

DOT/FAA AM-96/12

Office of Aviation Medicine
Washington, D.C. 20591

Ophthalmic Requirements and Considerations for the En Route Air Traffic Control Specialist: An Ergonomic Analysis of the Visual Work Environment

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April 1996

Final Report

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U.S. Department
of Transportation
**Federal Aviation
Administration**

ACKNOWLEDGMENTS

The opinions expressed in this manuscript are the views of the authors and do not represent the official position of the U.S. Department of Transportation or the Federal Aviation Administration. Citation of trade names does not constitute official Department of Transportation endorsement or approval of the use of such commercial items.

The authors express their appreciation for the technical assistance provided by Mr. Joseph Young, Research Physical Anthropologist at the Civil Aeromedical Institute, in measuring the different physical dimensions of the radar console, and Ms. Kathryn J. Wood, Health Technician in the Vision Research Section, in formatting the manuscript and consulting on ophthalmic dispensing considerations.

OPHTHALMIC REQUIREMENTS AND CONSIDERATIONS FOR THE EN ROUTE AIR TRAFFIC CONTROL SPECIALIST: AN ERGONOMIC ANALYSIS OF THE VISUAL WORK ENVIRONMENT

INTRODUCTION

One of the most important responsibilities of the Air Traffic Control (ATC) system, which is under the jurisdiction of the Federal Aviation Administration (FAA), is to prevent collisions between aircraft. This is achieved by expediting a safe and orderly flow of air traffic utilizing the air space as efficiently as possible. An Air Traffic Control Specialist (ATCS), or controller, is a person authorized to provide air traffic control service (1).

There are three basic ATC service facilities:

1. **Terminal Radar System Area** covers the airspace surrounding designated airports wherein ATC provides radar vectoring, sequencing, and separation for all instrument flight rules (IFR) and participating visual flight rules (VFR) aircraft.
2. **Automated Flight Service Station**, equipped with communications and computer display equipment, transmits required weather and flight plan information. It also provides pilot briefings, en route communications, VFR search and rescue services, assistance to lost aircraft, and relays ATC clearances.
3. **Air Route Traffic Control Center (ARTCC)** provides air traffic control during the en route phase of the flight between terminal areas using a Radar Data Processing system. At the ARTCC, each sector usually has one to three controllers assigned the function of separating aircraft. The main radar controller issues altitude, heading, and airspeed changes to keep the aircraft separated. The associate/nonradar controller assists the radar controller by separating aircraft that do not appear on radar display, updates flight progress strips, and must assume aircraft separation responsibility if the radar display malfunctions.

It is generally acknowledged that ARTCC, or en route, controllers have greater responsibilities and experience greater stress levels in the work environment than the terminal or flight service station controllers (1). These duties and responsibilities are reflected in the different medical standards for initial hire and retention (Note: Table 1).

The en route controller works with a unique radar console unit when controlling aircraft. The radar console is comprised of four primary components: a plan view display (PVD), an alphanumeric keyboard (ANK), an airways map, and a "D" console. A schematic of the radar console is presented in Figure 1.

From observations of en route controllers and students working at the radar console, the approximate viewing times for the four primary components are 75% for the PVD, 12% for the ANK, 10% for the D console, and 3% for the airways map.

As part of an ongoing field study investigating the potential benefits of task-specific lenses used by presbyopic ATCSs on the job, we performed an ergonomic evaluation of the occupational visual requirements of the radar console, including the accommodative, vergence, and version demands.

METHODS

The physical dimensions of the radar console were recorded using the apparatus illustrated in Figure 2. To evaluate the range of visual measurements, a tape measure was secured to a vertical stand on which the eye height levels were marked for subjects in an assumed erect sitting posture. Two levels representing the low female value (5th percentile) and the high male value (95th percentile) were used. These eye

height levels were fixed at 115.57 cm (45.5 in.) and 133.07 cm (52.39 in.) above the floor, respectively. The stand was positioned a distance of 10.2 cm (4.0 in.) from the front edge of the current model radar console used by en route ATCSs, where the ANK is located. There may be minor variations in the configuration of en route radar consoles used in the field. However, the model evaluated is the standard used to teach students at the FAA Academy in Oklahoma City, Oklahoma.

The distances from the low and high eye heights to five positions (top, center right, bottom, center left, center) on each of the primary components of the radar console were recorded to the nearest 1/8 in. and converted to centimeters (2.54 cm = 1.0 in.). The following were computed from the measured distances: 1) Accommodative demand, measured in

diopters (D), is the adjustment required to maintain a sharp retinal image. 2) Vergence demand, measured in prism diopters (Δ), is the adjustment to maintain single binocular fixation. (Note: An interpupillary distance of 60 mm was used for the low female value and 67 mm for the high male value.) 3) Version demands, measured in degrees ($^\circ$), are the vertical and horizontal conjugate eye movements from straight ahead, and are calculated assuming no head or neck movement.

