

### Introduction

This paper presents an outline with commentary on selected aspects of space station windows and remote television monitoring. The fundamental question may be asked at the outset:

#### *Are Windows Needed?*

Of course this question has to do with the issue of whether the crew can carry out their duties as well by means of remotely controlled TV cameras as they can by viewing through windows. This is a complex question which has been discussed for years. The literature which compares human visual capabilities with those of closed circuit television hardware appears to favor human vision when everything is considered. This literature is not reviewed here. It is instructive to note that windows have been included on every previous manned space flight of both the Soviet Union and the United States. Astronauts Truly and Crippen remarked about the value of space vehicle windows. They state, "A wealth of scientific information was gleaned from the hand held photography of the heavens and the earth taken from these six (Skylab) windows. However, quite often there was not a window available to view a desired objective.... Every attempt should be made to provide spacecraft of the future with enough windows of good optical quality to always offer a view of earth and space." A review of many post-flight debriefings of the American missions and other material has convinced this writer of the critical importance of windows.

Their major functions are listed here:

1. Permits outside visual observations.
  - a) rendezvous/docking with other objects
  - b) space station build-up/repair/(future) modification
  - c) emergency/rescue operations
  - d) earth surface experiments/monitoring
  - e) celestial experiments
  - f) experiment hardware moving and stowage using remote manipulators
  
2. Permits limited visual observations from outside to inside.  
For instance in the event of a communication system failure gestures/non-verbal communication would still be possible.
  
3. Can make it possible to "see through" a module from outside.
  
4. Allows natural sunlight to enter for possible use.
  
5. Contributes to general habitability of the living/working environment by virtue of the natural beauty of the heavens and earth viewed from orbital altitude and by the ability of a window to permit the viewer ready "visual escape" from the relatively small and confining habitat.
  
6. Contributes to the mental health of the crew by providing immediate visual and "psychological" access with the earth.

7. Can contribute to the physical health of the crew by providing access to natural solar radiation.

#### Subject Outline

##### *Primary Design Issues* (Discussed here)

- 1.1 Number of windows per module
- 1.2 Frontal area and shape of each window
- 1.3 Location of each window in each module in relation to station configuration
- 1.4 Field of view angles of each window (function of 1.2 and 1.3)
- 1.5 Ambient interior illumination control
- 1.6 Operations better suited for CCTV than windows
- 1.7 Preliminary design specifications

##### *Secondary Design Issues* (Not discussed here)

- 2.1 Optical characteristics of each window to permit execution of each required function
- 3.1 Solar radiation filtering requirements (UV, visible, IR)
- 4.1 Maintenance requirements (cleaning/polishing interior & exterior surfaces)
- 5.1 Internal heat balance considerations
- 6.1 Internal "habitability" considerations (need for visual escape, crew reassurance to the real world, shorter day/night cycle and circadian entrainment, etc.)
- 7.1 Visual accommodation considerations over time
- 8.1 Stimulus to human creativity

### *1.1 Number of Windows Per Module*

In order to determine the required number of windows per module from a human factors design point of view one should take the following factors into account. Not considered in this paper are such considerations as the mechanical strength or weight of glass, specific means for installing it into the space station, leakage-related problems, or other threat impact issues. Also, factors such as the abrasion-resistance of glass is of importance here only to the extent that periodic maintenance must be planned in order to restore the windows to some acceptable condition. Clearly, the more windows there are the more such maintenance will be required. Finally, it is assumed that the optical quality of each window will be adequate to support the particular task(s) that will be carried out using the window. The host of problems associated with poor optical design will not be discussed here.

- 1.1.1 Established need for external visibility during space station build-up period. Certain configurations of modules of a completed space station may block the external field of view from a given window so that another window would be called for in that module. Because of weight, strength, and other penalties, it is possible that a temporary CCTV might be used in place of a window during the construction phase.
- 1.1.2 Established need for field of view (FOV) overlap from two or more windows. Certain operations may require simultaneous multi-crew coordination from different windows. Can it be demonstrated that both crewmen will be enhanced in their ability to perform the required tasks because of this simultaneous viewing capability?
- 1.1.3 Established need for having "blind spots" only in non-critical areas. CCTV monitoring could be used to provide "fill-in" surveillance in these areas.
- 1.1.4 Established need for admitting solar radiation into the space station over a sufficiently large area (total) area. Certain experiments as well as the crew may require natural sunlight inside the space station.

### *1.2 Frontal Area and Shape of Each Window*

As with the other window design characteristics discussed here, window area and shape have been determined mainly on the basis of structural engineering constraints rather than by human factors related needs. A particularly strong case must be made by the human factors design professional if he intends to depart from so-called "standard" window shapes and sizes.

As used here, the term "area" refers to the physical dimensions of the window's transparent surface. The perceived shape of any window is determined by eye distance and head orientation relative to the window (cf. Figs. 7-9).

Of course an upper limit will be reached in window area set by strength and other considerations. There is a need to find creative solutions in re-

gard to enlarging or minifying window area visual effects. Can lenses (or fiber optics) be used in this way, perhaps to expand a patch of sunlight once it has entered a smaller window? Should windows be made of non-flat material such as the bubble canopies used on WW-II bomber and fighter aircraft?

