140° | 5 | DLP SXGA+ |
| 2.5m | 320° x 140° | 10+HUD | DLP WUXGA |

# Limited FOV using FPD

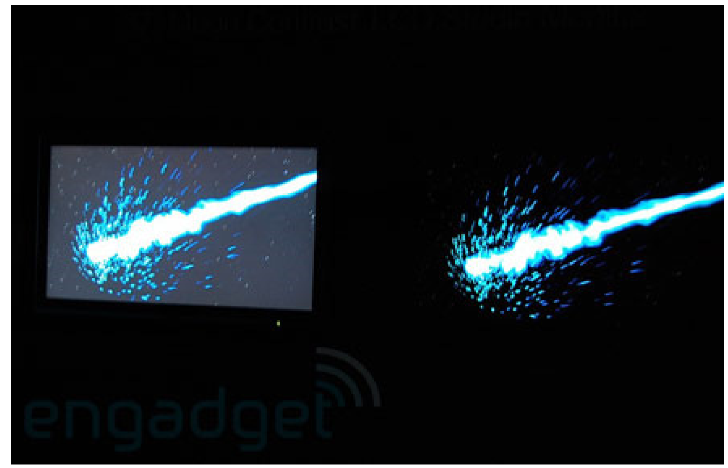


Loadmaster Station
of C-17 ATS

Earth moving simulator

# Flat Panel Displays (FPDs)

- Standard offering is Plasma or LCD
  - Up to 65" diagonal readily available
  - LCDs backlit with CCF or LED
  - 1080 NIL (HDTV) common & affordable
- OLED (Organic LED) becoming available
  - LG 65" Curved 4K UHD OLED TV
  - MSRP = $2,488 (WalMart)
    - Free shipping!



# NVIS Ranger 47 Binoculars

- Dual SXGA OLED micro-displays
  - 1280 x 1024 => 1.67 arcmin/pixel
- FOV = 47° diagonal
- IPD adjustment
- Independent ocular focus
- Dual video inputs => stereo
- 40 ft.L; 10,000:1 contrast
- Cost = $15,900 + tracker

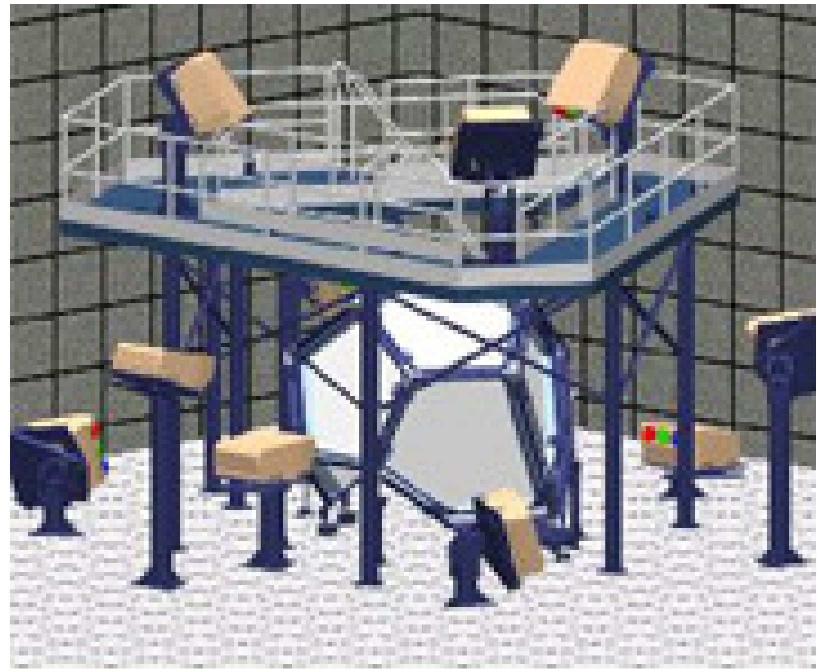
# Technology classification

- Types of display currently in use:
  - Screen front-projection or monitor viewing (real images)
  - *Screen rear-projection (real images)*
  - Monitor/projector-based collimation (virtual images)
  - Target-tracked AOI
  - Head- or head/eye-tracked AOI
    - Includes Head-Mounted Displays (HMDs)

# DART

- DART = Display for Advanced Research & Technology
  - Conceived at AFHRL (now AFRL)
  - Based on dodecahedron layout
  - RP using 6+ CRT projectors
  - Viewing distance ~ 1 meter
  - Versions include M2DART, VIDS, SimuSphere, Lucid, WASP, and SAFIR
  - Viewing distance ~ 1m


# L3-Link SimuSphere

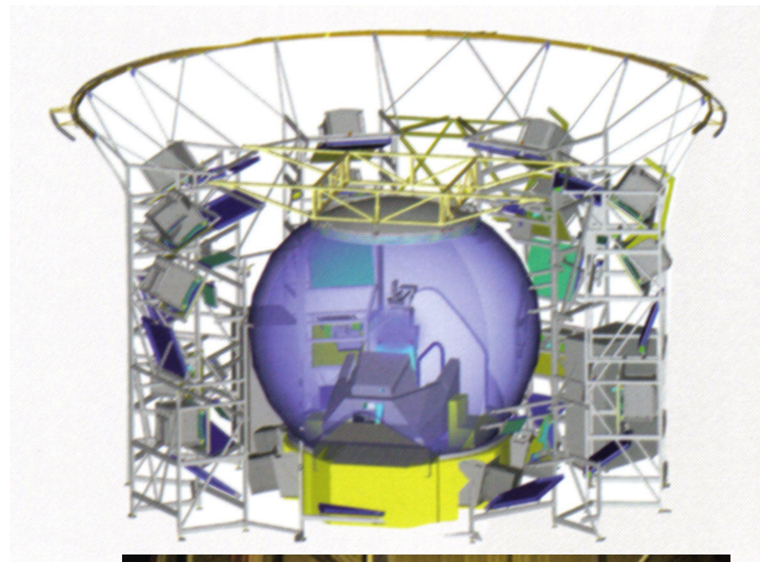


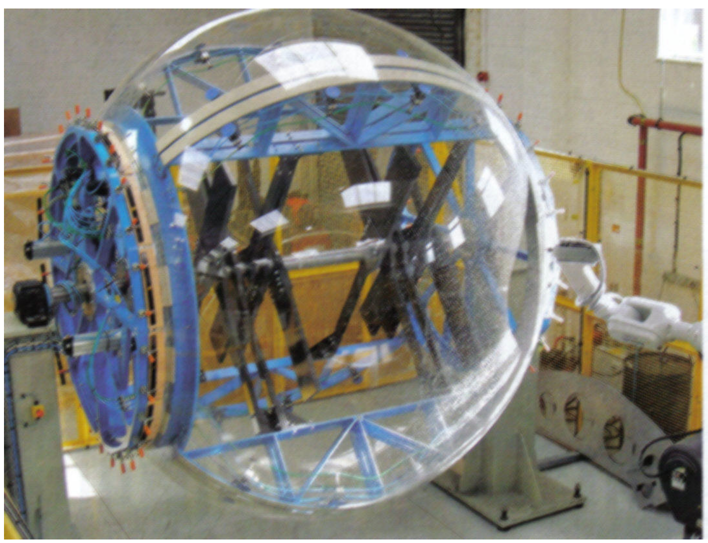
- 3-Facet: 180º H x 70º V
- 5-Facet: 300º H x 70º V
- 5-Facet: 180º H x 130º V
- 7-Facet: 300º H x 130º V
- 9-Facet: 360º H x 130º V

# Barco*/TREALITY RP-360

- Launch customer: IAI
- Uses 13 Sim10 projectors
  - MTBF ≥ 20,000 hrs (excl. lamp)
  - Brightness = 10 ft.L.
  - Resolution = 2.9 arcmin/OLP
  - Ethernet connectivity between projectors
    - Auto-corrects for brightness & color drift
- Sim cost < $2 million ea.