RESULTS

The PVD is 52.07 cm (20.5 in.) in diameter and is reclined 9° past vertical. The ANK is in a fixed location down-right of the PVD. The airways map is centered above the PVD and is 30.6 cm (31.75 in.) in

Type of Air Traffic Control Specialist	Terminal	Center	Flight Service Station
Visual Acuity	Distant and near of vision of 20/20 or better in each eye separately with or without correction. Refractive error must not exceed plus or minus 5.50 diopters (D) of spherical equivalent or plus or minus 3.00 D of cylinder (glasses or contact lenses). (Note: The use of orthokeratology or contact lenses for correction of near vision only or bifocal contact lenses is unacceptable.)		Distant and near vision of 20/20 or better in at least one eye. Refractive error must not exceed plus or minus 8.00 D spherical equivalent. (Note: The use of contact lenses for correction of near vision only or bifocal contact lenses is unacceptable.)
Color Vision	Must demonstrate normal color vision.		
Visual Fields	Normal central (within 30° of fixation) and peripheral (140° in the horizontal and 100° in the vertical meridians) visual fields in each eye.		Normal central (within 30° of fixation) in at least one eye.
Intraocular Pressure	Intraocular pressure must not exceed 20 mm of mercury, or a difference of more than 5 mm of mercury between the two eyes.		
Phorias	Hyperphoria must not exceed 1.50 prism diopters and esophoria or exophoria must not exceed 10 prism diopters.		Must demonstrate the absence of diplopia in the cardinal fields of gaze.
Eye Pathology	No form of either glaucoma, cataract, uveitis or any other acute or chronic pathological condition that would interfere with proper function or likely to progress to that degree.		
Chronic Eye Disease	No chronic eye disease that may interfere with visual function.		
Ocular Motility	Full extraocular motility.		No requirements.
History of Eye Surgery	Requires ophthalmological consultation. (Note: A history of radial keratotomy is disqualifying.)		

TABLE 1: Vision standards for Air Traffic Control Specialists. (Extracted from the Office of Personnel Management Operating Manual: Qualification Standards for General Schedule Positions, August 1994. Initial hire and retention vision requirements are identical.) (Note: In certain instances where a vision standard is not met, evaluation by a qualified eye specialist may be performed to ascertain the extent of the eye condition and how it would interfere with visual function. Depending on the diagnosis and prognosis, a waiver for the medical condition may be granted.)

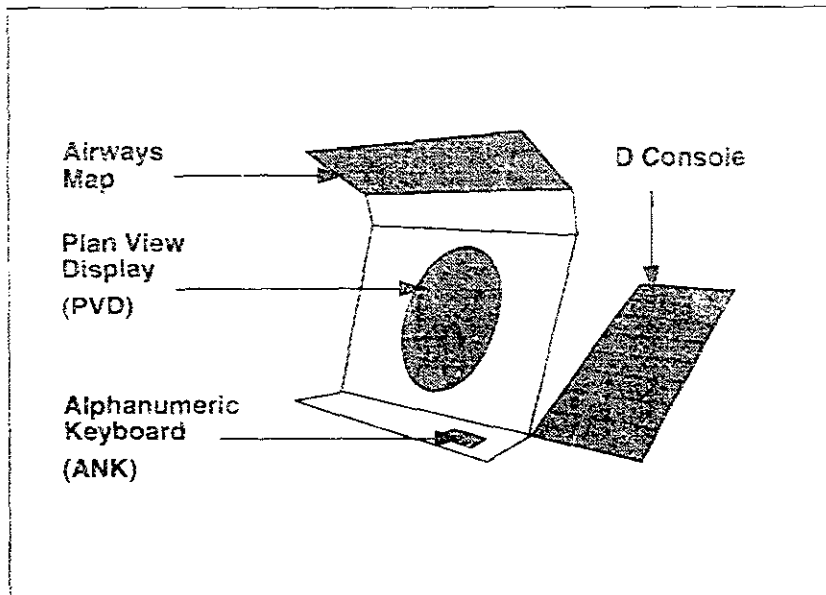


Figure 1: Schematic of the en route radar console.