A wide variety of window shapes have been used to date in America's manned space vehicles. The Mercury, Gemini, and Apollo vehicles all had small, irregularly shaped windows which provided only minimal external visibility. The Skylab vehicle had round windows. The astronaut could literally touch his nose to the glass which permitted a relatively wide external field of view (Figs. 2-5). The shuttle vehicle had forward windows remarkably similar in shape to those in today's commercial airplanes. At the top rear of the crew compartment are two square windows 19.75" on a side (with small radius corners) and at the rear bulkhead are two horizontally oriented rectangular windows measuring 14.25" wide. Their vertical dimension nearest the vehicle's centerline is 10.75" and farthest from the centerline is 9". They are recessed over 3" from the surrounding wall surface. To the author's knowledge no one has specifically analyzed the influence that this wide variety of windows may have had on how adequately the crew carried out their assigned tasks (Fig. 10). Anthropometric studies were conducted for the shuttle's rear work station windows in terms of eye to window distance to aid in planning for location of surrounding structure.

Before proceeding it is necessary to comment on the Design Eye Point (DEP) for a space station window. The DEP is the location of the two eyes relative to the window which will provide a desired external visibility envelope when looking through the window. This design approach was borrowed from airplane cockpit design. In the case of the space station's windows, the DEP must take into account not only eye to glass separation distance but also head-body orientation since the viewer will be in zero gravity conditions and may or may not have body restraint available. There will, therefore, need to be an azimuthal reference ( $A_z$ ) included which will represent the angle between the local vertical of the window ( $0^\circ$ ) and the longitudinal axis of the head with  $0^\circ$  at the top and measuring in the clockwise direction. Why will this  $A_z$  parameter be needed? Because the monocular and binocular visual field of the viewer may be larger or smaller than the FOV of the window depending upon head orientation and eye to window separation distance (see Figs. 11-15). It may be possible to maximize the total external visual field through a window by specifying a certain head orientation.

The following factors are considered relevant to designing the frontal area and shape of space station windows.

- 1.2.1 Number of persons per window. Can a need be shown for two or more viewers to look out of the same window at the same time? Of course window area and shape are closely related. A circular window with an area of one square meter will have a diameter of only 58.4 cm which will not permit more than one viewer (centered), but a rectangular window of the same area (but 20 cm by 500 cm) could accommodate as many as six viewers side by side. How each of the viewers is oriented relative to one another also will determine how many people can use the same window simultaneously.

1.2.2 Eye to window surface distance. Obviously, the nearer the viewer can get to the window the larger will be his external field of view (angle) (cf. Figs. 11-15). The nominal eye to window surface distance for the aft bulkhead window in shuttle was 55 cm (22 inches). Field of view plots for an eye distance of only 10.4 inches showed that the maximum angular field of view width out this window for the 50 % man (binocular viewing) was about 62° (monocular) and about 80° (binocularly) (See Fig. 8). Moving back farther would reduce this angle significantly. Future anthropometric design considerations should accommodate a crew ranging in size from the 5th percentile female to the 95th percentile male.

Calculations have shown that the outer edges of a docking vehicle may well disappear outside the window's field of view at a certain separation distance even with the eyes located very near the window's surface (see Figs. 1,6). If this happens it will be necessary to provide additional range and range-rate dynamic cues for the astronaut to use. Such cues might include carefully planned surface patterns and other detail of known size that provide orientation and texture information about the vehicle being approached.

Another important consideration is placement of wall-mounted equipment and other structure near each window. It is known that the volumetric work-envelope requirements of the body in weightlessness differs from those in a one-g environment. Provision should be made to permit the viewer to locate his eyes near the window for extended periods of time without neck muscle strain.

1.2.3 Maximum field of view needed from the window. Certain tasks involving external visibility through windows will call for wider visual fields than others. Certain windows may need to be "dedicated" to specific functions with all of their field of view, optical transmission, and other characteristics pre-established to support the required function(s).

An ultra-wide field of view may be desirable in future space stations in situations in which visual judgments need to be made of the "structural" continuity of a very long module. Such a module may be only partially visible when viewed through a narrow window but which would be totally visible when viewed through a wide angle window.

Several comments are in order concerning the shape of the windows. It is likely that most windows will be used for a wide variety of purposes and that shape of the aperture will not be particularly important. However, it is possible that during the approach, docking, and other close-proximity operations with another vehicle or module window outline shape could be important. Consider a round window. Roll attitude of a distant approaching vehicle could not be readily determined within such a window shape without

an additional reticle, head up display, or other aid. In addition, the viewer's body orientation would be harder to determine when viewing through a round window. A square or rectangular window outline would provide such attitude information.

If it is found that crew "self orientation" to a local vertical is needed, then correctly shaping and orienting all windows alike could help to provide these verticality cues just as wall-to-wall intersection lines do in the one-g (earth) environment.