# R-C Griffin for LM F-35 JSF





# Technology classification

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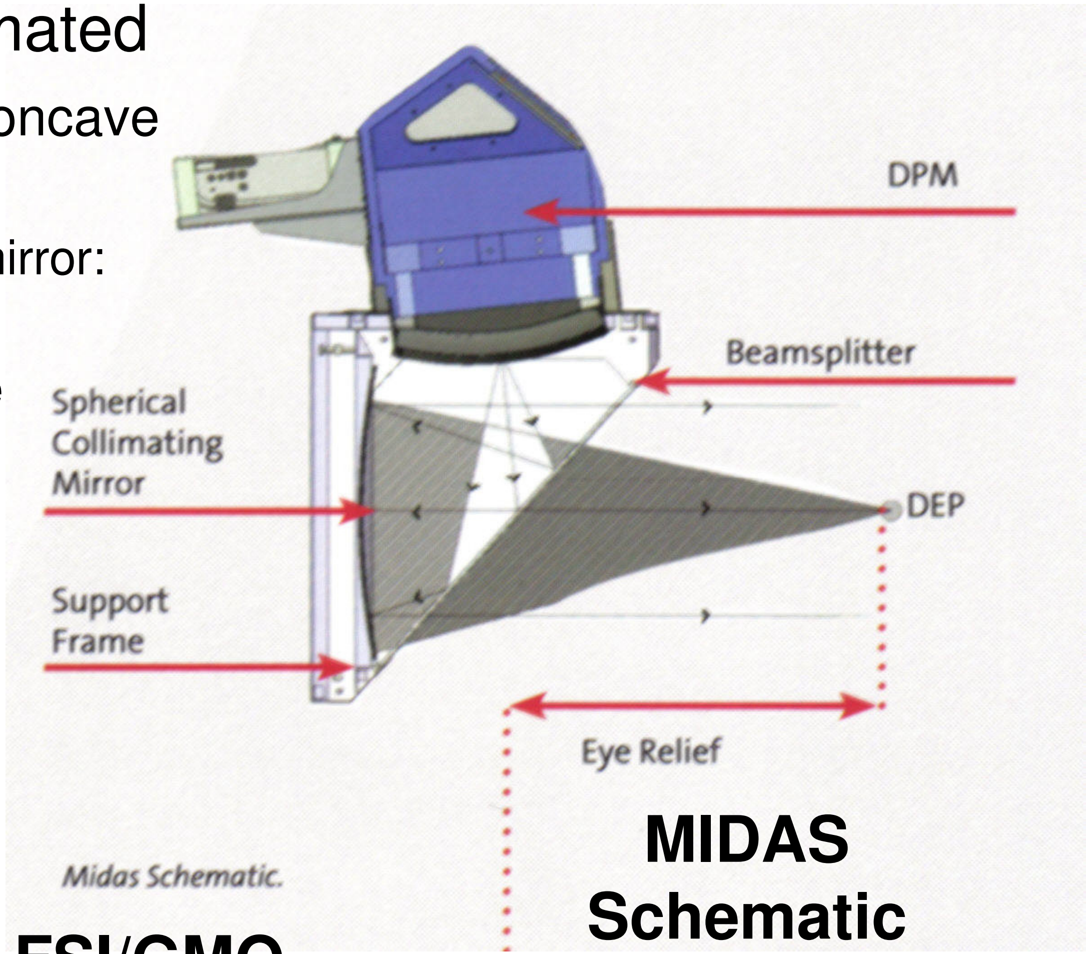
  - *Monitor- or projector-based collimation (virtual images)*
  - Target-tracked AOI
  - Head- or head/eye-tracked AOI
    - Includes Head-Mounted Displays (HMDs)

# Collimation with “monitors”

- Multi-channel on-axis collimated
- Folded optical path w/ BS and concave mirror (“WAC window”)
  - 25” diagonal CRT & 50” radius mirror: FOV = 35º x 47º
  - Viewing volume ~12” dia. sphere
  - Optical efficiency ~18%
- Large HFOV via juxtaposition

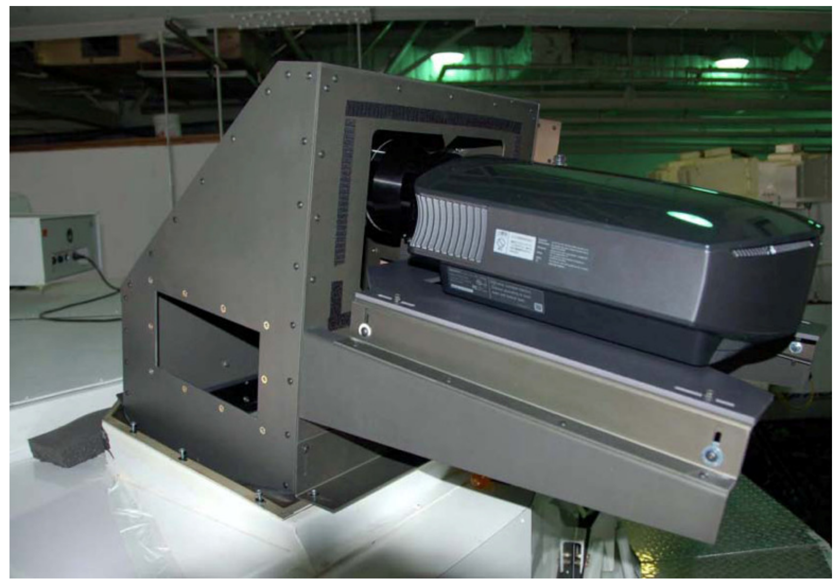
FSI/GMO




MIDAS Schematic

# Monitor Replacements

- Matsushita 25” CRT monitor obsolete
  - Large installed base in need of replacement
- FPD replacement not optimal
  - Faceplate curvature ~ Focal Length ($R_c$/2) needed for proper vergences
- RP replacements from:
  - EIS (CRT), now TREALITY
  - Diamond Visionics (DLP)
  - RC/SEOS (LCD/LCoS)
  - FlightSafety



**FlightSafety**

# Rockwell Collins LCoS DPM

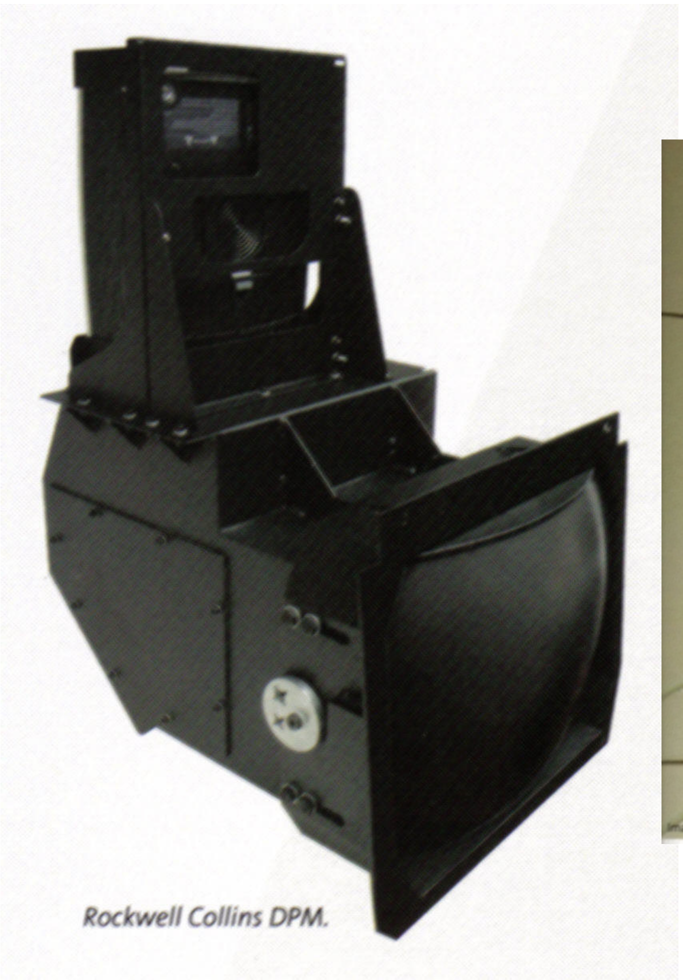

Rockwell Collins DPM.


Image courtesy of Finnair.

# RC Zorro 2015HC projector

- Now called ProSIM
- RGB+K, 4-panel LCoS projection engine
  - Brightness = 1000 lumens
  - Seq. Contrast=1,000,000:1 without iris
    - ANSI Contrast = 150:1
  - QXGA: 2048 x 1536 pixels
  - K-panel intensity modulation expands grayscale
  - Suitable for NVG stimulation

# Collimation w/projectors

- Off-axis/tilted projection
- Examples:
  - WIDE (the original; 1980)
  - Also AWARDS; MultiVIEW; MaxVue; Panorama; OmniVue; CrossView; CrewView; CPD; SupraVue; epic view; CD series
- Image projected onto large BPS
  - Replaces monitor faceplate of BS/M systems
- Large spherical mirror (mylar, plastic, glass)