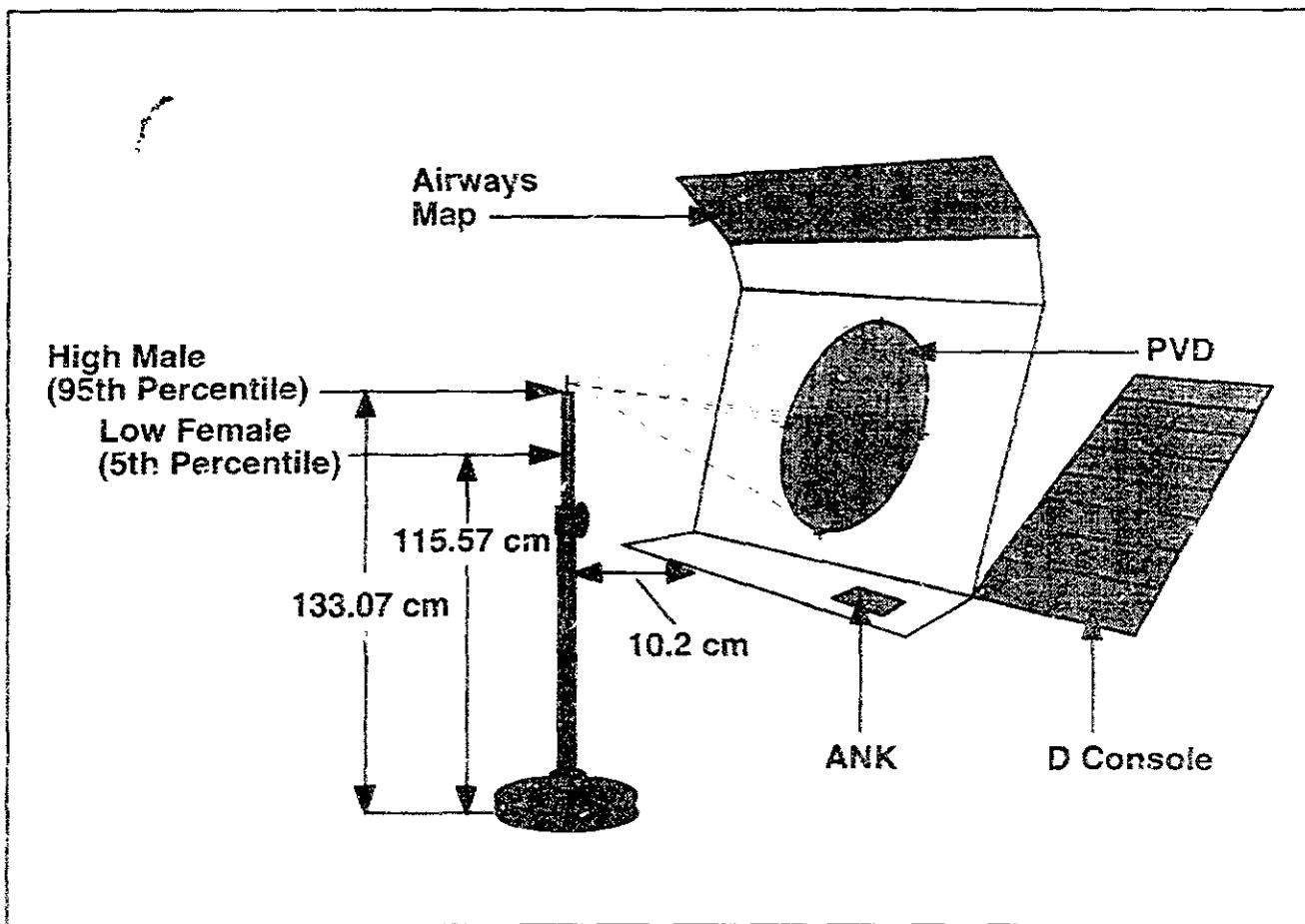


FIGURE 2: A schematic of the measuring apparatus and physical dimensions evaluated on the radar console.

width and 50.8 cm (20 in.) in height, and is inclined 38° to the observer. The D console can be located on either side of the primary console structure and is reclined 28° to vertical. (Note: For this study, the D console was to the operator's right side.)

5TH PERCENTILE VALUES

The low female values for each of the major components are presented in Table 2 and summarized below.

Plan View Display - Accommodative demands for the PVD range from 1.36 D to 1.54 D, while convergence demands range from 7.86^Δ to 8.89^Δ. The center of the PVD requires a 13.7° infraversion (down).

Alphanumeric Keyboard - Accommodative demands for the ANK range from 1.32 D to 1.81 D, while convergence demands range from 7.67^Δ to 10.35^Δ. The center of the ANK dictates a 51.6° infraversion combined with 35.9° dextroversion (right).

D Console - Accommodative demands for the D console range from 0.79 D to 1.42 D, while convergence demands range from 4.61^Δ to 8.20^Δ. The center of the console has version requirements of 15.8° infraversion with a 47.0° dextroversion.

Airways Map - The accommodative demands for the airways map range from 0.93 D to 1.27 D, while convergence demands range from 5.45^Δ to 7.37^Δ. The center of the map requires a 50.3° supraversion (up).

95TH PERCENTILE VALUES

The high male values for each of the major components are presented in Table 3 and summarized below.

Plan View Display - Accommodative demands for the PVD range from 1.31 D to 1.43 D, while convergence demands range from 8.49^Δ to 9.24^Δ. The center of the PVD requires a 30.4° infraversion

Device	Pos	Accom (D)	Vergence (Δ)	Version (°)	
				Vert.	Horiz.
Plan View Display	Top	1.36	7.86	8.4 sup	
	Right	1.44	8.31	13.7 inf	22.6 rt
	Bottom	1.51	8.73	13.7 inf	
	Left	1.44	8.31	13.7 inf	22.6 lt
	Center	1.54	8.89	13.7 inf	
Alphanumeric Keyboard	Top Rt	1.32	7.67	44.7 inf	41.3 rt
	Bot Rt	1.46	8.42	55.2 inf	51.5 rt
	Bot Lt	1.81	10.35	58.0 inf	22.9 rt
	Top Lt	1.57	9.06	46.3 inf	15.6 rt
	Center	1.57	9.06	51.6 inf	35.9 rt
D Console	Top Rt	0.79	4.61	2.0 inf	44.5 rt
	Bot Rt	0.94	5.49	41.6 inf	63.9 rt
	Bot Lt	1.42	8.20	45.4 inf	49.5 rt
	Top Lt	0.99	5.81	2.1 inf	26.4 rt
	Center	1.07	6.25	15.8 inf	47.0 rt
Airways Map	Top Rt	0.93	5.45	75.6 sup	62.3 rt
	Bot Rt	1.27	7.37	39.0 sup	27.5 rt
	Bot Lt	1.27	7.37	39.0 sup	37.5 lt
	Top Lt	0.93	5.45	75.6 sup	62.3 lt
	Center	1.23	7.14	50.3 sup	

Table 2. Accommodative, vergence, and version requirements of the four major components of the radar console based on the 5th percentile female eye height.

Device	Pos	Accom (D)	Vergence (Δ)	Version ($^{\circ}$)	
				Vert.	Horiz.
Plan View Display	Top	1.37	8.85	7.3 inf	
	Right	1.35	8.70	30.4 inf	19.3 rt
	Bottom	1.31	8.49	53.0 inf	
	Left	1.35	8.70	30.4 inf	19.3 lt
	Center	1.43	9.24	30.4 int	
Alphanumeric Keyboard	Top Rt	1.18	7.66	59.9 inf	44.4 rt
	Bot Rt	1.27	8.23	68.8 inf	58.5 rt
	Bot Lt	1.49	9.57	72.8 inf	31.6 rt
	Top Lt	1.35	8.74	59.1 inf	17.8 rt
	Center	1.35	8.74	65.3 inf	42.0 rt
D Console	Top Rt	0.79	5.19	9.2 inf	45.3 rt
	Bot Rt	0.89	5.85	56.8 inf	67.5 rt
	Bot Lt	1.25	8.10	58.1 inf	52.0 rt
	Top Lt	0.99	6.46	9.2 inf	26.8 rt
	Center	1.04	6.75	30.5 inf	48.2 rt
Airways Map	Top Rt	1.06	6.91	49.7 sup	36.2 rt
	Bot Rt	1.45	9.36	26.6 sup	38.9 rt
	Bot Lt	1.45	9.36	26.6 sup	38.9 rt
	Top Lt	1.06	6.91	49.7 sup	36.2 rt
	Center	1.47	9.48	33.5 sup	

Table 3. Accommodative, vergence, and version requirements of four major components of the radar console based on 95th percentile male eye height.