- 1.2.4 Established need for high optical quality. Much the same argument as given above (1.2.3) applies here. For example, if celestial observations will be carried out it may be justified to specify an "astronomy" window with all of the necessary optical characteristics.
- 1.2.5 Window thickness (depth) requirements. The thicker is the total window assembly the smaller will be the available external field of view for a given eye to window separation distance. Also relevant here are the total number of panes used in each window. Generally, the more panes the lower is the total light transmission and the greater is the possibility of multiple reflections (sometimes known as the "string-of-pearls" effect).
- 1.2.6 Established need for internal module ionizing radiation shielding. Unless the window assembly provides adequate cosmic radiation protection itself (at least comparable with surrounding walls), the fewer windows the better (all else equal).
- 1.2.7 Established criticality of maintaining clean windows. The larger the windows the greater will be the required maintenance (time/energy) "costs." In addition, certain shaped windows may require special cleaning implements. For example, a window having a small radius corner may prevent some implements from reaching all the way to the window frame. Such considerations may justify a limited number of space station window sizes and shapes.
- 1.2.8 Possibility/probability of needing to replace windows on-orbit. Windows may be damaged (cracked, scratched, unable to maintain an internal pressure over time). The frontal area of a becomes available. It also may be necessary to replace an existing window(s) as new technology makes improvements available.
- 1.2.9 Possibility of reflection of sunlight into a window from a near-by surface. Certain space station surface contours and sun angle orientations may produce very high intensity reflections into a window. Such reflected light could produce multiple reflections within multiple window panes, temporary visual impairment from so-called "flash blindness", and could alter the

heat load inside the station.

Since the human pupil of the eye requires from two to four seconds to contract completely to very high brightness scenes, an unexpected solar reflection could leave the viewer visually incapacitated for some period of time (see section 1.5).

### *1.3 Location of Each Window in Each Module in Relation to Overall Station Configuration*

In general, much the same considerations given above with regard to the number, size, and shape of the space station windows applies here as well. This issue is complex and calls for a careful prioritization of crew duties. There likely will be competition for wall space. Whether a window is installed rather than a cabinet or equipment should be dictated by a careful consideration of the long-term needs of the space station as well as a thorough knowledge of the capabilities and limitations of human vision and CCTV. Thus, while one might justify having no windows at all over the short-term, it is becoming increasingly obvious that having the ability to look out is very important. It is suggested that having this capability will become even more meaningful the longer the crew is on-board for psychological and social reasons.

A general design guideline should be kept in mind when considering the placement of each window in relation to the overall space station configuration, namely, the window designer must take into account all that is known about the capabilities and limitations of the human visual system. Take the perception of space for instance. There are a number of cues to distance and orientation present in most viewing situations (accommodation; convergence; light and shading, shadows, surface texture and gradients, motion parallax, flow fields, perspective transformations, occlusion of the farther object by the nearer, edge and corner configurations, redundancy, absolute size, etc.). The very high contrast environment of space will eliminate some of these cues while the relatively great viewing distances will eliminate or reduce others. The point is that window placement should attempt to plan for what cues will be available from the earth/sky background as well as from the other modules of the space station which will provide potentially useful distance ranging and translation rate cues.

Not discussed here are various engineering design factors such as module rib-spacing, radius of curvature of the walls, weight penalty, or other such subjects. The following general factors are presented to help plan for where to locate each window in a module.

**1.3.1 Space station build-up sequence and module shape, number, and size.** Window placement in each module may be partially dictated by the need to use each window during the construction phase of the space station. It is possible that CCTV may perform the desired viewing functions better from temporary locations than providing fixed windows at locations which may become "non-functional" or of reduced utility later when the space station is completed.

**1.3.2 Module internal layout design.** Windows must be located with regard to their proximity to internal equipment that

may require human monitoring and to fixed walls and/or other structure. Human anthropometric measurements as well as full scale mock-ups should define the necessary maximal and minimal separation distances.

If it appears that natural sunlight can be used for general interior illumination purposes an approach might be to locate a relatively large window at the end of the module and orient the module with the window pointing toward the sun. The shaft of light running the length of the module could then be "tapped" by inserting a reflecting (diffuse) surface at any location desired.

- 1.3.3 Necessity for sunlight at certain internal locations. It is conceivable that certain on-board tasks would benefit by being illuminated by natural sunlight. Window placement should take this possibility into account.

The opposite situation also exists, namely, those areas within the space station that must be shielded from sunlight such as sleeping areas.

- 1.3.4 Personal privacy needs should be considered. Window placement should consider the needs of the crew's personal privacy in "staterooms" and "heads." If a stateroom has a window it should be capable of being temporarily shuttered (see Section 1.5).

- 1.3.5 External visibility from multiple windows simultaneously. It may be desirable to use full visual field human vision (e.g., during the final stages of a docking/berthing operation). If a single window will not permit this wide a single field of view perhaps the use of two (or more) adjacent windows would suffice.