# WIDE-type (CCCD) Installations

CAE MaxVue

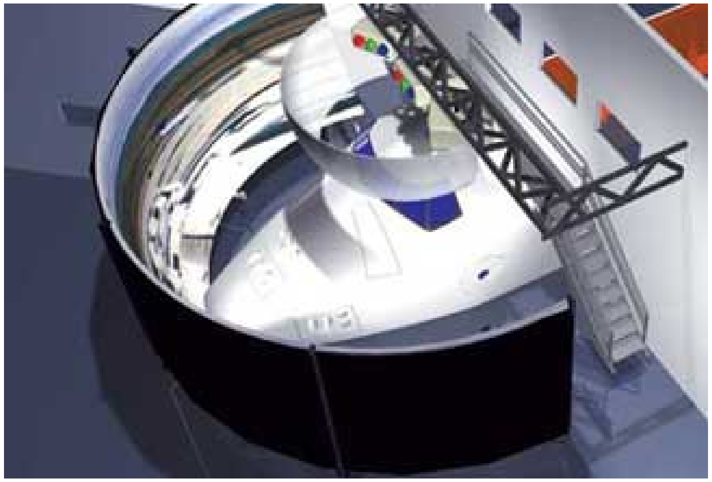
CAE C-130J2 simulator

# Mirror and BP Screen (FSI)

# BP Screen Installation (FSI)

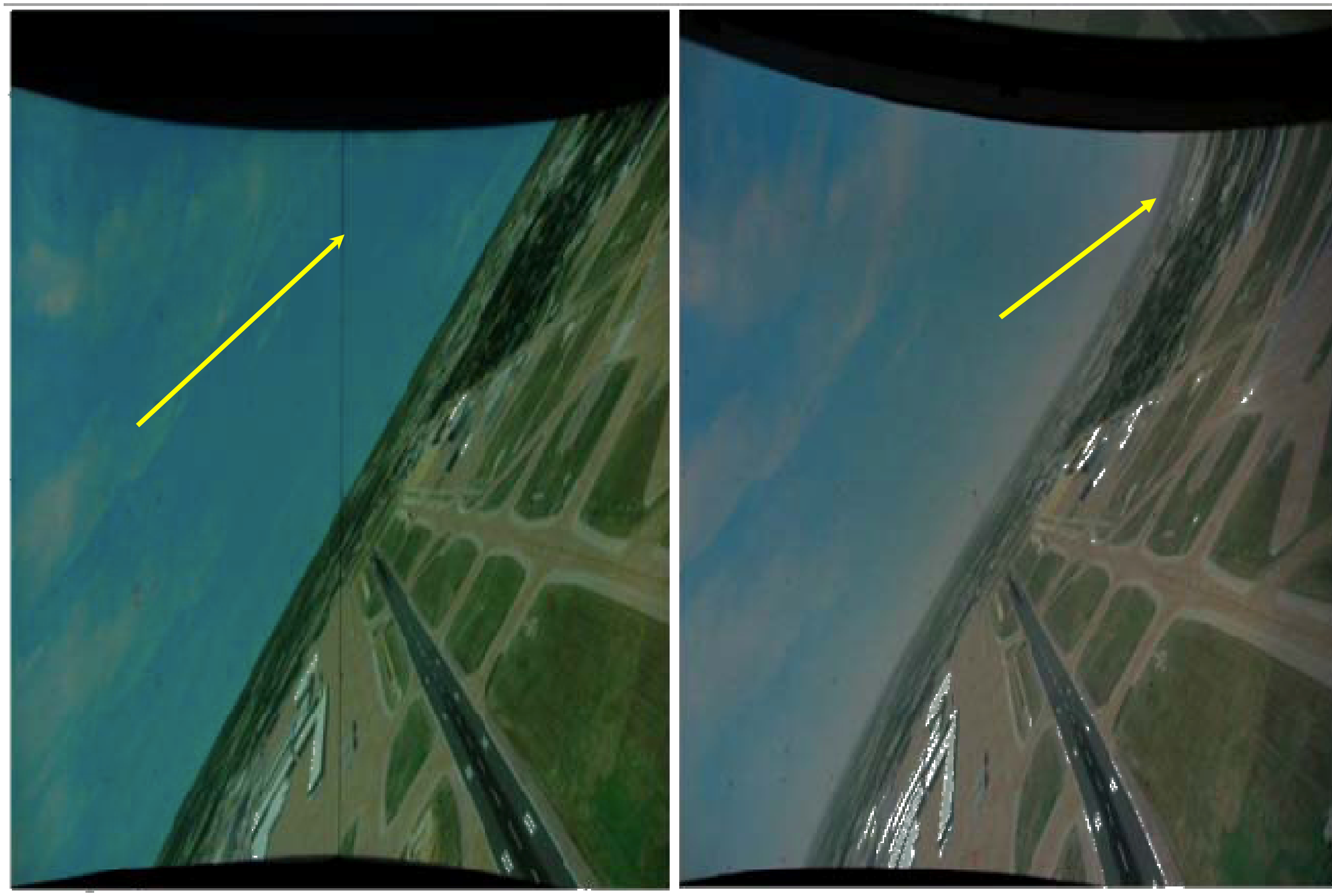
# WIDE: Pros & Cons

- Advantages:
  - Viewing volume = entire crew station, thanks to large optical elements
  - Focus & vergence ~ real-world distances
- Disadvantages
  - Reduction in brightness & contrast
  - Large footprint
  - Mylar vs. Glass



# Mylar vs. Glass I

G
L
A
S
S



M
Y
L
A
R

# Mylar vs. Glass II

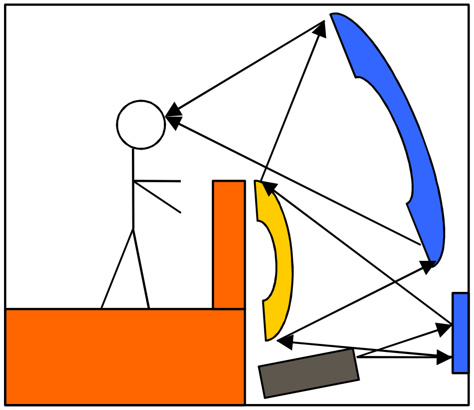
| Attribute | Mylar | Glass |
| --- | --- | --- |
| Material | 1-2 mil mylar; aluminized | 1/4" glass + 1/4" composite |
| Handling | On roll | As cut; back layer offers stiffening and safety in case of breakage |
| Operating costs | Vacuum pump needs UPS | N/A |

# Mylar vs. Glass III

| Attribute | Mylar | Glass |
|---|---|---|
| Cleaning | Difficult | Standard glass cleaning products |
| FOVs | $60^o$ V x $220^o$ H; possibly more | FSI selling a $60^o$ x $300^o$ system to USCG |
| Spares Holding | Stored on a roll | Mirror segments must be boxed; cumbersome |

# Panorama “Lightning”

- Collimated front projection
  - Digital LCD projectors
  - Greater brightness (3-4x)
  - Reduced mass/inertia; low CoG



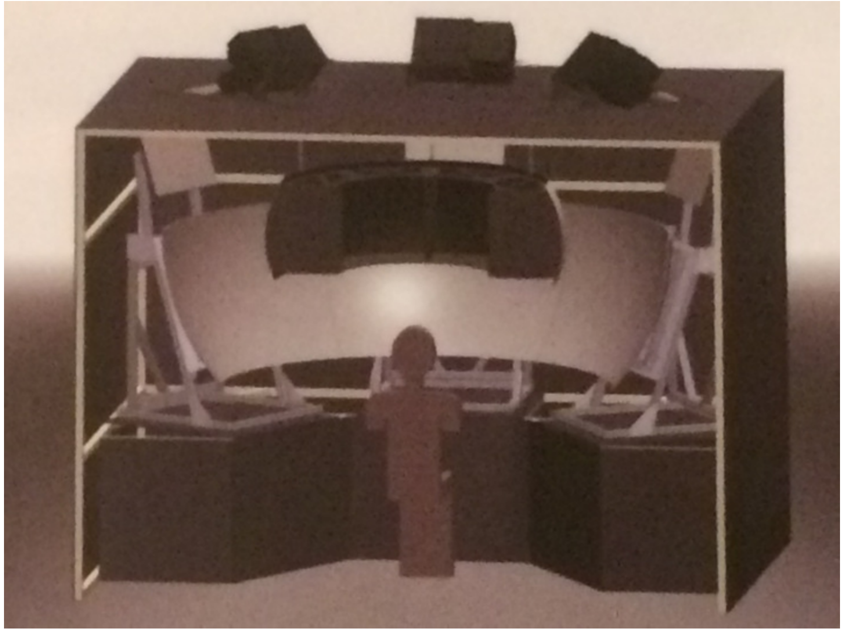
**Mechtronix B767NG Simulator**

# Panorama GFP (Glass Front Projection)

- Rockwell Collins prototype at I/ITSEC 2011
  - Configuration similar to Lightning (FP vs. RP)
    - Brightness > 15 ft.L; Contrast > 20:1
  - Compact (< 9 ft facility ceiling height)
  - Aimed at single eye point mobile applications
    - Also supports side-by-side seating (± 24")
  - Glass mirror; smaller radius (< 10 ft)
  - 3 projectors @ $120^{o}$H x $36^{o}$V (up to $240^{o}$ x $50^{o}$)

# Displays & Optical Technologies

- S.T.A.A.G. = Simulation Training and Advanced Gaming
  - 180º H x 40º V FOV
  - Spherical Glass mirrors
  - Front Projection Screen
  - Designed for rapid assembly by 2-3 people



# Hybrid: Collimated & Real Image Front Projection

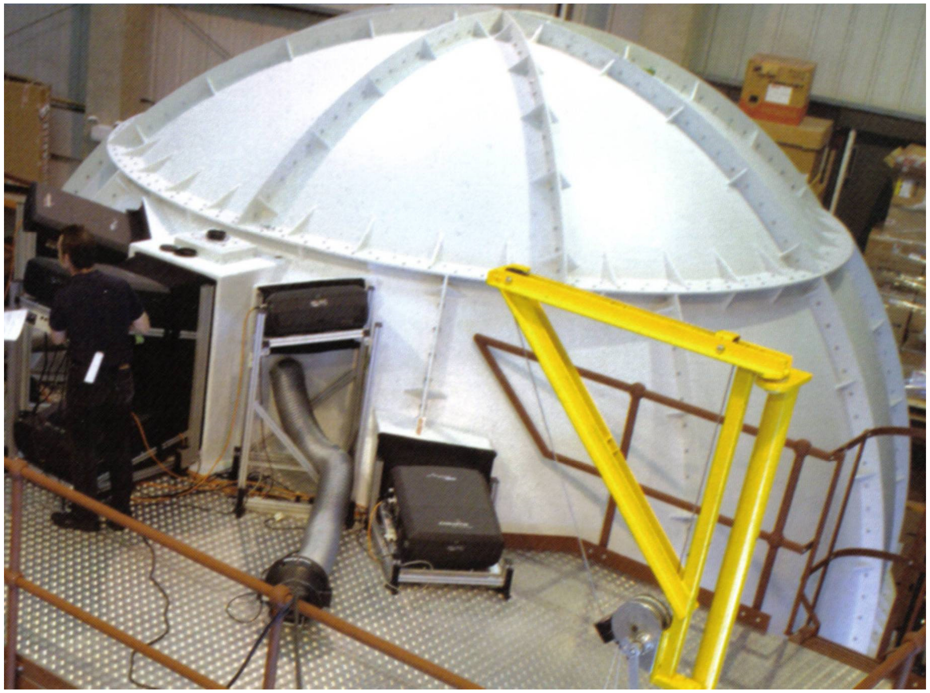
- FlightSafety’s AFSOC HH-60G WST
  - Integrated Flight Deck and 2 Gunner Stations
    - Collaborative training
  - OTW = $200^{o}$ H x $60^{o}$ V
  - Large FOV Gunner Station viewports
  - Compatible with 6-dof motion platform