Alphanumeric Keyboard - Accommodative demands for the ANK range from 1.18 D to 1.49 D, while convergence demands range from 7.66^A to 9.57^A. The center of the ANK dictates a 65.3° infraversion combined with 42.0° dextroversion.

D Console - The accommodative demands for the D console range 0.79 D to 1.25 D, while convergence demands range from 5.19^A to 8.10^A. The center of the console has version requirements of 30.5° infraversion with a 48.2° dextroversion.

Airways Map - The accommodative demand for the airways map range from 1.06 D to 1.47 D, while convergence demands range from 6.91^A to 9.48^A. The center of the map requires a 33.5° supraversion.

Overall, the accommodation range was from 0.79 D to 1.81 D (1.02 D) for lower eye heights and 0.79 D to 1.49 D (0.70 D) for higher eye heights. The

convergence demands range was from 4.61^A to 10.35^A (5.74^A) for the lower eye heights and from 5.19^A to 9.57^A (4.38^A) for the higher eye heights. Version demands ranged from 75.6° supraversion, 72.8° infraversion, and 67.5° horizontal version. Of the 80 versions measurements, only 17 (21.25%) required less than 15° of eye movements.

DISCUSSION

The accommodative and convergence demands of an en route radar console would not be expected to have a substantial clinical effect on vision performance for younger controllers with normal phoria and fusional reserve capabilities. Version demands of the en route radar console are substantial and may be a clinical concern to the ATCS. Compensatory head

and neck movements would be necessary to minimize versional eye movements, but could contribute to muscle fatigue and other symptoms. Particularly with presbyopic controllers, proper alignment of the eyes through a variety of near vision lenses would be critical to proper viewing.

Presbyopia is a reduction in accommodative ability occurring normally with age, which necessitates a plus lens addition (or add) for satisfactory near vision. The maximal accommodative demands of the radar console (1.49 D to 1.81 D) would not be expected to have a substantial clinical effect on vision performance for pre-presbyopic and early presbyopic controllers. Current demographics for the ATCS population are presented in Table 4. For the en route controllers, the majority (69.13%) are in age groups that are typically pre-presbyopic. However, within the next decade, the data suggest that a majority of these controllers will be in age groups that are associated with early and mature presbyopia.

To achieve clear and comfortable vision, half of the accommodative amplitude should be left in reserve (2). The distances at which this occurs, relative to the near add power focal lengths, are presented in Figure 3. The horizontal bars represent theoretical distances where optimum, usable (adequate for short periods), blurred, and no usable vision would be expected through the distant and near add portions (ranging from 1.00 to 2.00 D) of bifocal lenses. The focal distances of the major components of the radar console are contained in the area within the bordered box. It is important to note that lower add powers (1.00 D to 1.25 D, equivalent to about 40-45 years of age), typically associated with early presbyopia, should allow the components to be seen without discomfort over an extended period of time. A marginal amount of visual discomfort may arise with a 1.50 D add. With add powers higher than 1.50 D, the range of blurred vision, due to the lack of accommodation, is fully within the focal distances of the major components of the radar console.

For example, a controller with a 1.75 D add has approximately 2.00 D of accommodative amplitude. With corrected distant vision, the individual can view objects between 66.7 to 133 cm, although only for short periods of time, since the accommodative demand

is greater than one-half the accommodative amplitude. Any objects closer than 66.7 cm are, for practical purposes, non-viewable. When viewing through the 1.75 D add segment, the controller has optimum vision to 57.1 cm. Acuity objects beyond 57.1 cm are blurred. An eye doctor may prescribe an intermediate distant vision lens in an attempt to resolve the occupational vision problems of this controller, such as a 1.00 D add. With such an add power, the optimum near vision range is moved out to 100 cm. Even with this lens, there are certain distances where the controller may suffer from marginal visual discomfort and fatigue. Therefore, a single vision lens for intermediate distant vision or a standard prescribed bifocal lens may not be functional for a mature presbyopic controller who needs to monitor the entire radar console. A special occupational lens, probably of a multifocal design, would be required to view the full extent of the radar console.

The maximal vergence demands of the radar console (9.57^Δ to 10.35^Δ) would not be expected to have a substantial clinical effect on vision performance for controllers with normal phoria and fusion reserve capabilities. Since ARTCC controllers are required to meet vision standards for hyperphoria of < 1.5^Δ and esophoria or exophoria of < 10^Δ, most of the ATCS population should easily meet these phoria and fusion reserve requirements. For individuals with fusional problems while working at the radar console, an optical correction (i.e., prism therapy) or vision rehabilitation (orthoptics or vision training) may be helpful.