#### *1.4 Field of View Angles of Each Window*

The angular width and height of each window is determined by window size and shape and the eye to window distance. Laboratory research has shown the importance of having stable visual references within the observer's field of view during those times when he must judge precise absolute and differential motions. For the final stages of docking, for example, a special purpose alignment system such as is used on the shuttle (COAS) plays an important stabilization role. However, if the astronaut can hold his head in a constant position relative to the window frame, the fixed frame will serve the same purpose without the need for additional (input) power or special optical display hardware.

The field of view of each window may be effectively varied by moving the position of the eyes relative to the window. Computerized plots made for the deployment of payloads on shuttle using the remote manipulator arm provided valuable insight into how these fields of view change with head movement.

The recommended minimal window field of view width is 120° arc since this will provide for full binocular visual field stimulation. That is, the region



of the visual field that is mediated by the right eye will be fully overlapped by that region of the visual field that is mediated by the left eye. If significant head rotation is anticipated (rather than just eyeball rotation within the eye socket), then this minimal horizontal angle should be increased accordingly.

- 1.4.1 Optimal eye location behind a window to yield maximum field of view with minimal head movement. It can be shown that for a given size and shape window, there is an optimal location for the eyes in terms of minimizing head movements yet keeping the target in sight.
- 1.4.2 Provision for allowing the eyes to be positioned very near the window's surface. Despite possible problems of window surface scratching and abrasion and moisture condensation from the crew's breath, it is strongly recommended that the area surrounding each window be designed with minimal interference for the shoulders and upper torso to permit him to come up close to the windows' surface when necessary.

### *1.5 Ambient Interior Illumination Control*

There is a rather extensive literature which shows the critical importance of providing adequate illumination to support the performance of various tasks. This is no less the case on the space station. The availability of full sunlight makes possible the application of "light pipe" technology to bring sunlight to a desired interior location directly rather than via photovoltaic cells transduction. Direct solar radiation at mean solar distance =  $1.99 (+/- .02) \text{ cal cm}^{-2} \text{ min}^{-1}$ . The mean luminance of the solar disc viewed from orbital altitude =  $2.02 \times 10^{11} \text{ stilb}$  ( $= 5.88 \times 10^8 \text{ foot Lamberts}$ ). Solar illuminance at mean solar distance (outside earth's atmosphere) =  $1.37 \times 10^5 \text{ lux}$  ( $\text{lumen m}^{-2}$ ). The lack of a local light-scattering atmosphere surrounding the space station produces an extremely high contrast between the blackness of space and the solar disc or objects illuminated by sunlight. This high contrast may call for special optical filtering at the windows, particularly for operations which must be carried out over long periods of time. Neutral density optical coatings, crossed polarizing filters, photochromic filters, and other kinds of light-controlling means are presently available. Several preliminary planning factors are given below.

- 1.5.1 Established need for having natural (full spectrum) sunlight available inside the space station. It is possible that various biological, medical, physical, and psychological experiments will require natural sunlight. Permanent windows having special glass will need to be installed to support these experiments. It is suggested that each module have at least one such window which transmits as wide a wavelength band as possible but that a "snap-on" spectral blocking filter also is provided for these particular windows.

- 1.5.2 Established utility of sunlight in health maintenance of the crew. It is known that calcium loss from the bone in weightlessness continues to be a major problem. It is also known that vitamin D from certain wavelengths of natural sunlight facilitate the absorption of calcium by the gastrointestinal tract. It may be justified to require periodic "sunlight therapy" on space station. If so, special optical glass will be required for the windows.
- 1.5.3 Established validity of using natural sunlight inside the space station to supplement or replace artificial illuminants. It is possible that on-board power generation requirements might be reduced through the creative use of fiber optics and/or reflective surfaces to redirect sunlight into and through the interior of the space station.
- 1.5.4 Established validity of using sunlight to enhance the habitability of the space station's living and working areas. Most people enjoy looking out of windows at out-of-door scenes. A careful review of in-flight voice communications from earlier space flights has shown the importance of having windows for reasons other than to support experiments.
- 1.5.5 Established need for having a test-bed for evaluating new means for controlling sunlight. It is conceivable that new technology will be developed for controlling ambient illumination for terrestrial applications. Having windows on space station will make testing of this new technology possible as long as the windows possess adequate transmission in the IR, visible, and UV wavelength bands.

### *1.6 Operations Better Served for CCTV Than Windows*

Justifications commonly given for using closed circuit TV monitoring include: operating environments which may be hostile to the human, operations which call for inobility and/or surveillance in small areas too restricted for man. Experience gained from recent shuttle flights has proven the utility of remotely aimed and controlled TV cameras. The remote manipulator (cherry picker) arm was able to be positioned precisely at full extension by means of a TV camera attached to its end.

A prudent approach to the matter of how best to provide for the visualization of external space station operations would seem to be to provide a carefully integrated combination of CCTV and windows. Computer-aided 3-D perspective views of the completed space station for each vantage of concern should be produced so as to determine whether a window or CCTV camera is the best solution. Following are some general factors to consider in deciding whether CCTV should be employed in place of permanent windows on space station.