# Technology classification

- Types of display currently in use:
  - Screen front-projection or monitor viewing (real images)
  - Screen rear-projection (real images)
  - Monitor- or projector-based collimation (virtual images)
  - *Target-tracked AOI*
  - Head- or head/eye-tracked AOI
    - Includes Head-Mounted Displays (HMDs)

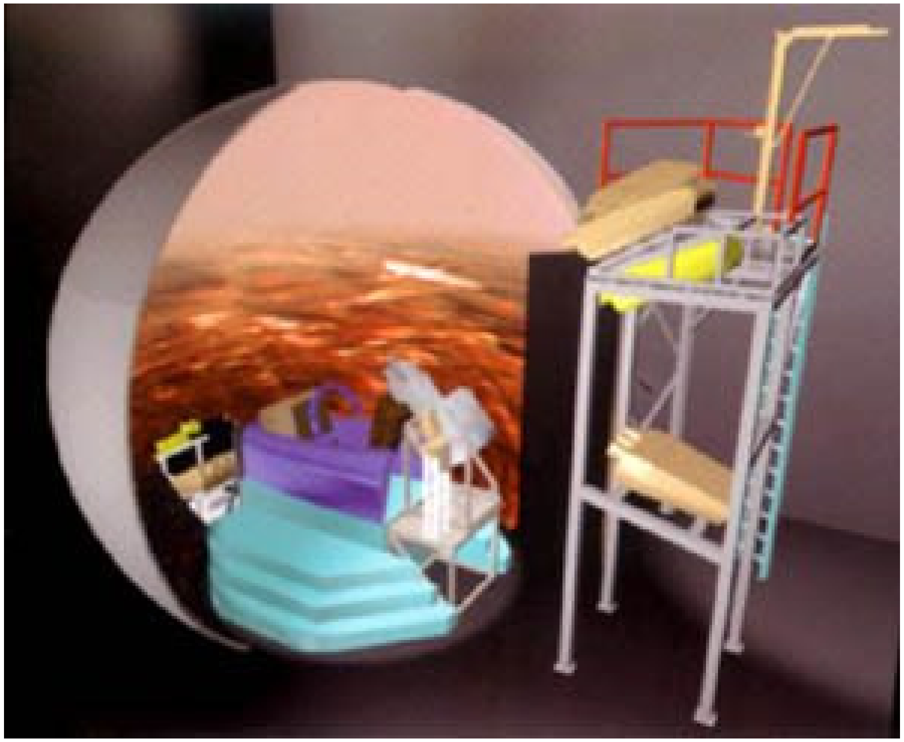
# Dome displays with AOI

- Multi-channel dome + AOI
  - Used when wide FOV required, but not motion
  - Low-res, wide FOV BG + hi-res, narrow FOV target-tracked AOI
- Ex: Many air combat sims
  - Dome with low-gain coating
  - Sky/earth projection + target generation
  - Projection can use several display technologies



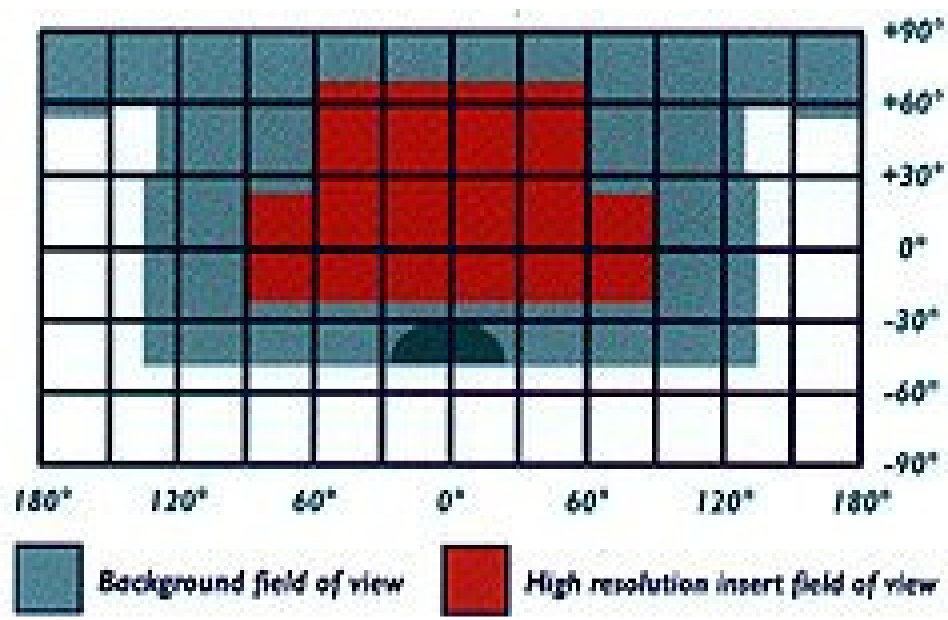
**Rockwell Collins dome**

# JAS 39 Gripen Trainer



# Hybrid: RC/SEOS PRODAS AcuView

- JAS 39 Gripen simulator
  - 10-ft spherical screen
  - 8 projectors:
    - 4 CRT for forward AOI
    - 2 LCD for background
    - 1 HUD projector
    - 1 Marksman LCD target projector



# RC/SEOS Marksman (LCD)

- Ingredients: Display + gimballing
- >10$^{o}$ optical IFOV
- > 270$^{o}$/135$^{o}$ AZ/EL coverage
- Illuminance > 60 lumens
- Full color
- Typ. Luminance: > 5 ft.L. @ 10' dome & G = 0.5
- Contrast > 300:1
- Update/delay: 60 Hz/< 60 msec
- 1024 pixels across image
- Target halo suppression
- 195 rad/sec$^2$ at steering head
- 30 rad/sec at steering head
- NLIM

# T-T AOI: pros & cons

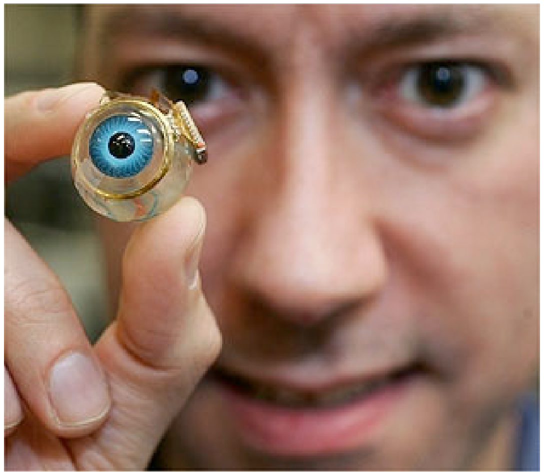
- Advantages:
  - Puts high resolution where instructor wants it
  - Expansion of training; e.g., A-to-A combat
  - High light-level special effects
- Disadvantages:
  - Reversed contrast on air targets
  - Occultation not possible for ground targets
  - Typical LV projection produces target halo

# Technology classifications

- Types of display currently in use:
  - Screen front-projection or monitor viewing (real images)
  - Screen rear-projection (real images)
  - Monitor- or projector-based collimation (virtual images)
  - Target-tracked AOI
  - *Head- or head/eye-tracked AOI*
    - Includes Helmet-Mounted Displays (HMDs)

# Head- & eye-tracked AOI

- Rather than locked to a specific object, AOI is determined by pilot's LOS
- HT bases LOS on position and orientation of head relative to a tracking device
- Eye-tracking supplements HT with gaze angle of one eye

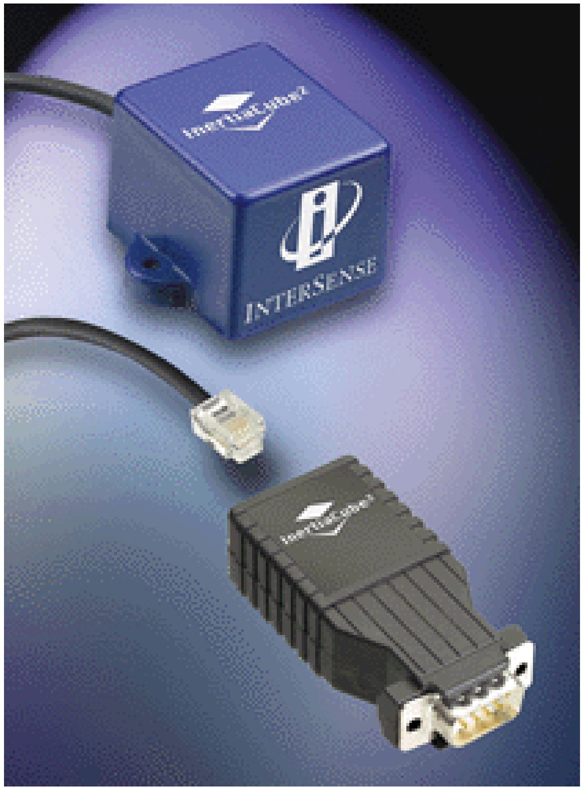


# Types of head tracker

- Electromechanical
  - Low cost
  - Excellent resolution
  - Minimal lag
  - *Restricted movement*
- AC Electromagnetic
  - Moderate cost
  - *Nearby metal => Error, so needs calibration*
  - Care needed to minimize lag
- Acoustic
  - Low cost
  - *Orientation best at close range*
- Optical
  - *High cost*
  - Low lag
  - Good noise immunity
- Gyroscopic/Inertial
  - *Orientation data only*
- Hybrids also available