The eyes do not normally move to the limits of the versional range. Typically, versions do not exceed 30° supraversion, 30° horizontal version, and 65° infraversion (3). Since only the PVD lies within this imaginary normal zone for both eye levels, version demands of the en route radar console may be troublesome to the controller. The airways map requires the largest vertical supraversion for both eye levels. For the lower eye level and the majority of measurements from the higher eye level, points on the airways map are greater than 30° superiorly. For the ANK, the vertical versional movements are within normal limits for the lower eye level, but three of the five measured points are greater than 65° infraversion for the higher eye level. The majority of the ANK is beyond the

Air Traffic Control Facilities				
AGE RANGE	TERMINAL RADAR	FLIGHT STATION	ARTCC	OTHER
< 30	1,613	151	1,920	5
30 - 39	5,047	1,158	3,518	190
40 - 49	2,541	1,521	1,548	345
≥ 50	971	1,071	880	302
% < 40	65.47%	33.56%	69.13%	23.16%
% ≥ 40	34.53%	66.44%	30.87%	76.84%

TABLE 4: ATCS population by facility and age

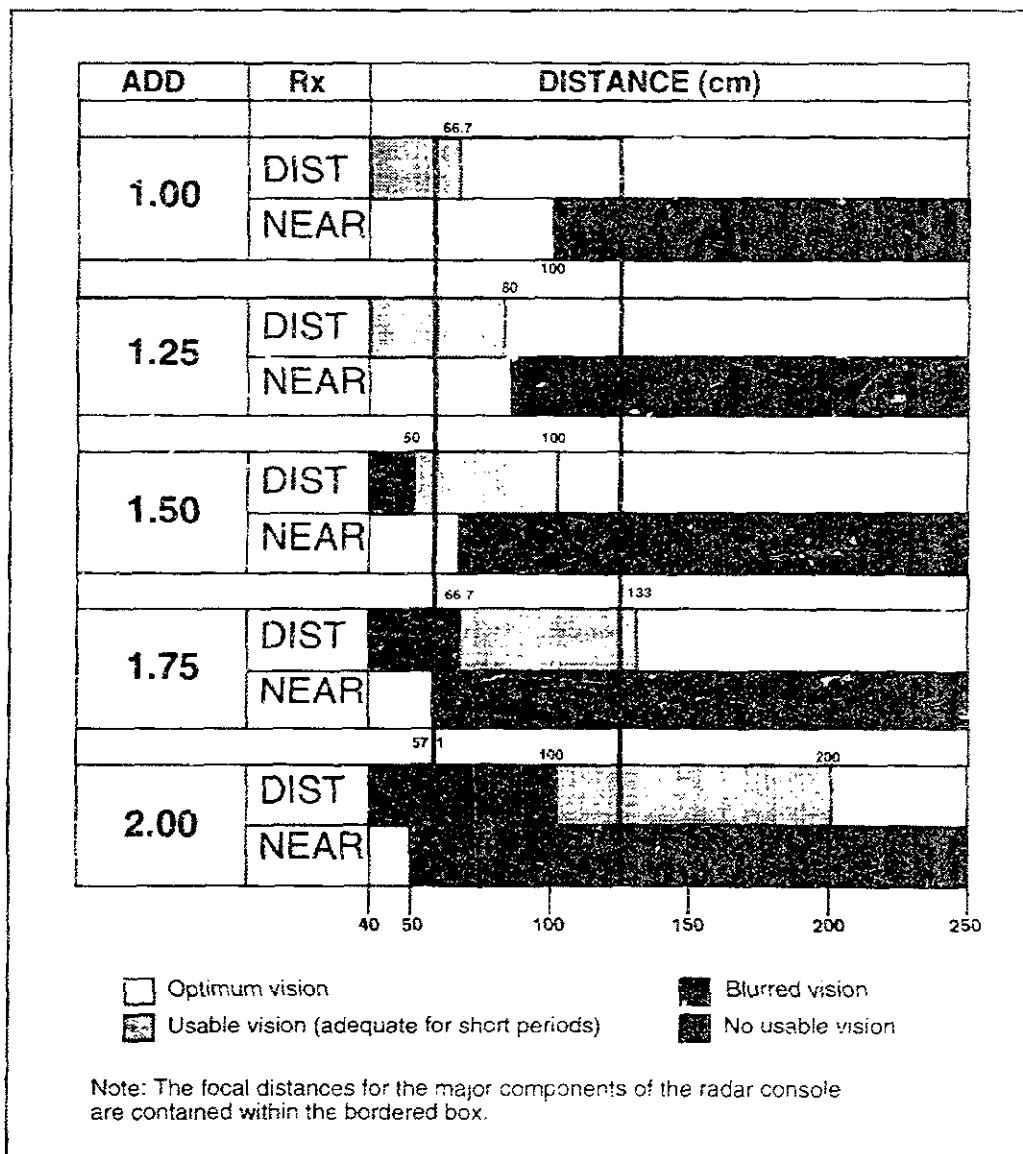


FIGURE 3: Distances of clear, comfortable vision with bifocal lenses

normal horizontal version movements for both eye levels. For the D console, the vertical versional movements are within normal limits for both eye levels. However, the horizontal versional movements are well past the 30° limit for most usable portions of the D console for both eye heights. All of these large versional requirements would require some supplemental head or body movements to be seen, and would be a problem for individuals with limited movement capabilities of the neck, head, or upper torso. Without full functional movements of the body and eyes, the resultant line of sight may be in an incorrect position to use the prescribed near vision segments in some ophthalmic lenses of presbyopic ATCS.

Most vision specialists agree that a visual display should be 15-20° below the line of sight. This is the most comfortable and natural position for the eyes when viewing at closer distances. Other viewing angles are fatiguing, especially when viewing above the line of sight. The study data shows that a significant portion of the controller's work surface lies above the eye level. Since most eye doctors attempt to place near viewing lenses to correspond to the patient's eyes in the slightly depressed and converged position, special considerations in positioning these near vision lenses would be required for ATCSs, depending on the height and viewing distances of the individual.