- 1.6.1 Necessity of having a "video" record of activities for later analysis. The CCTV camera's output may be stored on-board the space station and/or transmitted to earth.
- 1.6.2 Requirement for operating in the space environment over prolonged periods of time. While an astronaut could visually monitor external operations through a window, a properly positioned CCTV camera could also. Energy, weight, and volume tradeoff studies should be performed to justify use of either alternative.  
This factor also includes those physical characteristics of the space environment that are harmful to man (ionizing radiation, low temperature, low pressure) but which may be designed against for the CCTV system.
- 1.6.3 Requirement for "seeing" into very small and poorly lit areas. A properly designed CCTV system with its own illumination source(s) can permit visual access into volumes far smaller than that of the suited astronaut.
- 1.6.4 Operations where image magnification (zoom) are required. High quality optical magnifying lenses are now available with which to achieve wide ranges of field of view and magnification with minimal distortion and light loss. It should be noted, however, that range and range rate cues will be either missing altogether or severely distorted by a zoom system unless additional information is provided within the field of view.
- 1.6.5 Requirement to "see" ongoing operations but where physical impact is possible. It is best to sacrifice a TV camera (if absolute necessary) and not a person.
- 1.6.6 Requirement for a very long optical baseline. Certain future on-orbit operations may require ultra-large baselines as during the construction of very large antenna or solar cell arrays. Use of inertially stabilized CCTV systems positioned relative to each other (with appropriate retroreflective auto-alignment systems) over large separation distances could play a useful role here. It is difficult to see how the space station could be configured to provide this type of function no matter where the windows were placed.

### 1.7 Preliminary Design Specifications

FOV (width;  $A_z = 0^\circ$ ) .....  $120^\circ$   
 (Height;  $A_z = 0^\circ$ ) .....  $80^\circ$

Shape (general) ..... Rectangular or

	Square	
Transmission (general purpose viewing) .....	.80%	(400 - 725 nm)
(skin photo-therapy) .....	t.b.d.	
("full spectrum" applications) .....	approx.	340-850 nm
Design Eye Point (separation distance) .....	12"	(mean)
( $A_z = 0^\circ$ )		
(min., max. distance) .....	1"	task dep.
Line of Sight (angular) Deviation .....	0.5 mr	(note 1)
Optical Quality (general) .....	optical grade A	(no bubbles)
Protective Shield (outside) .....	if possible	
(inside) .....	yes	
Light Shade (complete light cut-off capability?) .....	yes	
(variable neutral density capability?) .....	yes	(0 - 100%)
(colored filters available?) .....	t.b.d.	

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Note. 1. This deviation requirement should apply for all head positions and over the total FOV. The 0.5 mr maximum allowable radial error should be computed as the root-mean-square of the azimuth and elevation component errors.

#### *Summary*

While it may be concluded that windows on space station will be required to support a wide variety of work and leisure time activities, their specific design should take into account at least those human factors issues addressed above. It also should be pointed out that in order to not overlook critical "interaction" effects which are liable to occur whenever humans interact with other humans and with equipment each of the above factors also should take into account the following:

**work vs. leisure time activities**  
**small vs. large interior volume availability**  
**long vs. short term occupancy**  
**inflexible vs. flexible interior configurability**  
**major vs. minor physiological stressor(s) present**  
**major vs. minor psychological stressor(s) present**

The importance of providing for optimal human vision in space flight has been adequately demonstrated over the past twenty five years. Now is the time to plan for the overall best design for the windows on space station.