# Ex: Inertial/ultrasonic tracker

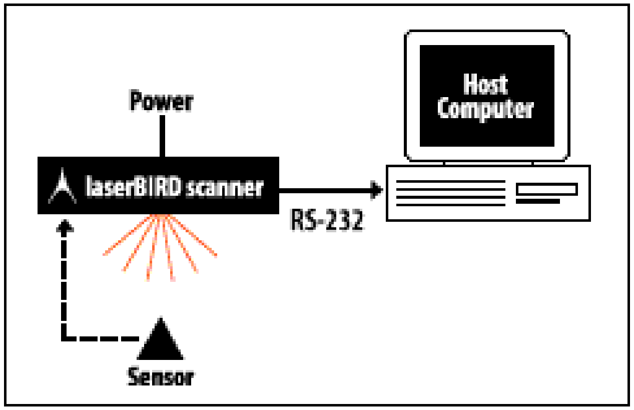
- InterSense IS-900 SimTracker
  - Std tracking volume: Up to 20 $m^2$
  - Immune from optical, magnetic, & acoustic interference
  - DOF sensing - HYBRID
    - InertiaCube for orientation (P/R/Y)
    - MicroTrax Devices for 6-dof
  - Rate: 180 Hz (120 Hz if wireless)
  - Latency: 4 msec
  - Static Accuracy (wired)
    - 2.0 – 3.0 mm RMS
    - P & R / Y = 0.25º/0.50º RMS




**InertiaCube orientation sensor**

# Ex: Optical head-tracker

- LaserBIRD
  - Ascension Technology Corp.
  - Unaffected by nearby metal, acoustic noise, or ambient light
  - 6-dof sensing
  - Rate: 240 Hz
  - Tracking Response: 5.17 msec
  - Accuracy (averaging ON):
    - 1 mm RMS at 1 m
    - $1^{o}$ RMS
  - Sensor weight: 40 gms




# Ex: AC Electromagnetic HT

- Polhemus SCOμT
  - 6-dof
  - Helmet sensor can communicate directly with image generator
  - Update rate = 240 Hz; Latency = 3.5 msec
  - Static Accuracy:
    - 0.18° for P/Y/R and 0.03" for X/Y/Z
  - Price: ~$12,000

# RC VistaView & TargetView

# RC SimEye SX100 HMD

- SXGA resolution (1280 x 1024)
- FOV: 100º H x 52º V
- Other attributes:
  - Binocular overlap: 30%
  - Eye pupil diameter = 15 mm
  - IPD Adjustments: 55-75 mm
  - Eye relief: Eyeglasses compatible
  - HT: Includes InterSense IS900
  - Weight: 2.5 lbs (helmet incl.)
  - Luminance > 20 ft.L.
  - Transmission: See-through > 20%

# RC SimEye SX45 HMD

- FOV: $36^o$ x $29^o$ (100% stereo overlap) @ 1280 x 1024 (SXGA)
- Brightness: 20 ft.L. nominal; 35 ft.L. maximum; OLED input
- Eye relief: 25 mm (eyeglasses compatible); no separate ocular focus
- Vertical & Fore/Aft adjustable; IPD range: 56 – 75 mm (rocker switch)
- Weight: < 1 lb.
- Immersive

# SA Photonics HMDs

- Immersive and see-through variants
- Inputs are WUXGA color OLED displays
- Adjustments: Fore/Aft; Vertical; IPD

SA-62

SA-62/S

SA-36

# SA-36 vs. SA-62/62S

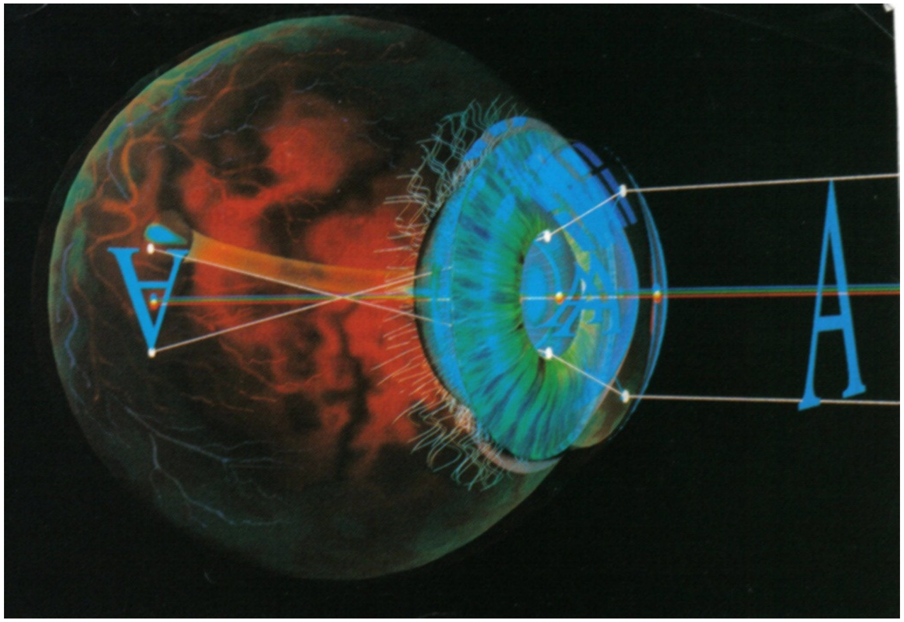
| Parameter | SA-36 | SA-62/62S |
|---|---|---|
| HFOV | $30^o$ | $53^o$ |
| VFOV | $19^o$ | $33^o$ |
| Binocular Overlap | 100% (?) | 100% |
| Eye Box | 12 mm | 10 mm |
| Eye Relief | 25 mm | 25 mm |
| Display Resolution | 1920 x 1200 | 1920 x 1200 |
| IPD Adjustment | 55-85 mm | 55-75 mm |
| Binocular Weight | 294 g | 217 g |

# L-3 Link - Advanced HMD

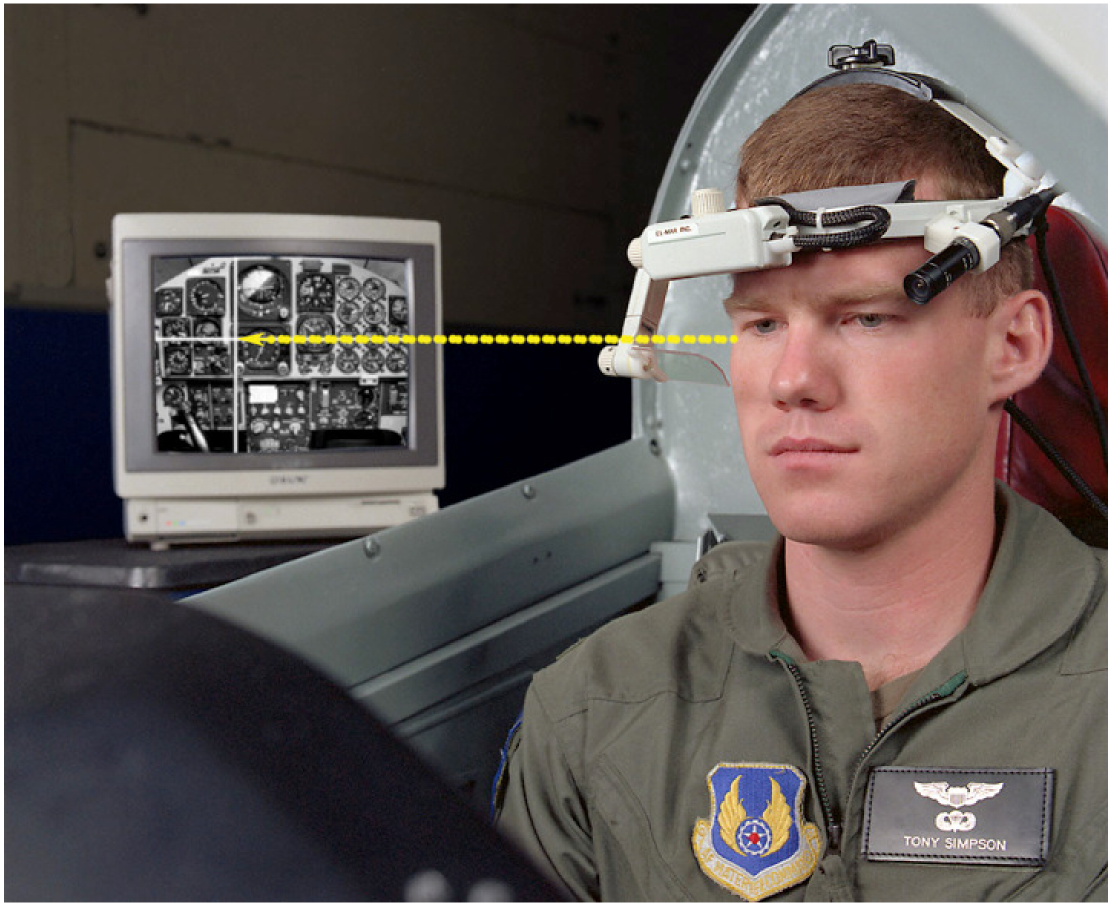
- USAF will use on F-16 UTDs
- Replaces current FPDs
- OTW and symbology over a 360° FOV
- 1280x1024/eye
  - HD version also
- Weight?