The PVD, which is viewed for the largest percentage of time by the ATCS, has a majority of its surface at the correct visual angle for comfortable viewing for the lower eye levels. For higher eye levels, the PVD is too low for optimal viewing. The controller would have to be physically lowered to obtain proper viewing angles. If that is not possible, reading segments of multifocal lenses would have to be carefully positioned for taller ATCSs.

The ANK, D console, and airways map are viewed so infrequently that the viewing angles should not be major problems for pre- and early presbyopes. The ANK and D console are viewed about equal percentages of time. The ANK's most difficult problem is its large inferior versional components. Fortunately, the time required for viewing this component is probably not long enough to produce substantial visual symptoms. For presbyopes, the near vision portion of a standard bifocal or trifocal design should provide

adequate vision. The D console is a more difficult component to manage. It contains both the lowest accommodative demand and the largest accommodative range. This range is probably clinically insignificant, even for mature presbyopes. If a second ATCS is available to monitor the D console, which is often the case, this would minimize any viewing problem for the presbyopic ATCS, since the viewing time would be considerably lessened. The airways map is much higher than eye level. Viewing this component for the presbyopic ATCS with standard bifocal or trifocal designs would require large movements of the eyes, head and/or neck. In some cases, controllers may need to move their eyeglasses to view through a different portion of the lens or even remove their eyeglasses entirely to see this component. Most often, the presbyopic ATCS may stand up in order to obtain a clear image. Fortunately, this is not a major occupational concern since this component only requires about 3% of the viewing time.

There are two important environmental differences between the radar console control user and the traditional VDT operator. First, the radar room is often void of outside lighting and has minimal artificial lighting. Coupled with luminance from the radar console, which is less than that of a typical terminal display, this results in a relatively darkened work environment. Second, due to the large surface area of the radar console's major components, the ATCS would likely need to be constantly scanning the entire surface area of the major components. This may require a larger viewing area through corrective lenses than for the typical VDT user, who frequently focuses on the cursor or areas immediately surrounding it.

Considering the viewing and environmental requirements of the en route ATCS, the following are ophthalmic considerations for correcting vision problems for these controllers:

1. A larger viewing area through an ophthalmic lens may be beneficial to see the substantial surface area of the radar console's major components. Single vision lenses would provide the largest and most optimal viewing area, and should be prescribed for pre-presbyopes and early presbyopes (e.g., 1.00 and 1.25 D adds). For more mature presbyopes (≥ 1.50 D), standard bifocal (ST-25, -28),

- progressive addition lens (PAL), and trifocal (7x25, 7x28) designs may provide inadequate vision due to the large console surface area. Larger standard bifocal or trifocal designs (e.g., executive) may be advantageous (Note: Figure 4).
- Smaller standard trifocal designs (e.g., 7x28 mm, executive) may not be large enough either in the vertical or horizontal dimensions. An occupational (CRT Lens) lens design may provide more optimal viewing areas (Note: Figure 5).

- For overhead viewing, the use of Double "D" or Varilux Overview lenses may be beneficial (Note: Figure 5).
- Standard PAL designs may not be wide enough in the near and intermediate vision segment for the presbyopic controller. A "hard" transition PAL offers a wider near vision zone with a shorter progression from the distant to near power than a "soft" design. However, an abrupt transition from the clear reading zones to the distorted areas of the