BASIC FIELD OF VIEW ANGLE VARIABLES

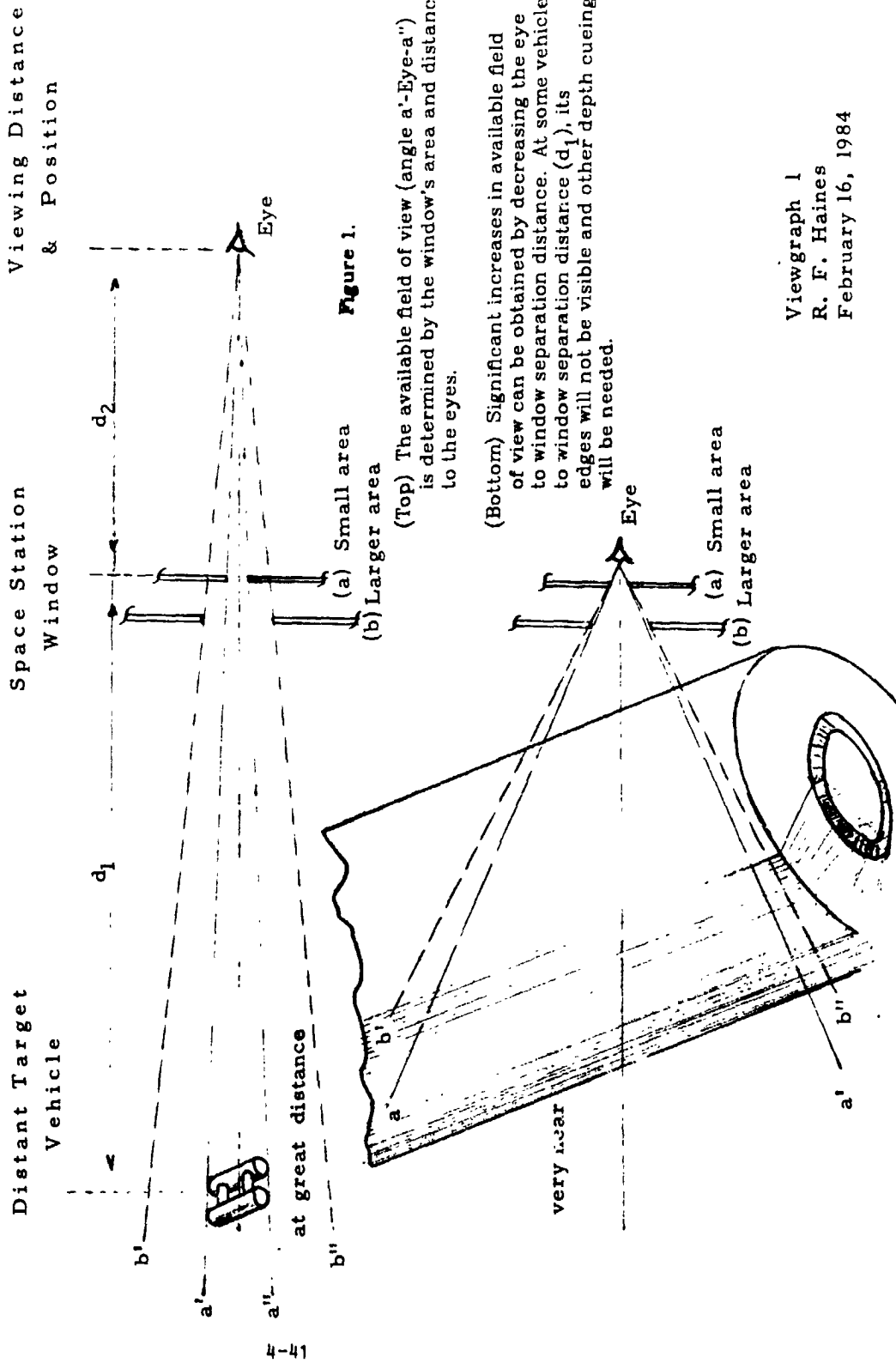


Figure 1.

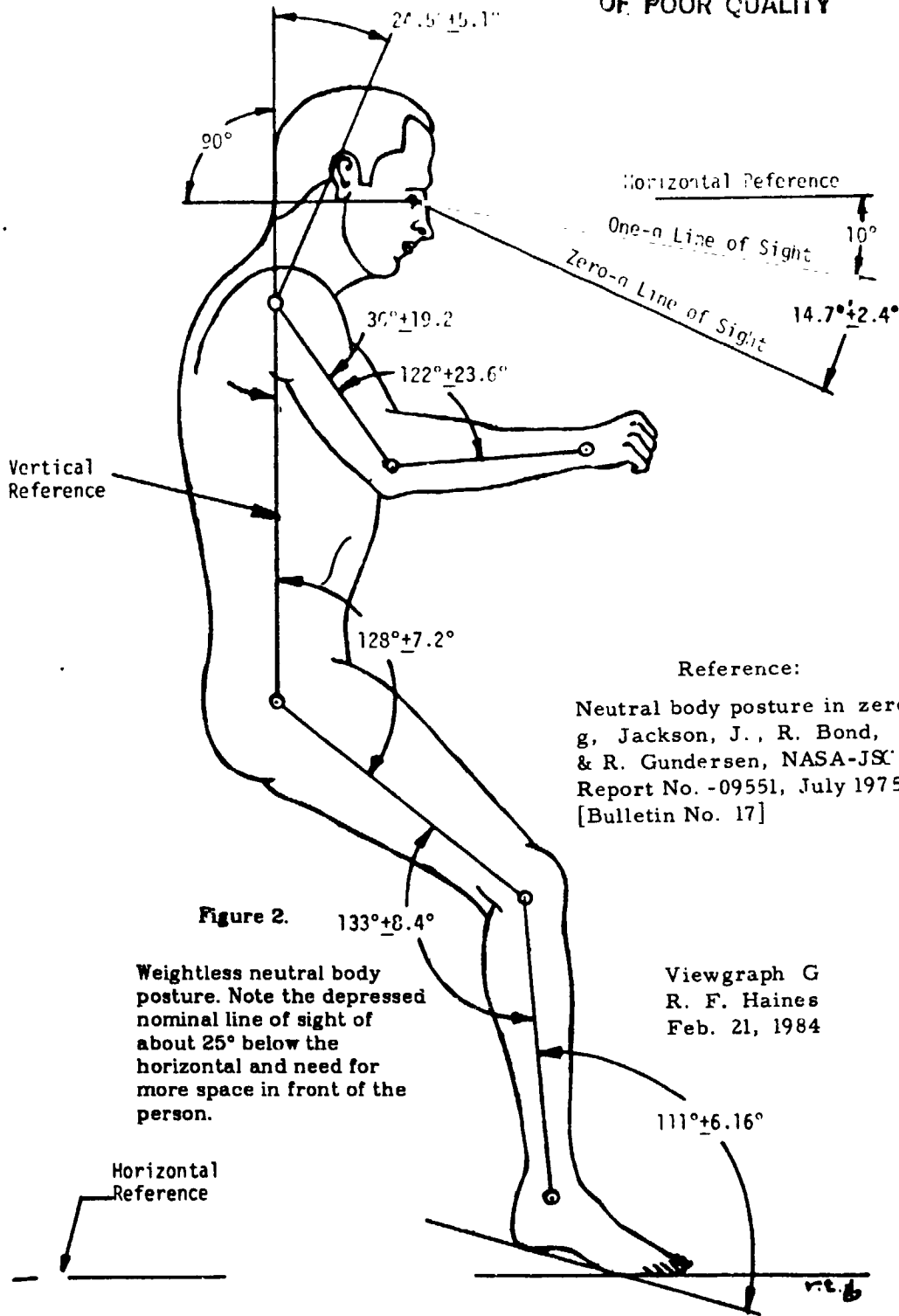
(Top) The available field of view (angle a'-Eye-a'') is determined by the window's area and distance to the eyes.