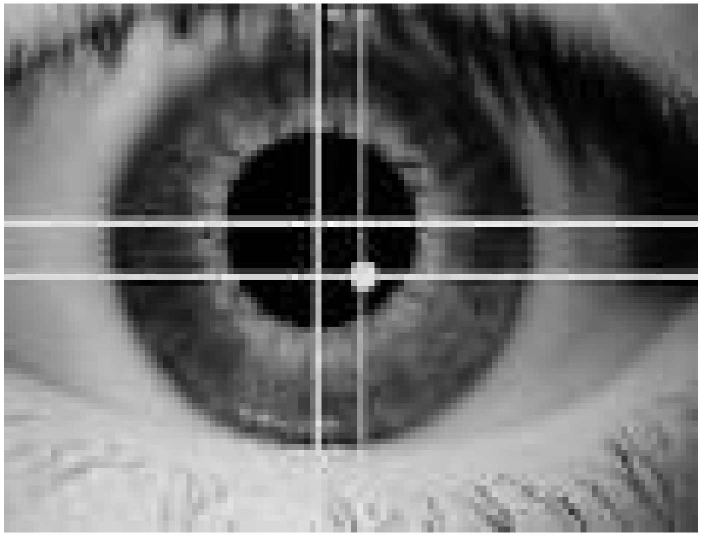
# Principle of eye-tracking

- Provides angular LOS info
  - Based on projecting IR light into eye and detecting corneal reflection, pupil image, or both
  - Used with HT on an HMD to position a hi-res AOI inset to coincide with foveal vision
  - Small, lightweight, & inconspicuous
- Experienced suppliers include:
  - El Mar & Applied Science Labs
  - Polhemus with ISCAN (VISIONTRAK)
  - Arrington Research (with Boeing)



# EL-MAR Eye Tracker



# Eye-tracking difficult!

- High spatial & temporal resolution
  - Accelerations of several thousand $^{o}$/sec$^{2}$ and velocities > 800 $^{o}$/sec during saccade
- Distinguish between movement & artifact
- Accurate even when illuminance changes
- Robust with regard to varying pupil size
  - Apparent pupil size changes with eye position
  - Pupil size varies across population

# Boeing 360°VIDS 20/20

- Gaze-tracked, color, inset Hi-Res projection system
  - 7 background, low-res images with up to 2048 x 1536 pixels/channel
  - 360° instantaneous FOV
  - Provides positive or negative target contrast
  - 18 eye-trackers purchased

**F-15E VIDS at RAF Lakenheath**

# Development goals

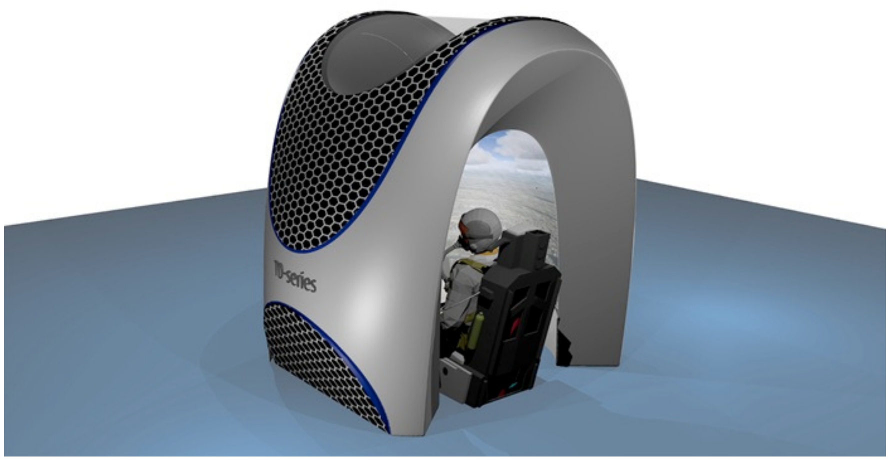
- Display R&D must enhance display value
- Value is derived from:
  - Compatibility with trainers & facilities
  - Better performance
  - Lower cost
- Display R&D can be found in all 3 areas

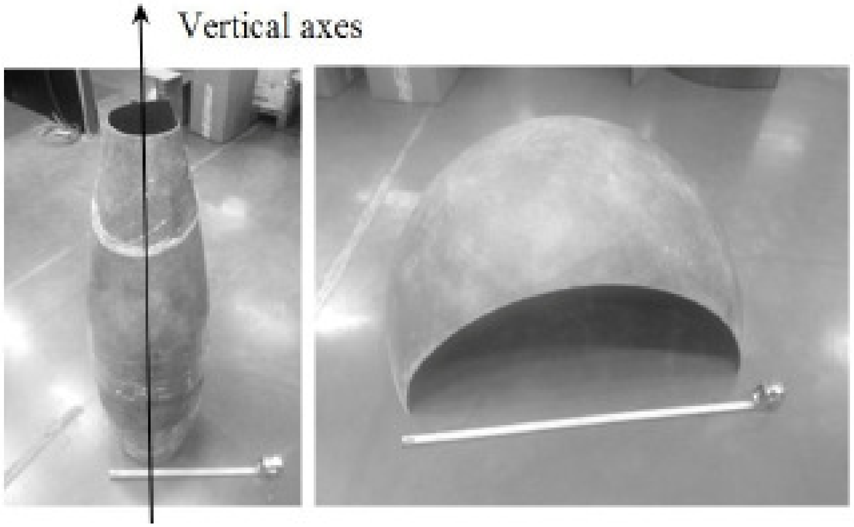
# Examples - New & Unusual Recent Developments

- TREALITY - Transportable projection displays
- Boeing - *Constant Resolution Visual System*
- *JVC - E-Shift 4K projector technology*
- *JVC /Sony/Christie - Laser light illumination*
- Oculus *Low-Cost Head-Mounted Display*
- Microvision & Avegant - *Retinal display*

# Transportable Domes

- TREALITY TD-series
  - Deployable: fits inside an ISO container
  - Lightweight structure; semi-rigid screen
  - Available with 1, 3, or 5 projectors



# Toshiba's Hyper-Reality Head-Dome Projector

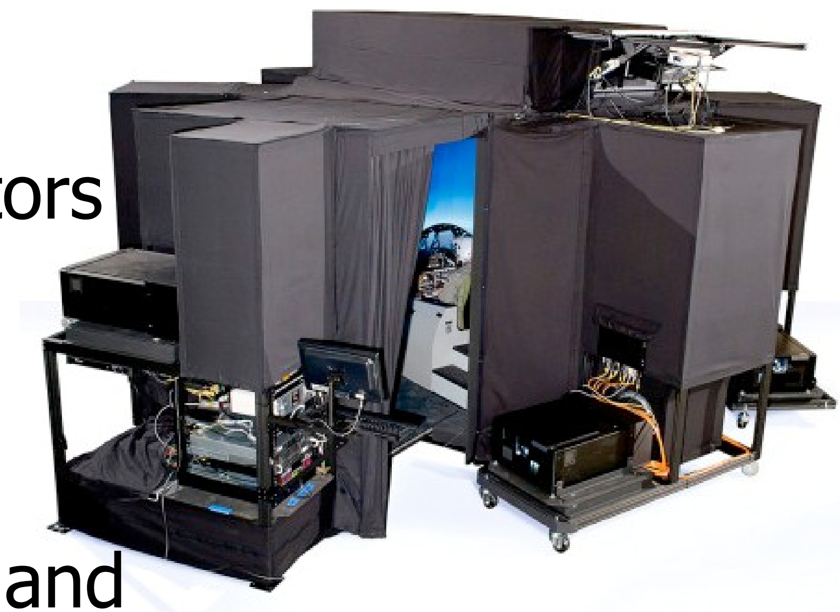
- Compact dome-shaped screen of 40 cm radius
- LED projector with ultra-wide projection lens
- IFOV: 120°Hx70°V
  - HT =>360° x 360°

# Boeing - Constant Resolution Visual System

- Promises high resolution over entire FOV using ~1/2 the number of COTS projectors
  - Removes size difference of center & edge pixels