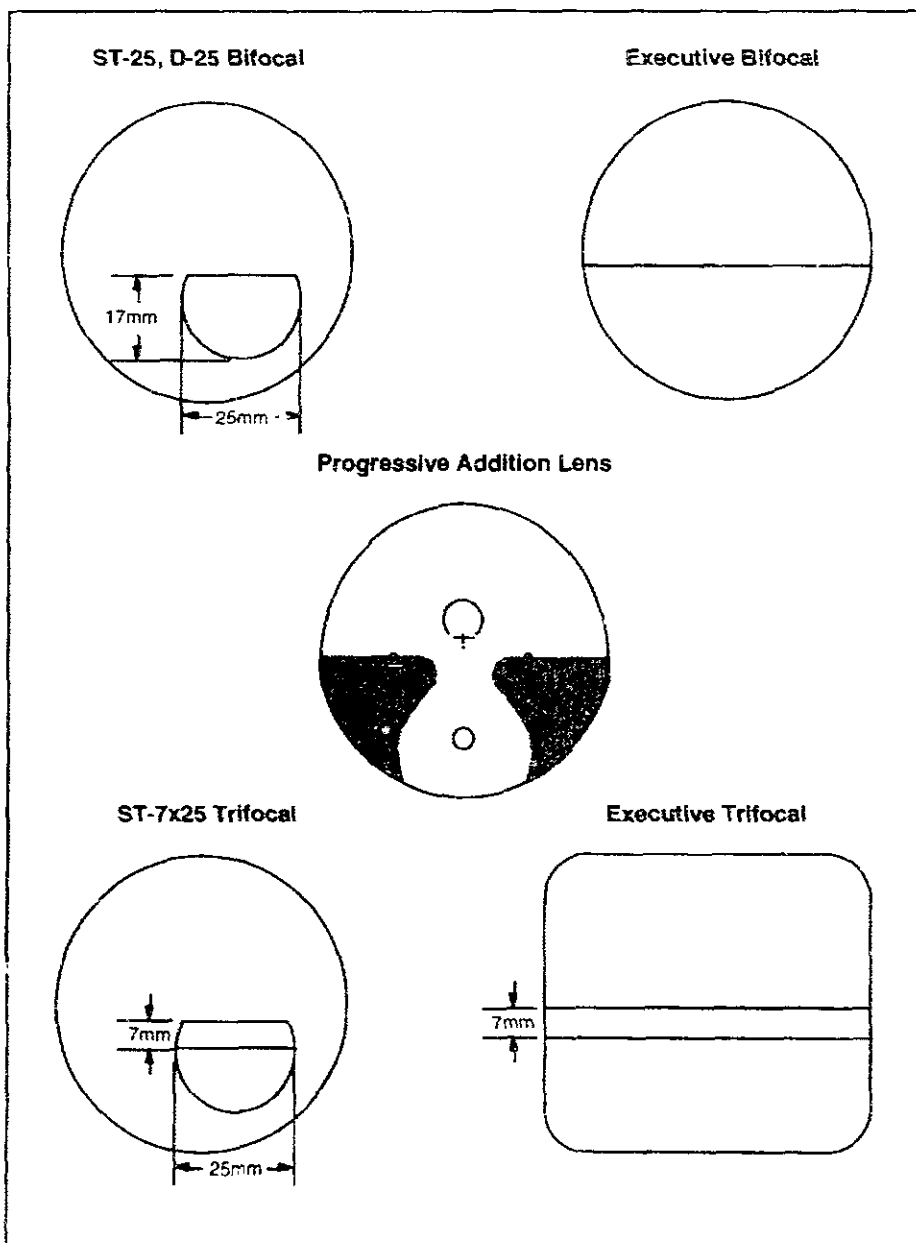


FIGURE 4: Standard bifocal and trifocal lenses.

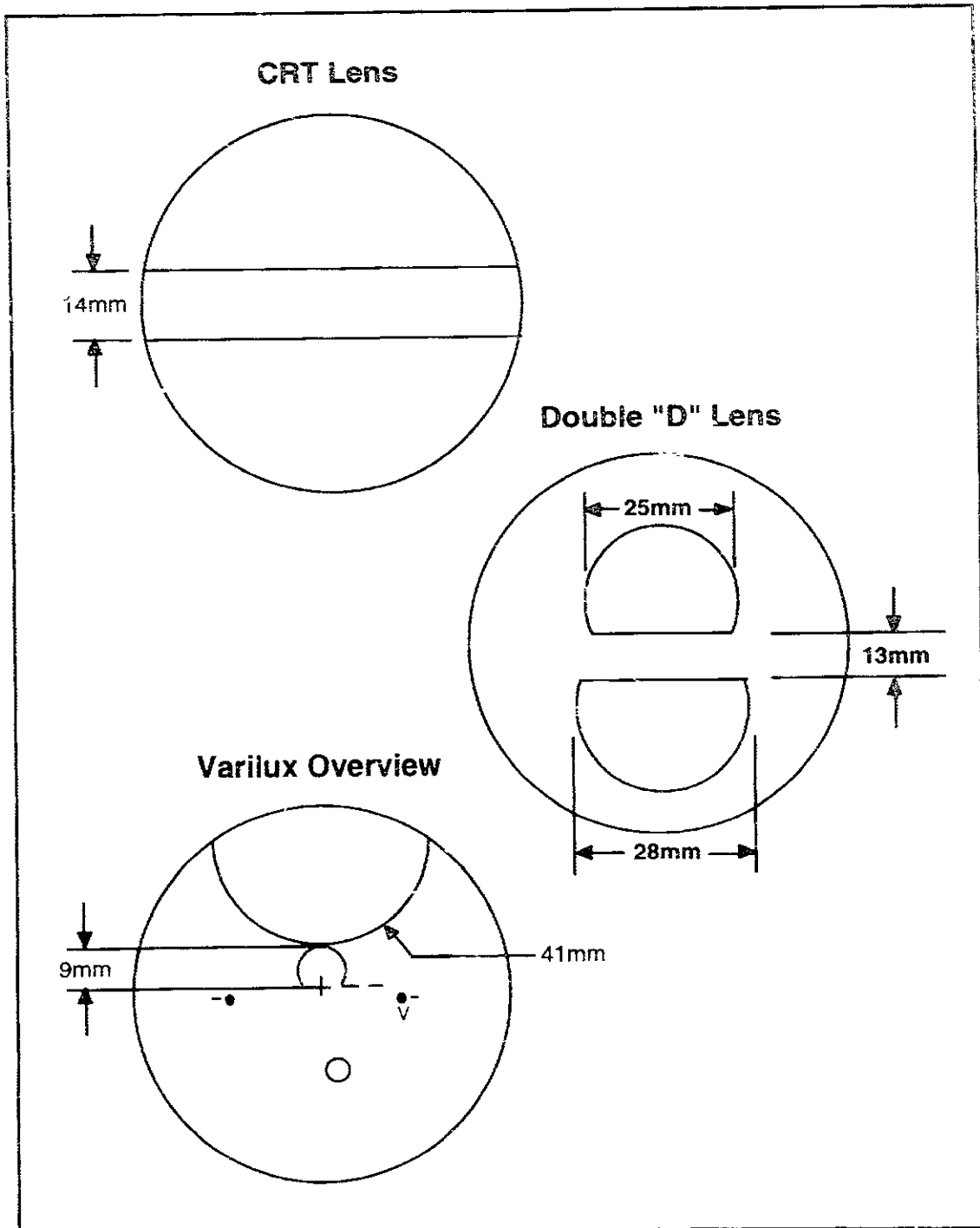


Figure 5: Occupational lenses.