(Bottom) Significant increases in available field of view can be obtained by decreasing the eye to window separation distance. At some vehicle to window separation distance ( $d_1$ ), its edges will not be visible and other depth cueing will be needed.

Viewgraph 1  
 R. F. Haines  
 February 16, 1984

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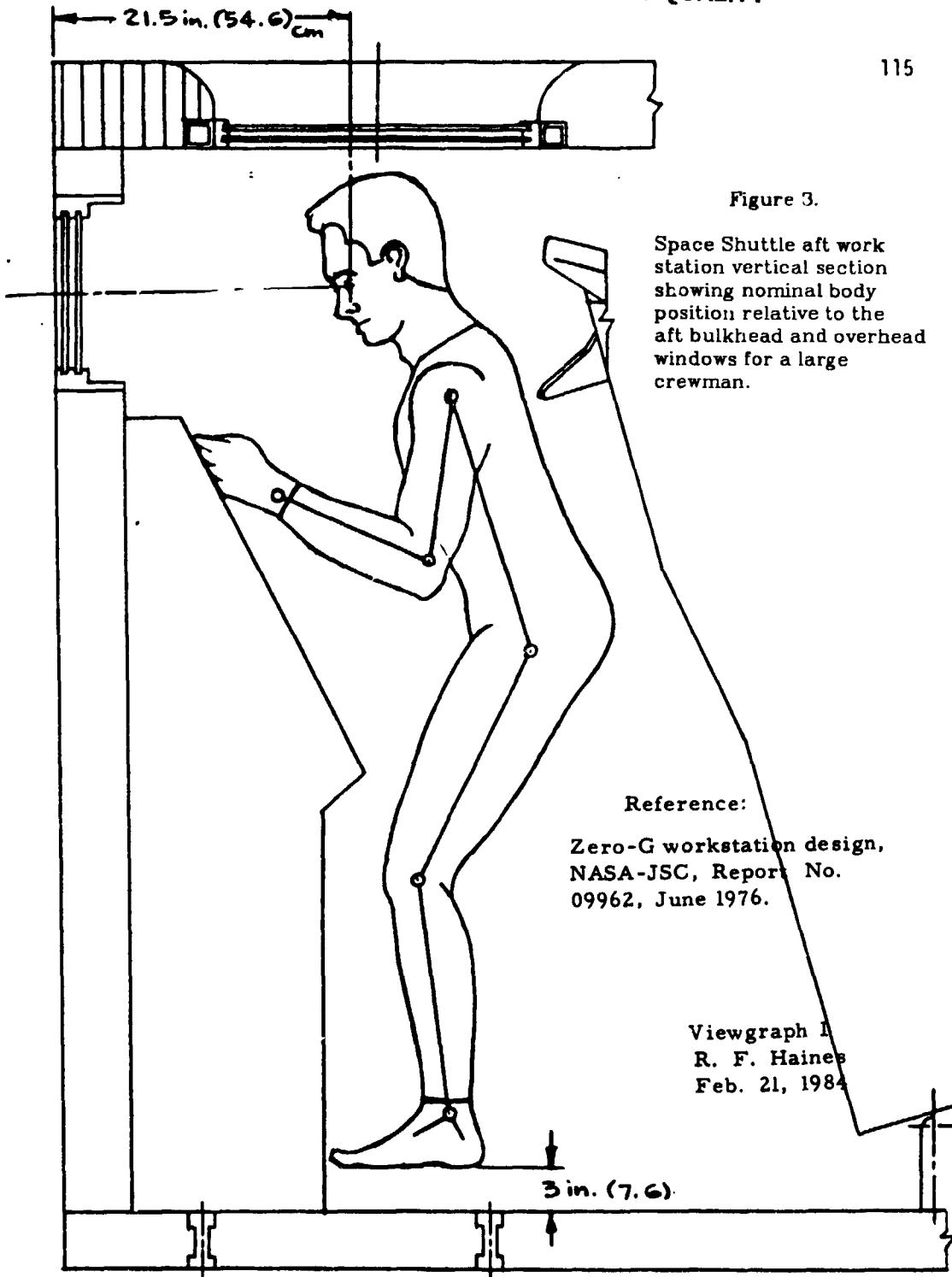


Figure 3.