# Boeing 20/20 CRVS

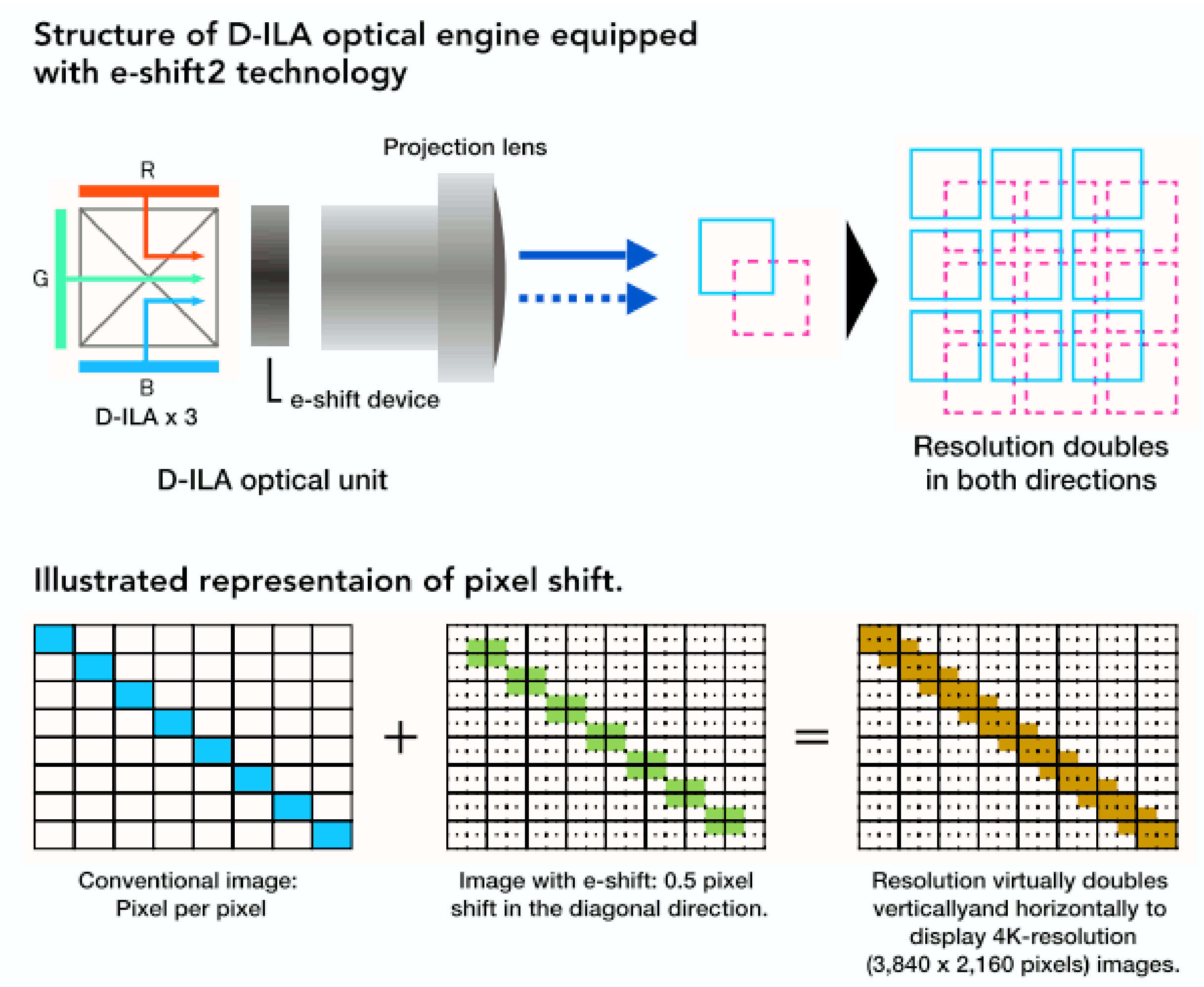
- Demo at I/ITSEC 2016
- RC EP8000 image generator (with NLIM)
- JVC D-ILA e-Shift 8K projectors
  - Laser hybrid
  - Currently non-production
- Specially shaped concave projection surface => edge and center pixels the same size
- 2 arcmin resolution for air-to-air



# JVC E-Shift 4K Technology

- Have (3) x 1920 x 1080 D-ILA imaging chips
- Shift 0.5 pixel horizontally & vertically
  - Result: “Effective” resolution = 3840 x 2160
  - Shifted & unshifted images alternate @ 120 Hz
- Boeing CRVS uses an E-Shift 8K version

# How E-Shifting Works



# Laser Phosphor Projectors

- JVC DLA-VS2300 and DLA-VS2500 projectors
- Sony VPL-GTZ1 4K Ultra-Short Throw projector
- Christie GS Series


Christie

Sony

JVC

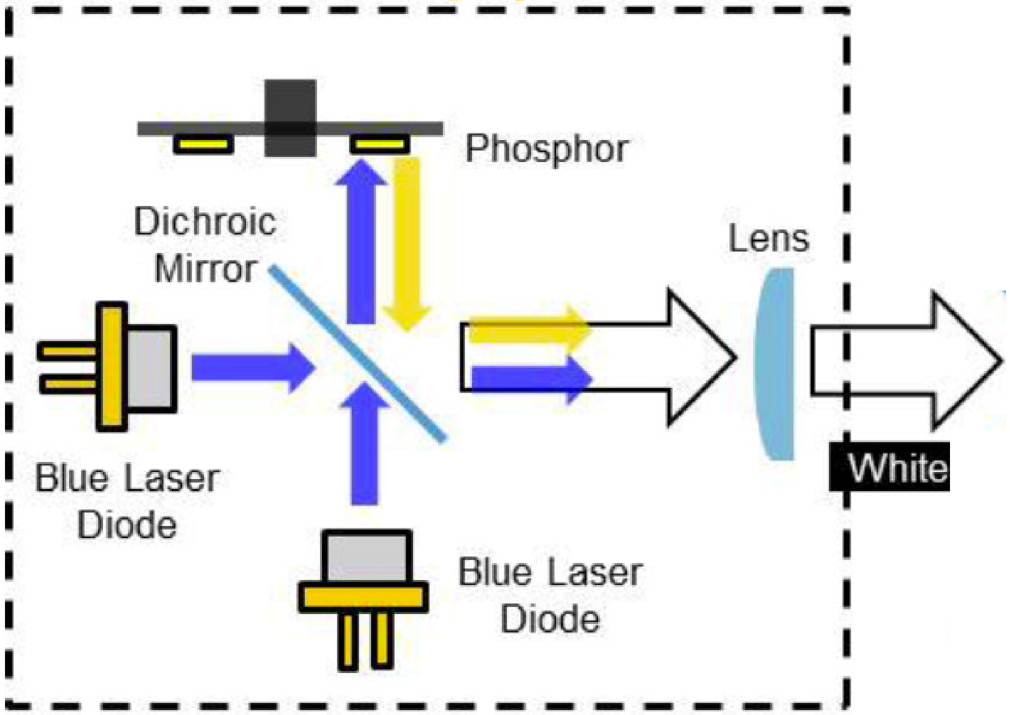
# JVC DLA-VS2300 Projector

- Meets FAA/ICAO Level D requirements
- BLU-Escent illumination technology
  - Blue laser diodes => blue light.
    - Also excites yellow phosphor on spinning aluminum disk
  - Yellow + blue light => White light
  - Uses (3) x 1920 x 1080 D-ILA imagers
- DLA-VS2500 has e-shift => 3840 x 2160

# Sony VPL-GTZ1 Projector

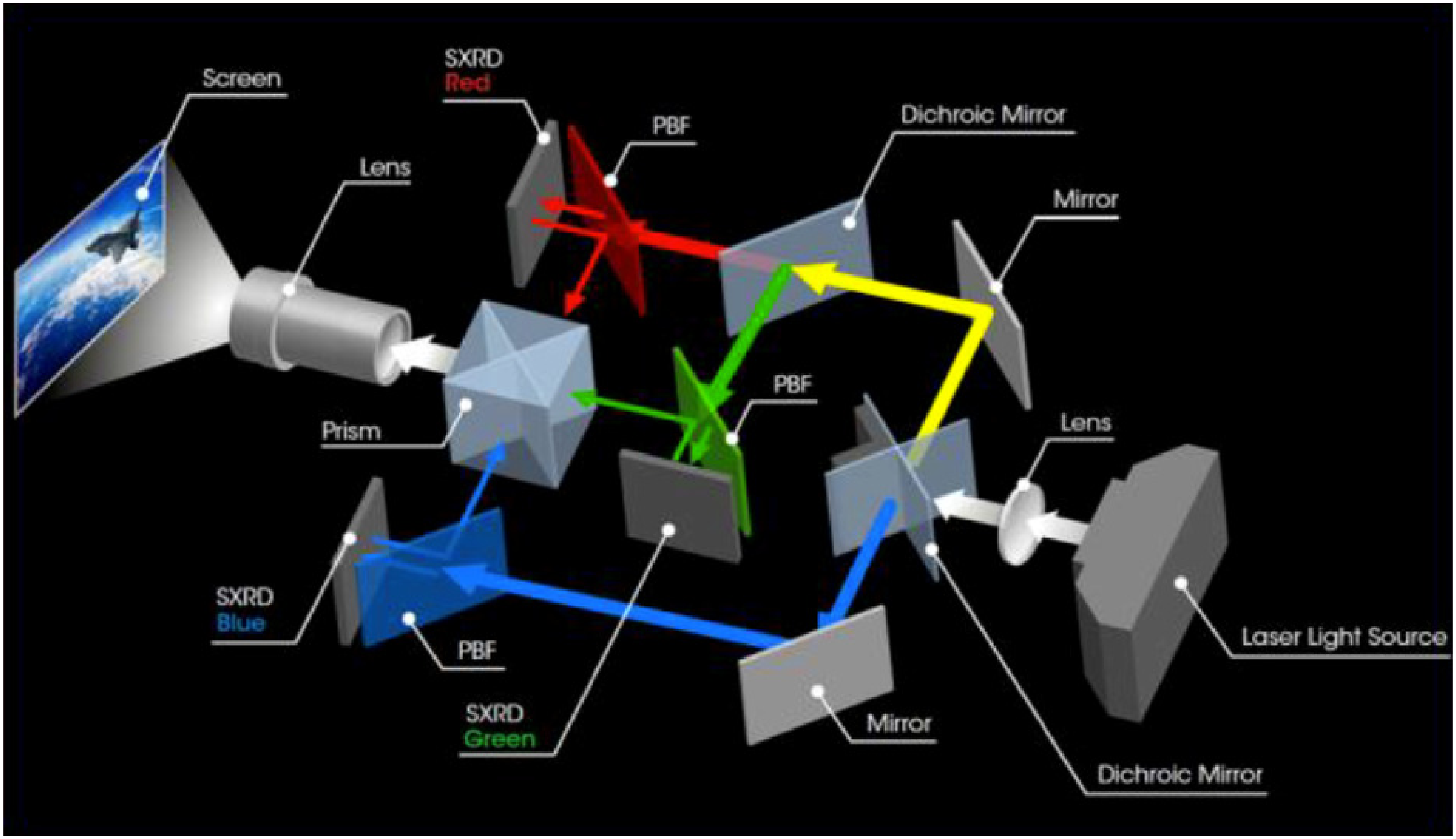
- Uses VAN (Vertically Aligned Nematic) Liquid Crystal light valves (3 x SXRD Panels)
- LC material aligned vertically and not horizontally => boost in contrast to 4,000:1
- Brightness: 2,000 lumens (Z-Phosphor with laser diode)
- Resolution = 4,096 x 2,160
- Ultra-short throw ratio: 0.16:1 to 0.25:1
- Price: ~$50K