- lens is necessary to achieve these wider zones. The "hard" design PAL produces greater peripheral lens distortions and a narrower intermediate field of vision (4), which may be a disadvantage to the ATCS due to the large work area (Note: Figure 6).
- Recent lens designs marketed for the desk-top and VDT working environments (e.g., American Optical Corporation's Truvision Technica®, Varilux Corporation's Readables), with progressive add powers and larger intermediate viewing zones may be appropriate occupational lenses for radar console users. A disadvantage of these lenses is the limited distant vision capabilities.
 - Using lenses prescribed for standard reading distance (e.g., 35-40 cm) would reduce clear, comfortable vision for the mature presbyopic ATCS on the job.
 - Lenses should be prescribed for the working distance of the ATCS (approximately 60-120 cm). For approaching absolute presbyopes (≥ 2.25 D add), a weaker intermediate vision add power (e.g., 90-120 cm) may be placed in the distant vision (top) portion of the lens and a stronger intermediate vision add power (e.g., 60-90 cm) in

the near vision (bottom) portion. This can be done, since sharp distant vision is not a major requirement for en route controllers.

- Due to the dark work environment, the eye's pupil should dilate, resulting in a reduced depth of field. The theoretical depth of field for an object at 1 meter with a 4 mm pupil is ± 3 cm (5). With a narrower depth of field, accuracy of the refractive correction becomes more critical. In general, tinted lenses should be discouraged in such a darkened work environment.
- ATCSs should be educated on how to best use their prescribed corrective lenses, what limitations of vision might occur, and how to compensate for these weaknesses. This may be best performed by the ophthalmic professional dispensing their lenses, or by the workplace medical or safety personnel, for the more mature presbyope.

In summary, understanding the unique visual environment of the ATCS will assist eye care professionals in meeting their visual needs. The intermediate working distances, the low light levels, and the extensive versional eye movements necessary for scanning the

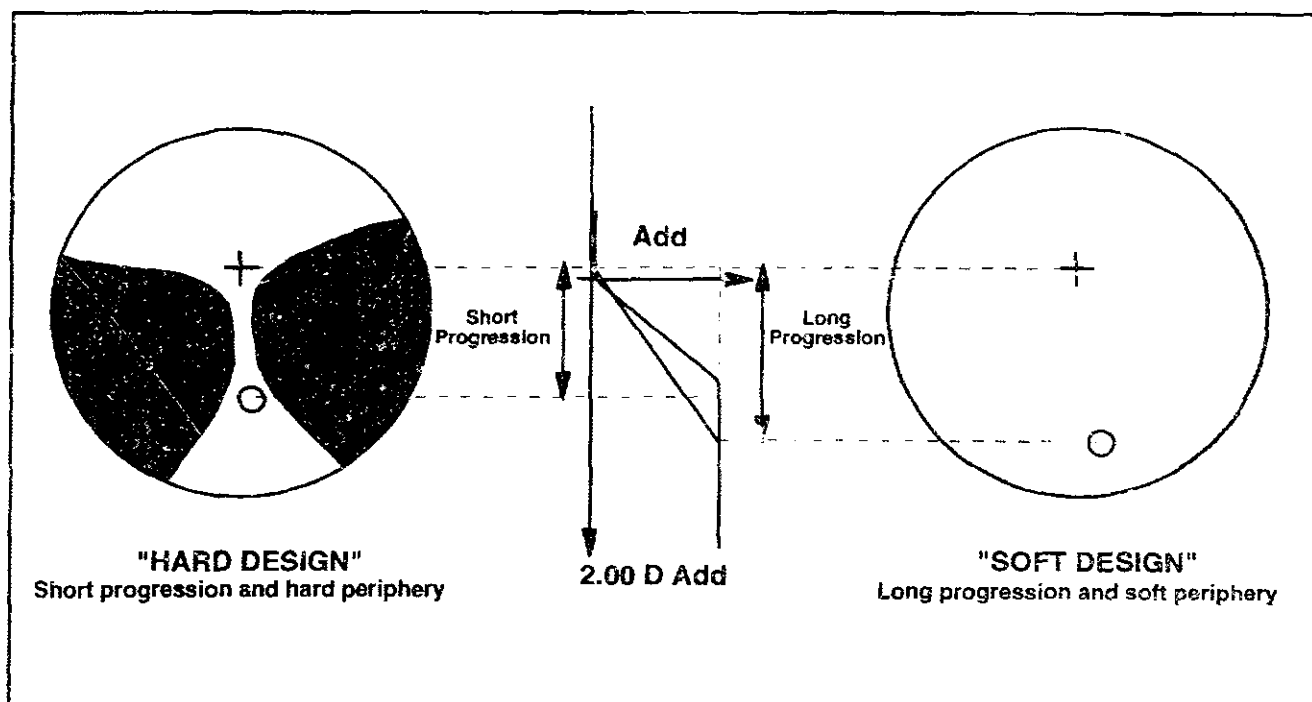


Figure 6: Types of progressive lenses. (Reproduced courtesy of Varilux Corporation)

radar console will influence the specialist's recommendation of an optimum multifocal lens design to satisfy the needs of a particular patient. An all-inclusive lens design for the mature presbyopic ATCS that would provide adequate viewing of all components of the radar console may be problematic, if not impossible. Improved viewing of one component would often be at the detriment of viewing another component.

Visual fatigue is normally more frequent in older age groups. Rest periods have been found to significantly reduce the performance decrement of older subjects on a radar monitoring task (6). Also, since the physical structure of the radar console is fixed, allowing little or no flexibility in the positioning of the different components, a properly designed ergonomic chair is recommended. With correct body positioning, postural movements may be lessened in order for the ATCSs to view the extremes of the radar console components. This is especially true for those individuals at the low and high levels of physical stature. Since changing refractive prescriptions and lens designs often require an adjustment period, it is recommended that ATCSs be carefully monitored to ensure satisfactory performance whenever new prescription lenses, especially multifocal designs, are initially used on the job. Future studies of presbyopic ATCSs in the work environment with different multifocal designs are recommended to verify the suppositions extracted from this study.

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