# Z-Phosphor Light Source Unit




Light Source Unit

# Sony's LP Projection



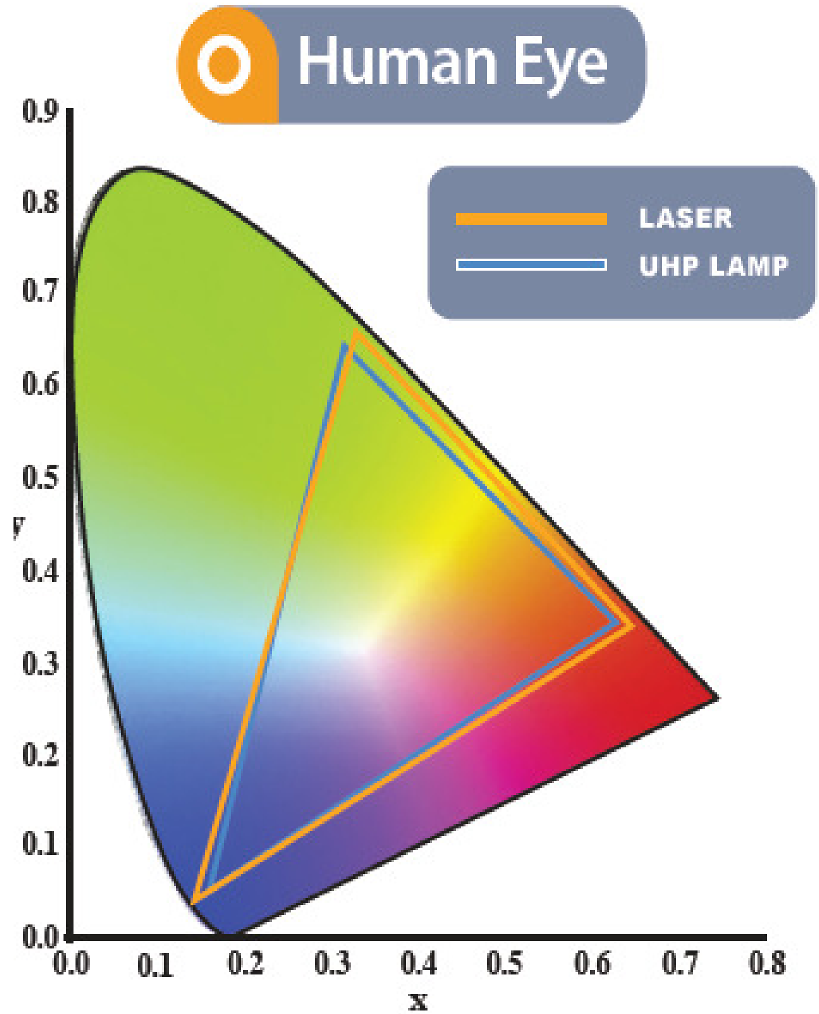
# Digital Projection

- Comparison: Insight (3) x DLP projectors

| Projector | Brightness: ANSI lumens | "Lamp" life (hrs) | Thermal (BTU/hr) |
|---|---|---|---|
| 4K Quad Lamp | 25,000 | 6,000 (4x1,500) | 7,165 |
| 4K Laser | 12,000 | 20,000 | 5,027 |
| 4K Dual LED | 3,000 | 60,000 | 3,070 |

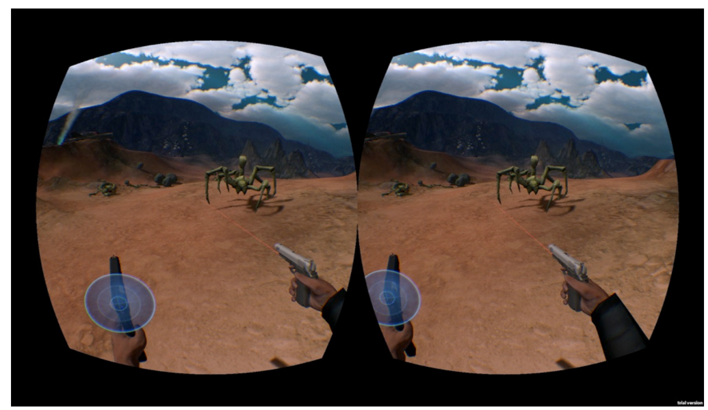
# Color Space: Laser vs UHP

- Laser illuminator a good match to UHP Lamp
- Neither has saturated green of LED



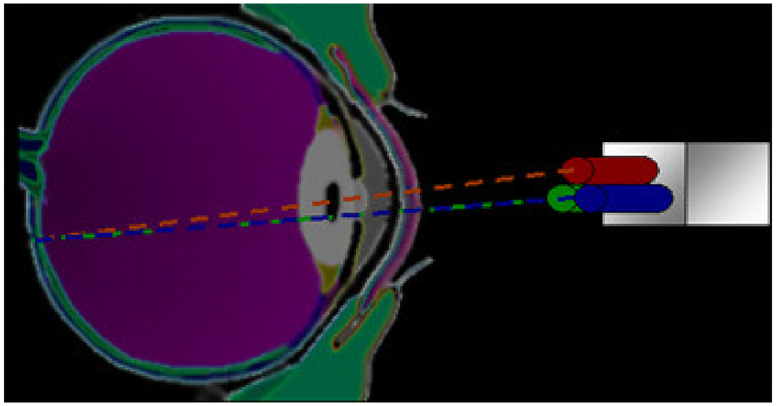
# Oculus Low-Cost Rift HMD

- Now "powers" Samsung Gear VR
- 800x1280 LCD input
- Stereo 3D: 800 x 640
- 110º diagonal FOV
- 6-dof head tracker
- Lightweight < 300g
- Purchased by Facebook
- Price: $300??



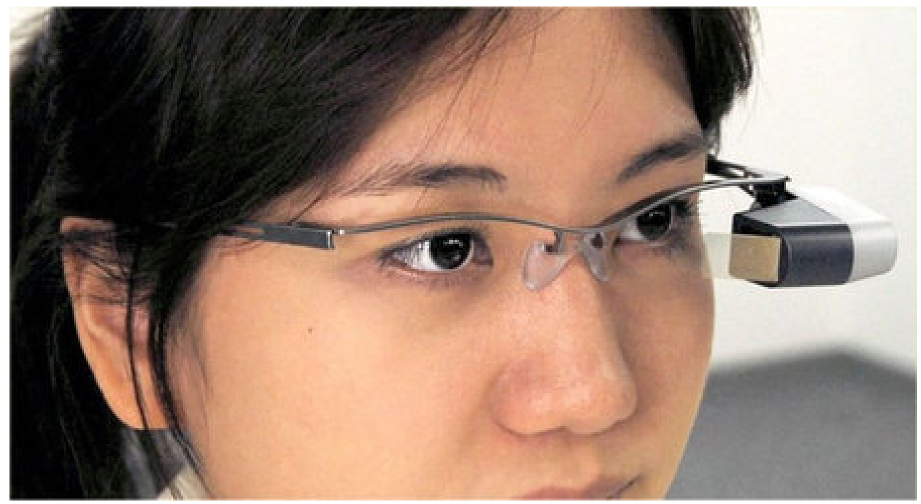
# Encouraging trends

- Faster SLMs with more pixels & lower cost
- Cost: Migration of consumer enhancements to simulation (and vice versa via gaming)
- Effort to eliminate external image altogether!
  - Virtual Retinal Display” - Microvision & Avegant



# Virtual Retinal Display

Today



"The promise..."

# Conclusion

- Choosing a display not straightforward
- System engineering is a must: An IG is no better than its display!
- Display technology lags IG technology. Why?
  - Fewer engineers
  - MMI limits size reduction

# Top Ten "rules of thumb" – 1

1. Reduce FOV and resolution whenever possible - $
2. Use collimation only when necessary - $
3. Don't increase brightness unless contrast & refresh rate are sufficiently high
4. Pay attention to latency, including contributions from warping/blending electronics
5. Remember time constants affect dynamic resolution, which ≠ static resolution

# Top Ten “rules of thumb” – 2

6. Think twice before using head-tracking, and especially head/eye-tracking - $
7. Use “stereo” only to depict close objects in murky or sparse scenes lacking 3-D cues - $
8. Assess ease of display setup and routine adjustment - $
9. Display maximization ≠ system optimization
10. NEVER trust display specifications; get a custom, use-appropriate demonstration!

# References - a sampling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