Space Shuttle aft work station vertical section showing nominal body position relative to the aft bulkhead and overhead windows for a large crewman.

Reference:

Zero-G workstation design,  
NASA-JSC, Report No.  
09962, June 1976.

Viewgraph I  
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Feb. 21, 1984

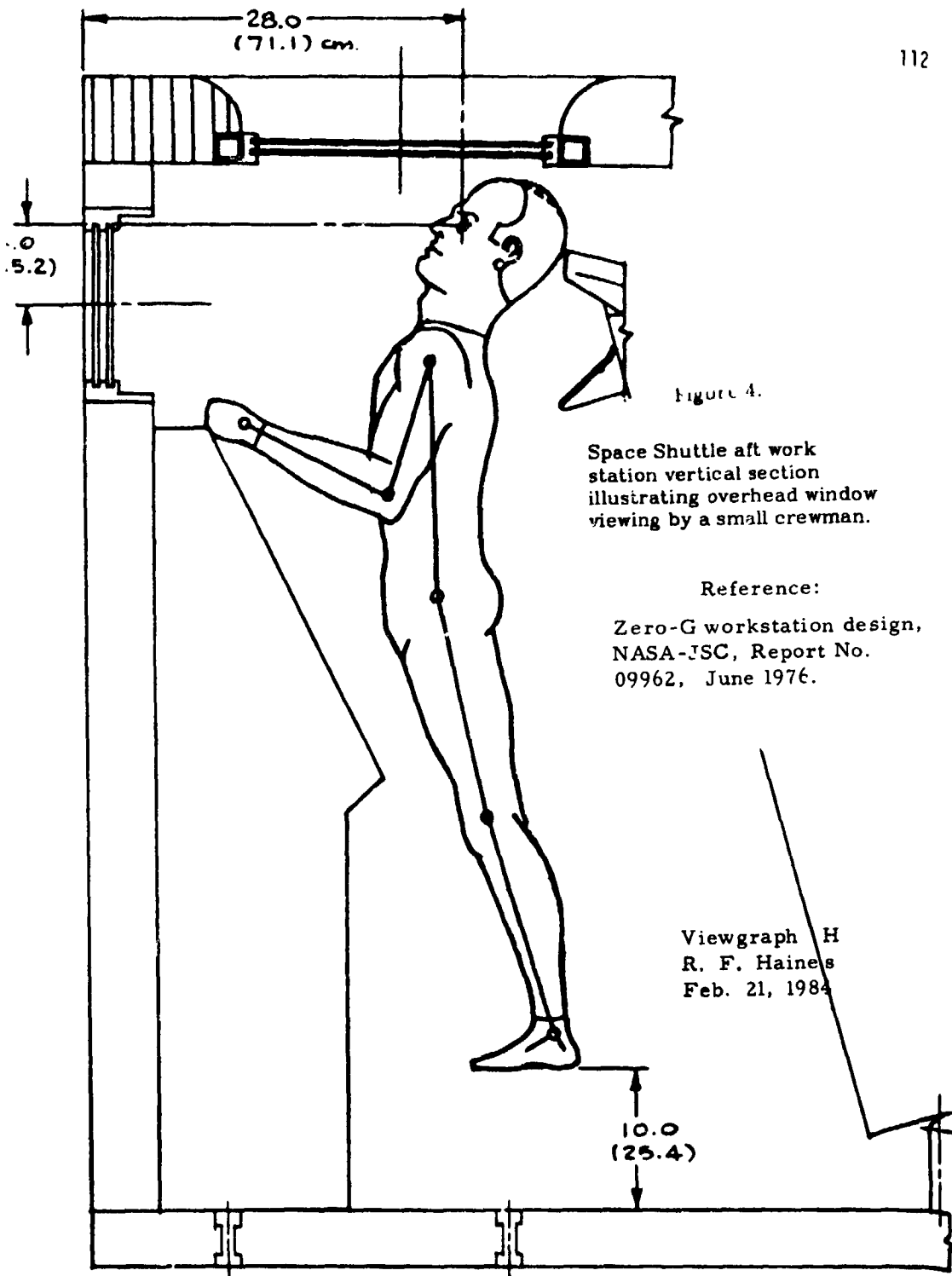


Figure 4.

Space Shuttle aft work station vertical section illustrating overhead window viewing by a small crewman.

Reference:

Zero-G workstation design, NASA-JSC, Report No. 09962, June 1976.

Viewgraph H  
R. F. Haines  
Feb. 21, 1984



ORIGINAL DESIGN  
OF POOR QUALITY.

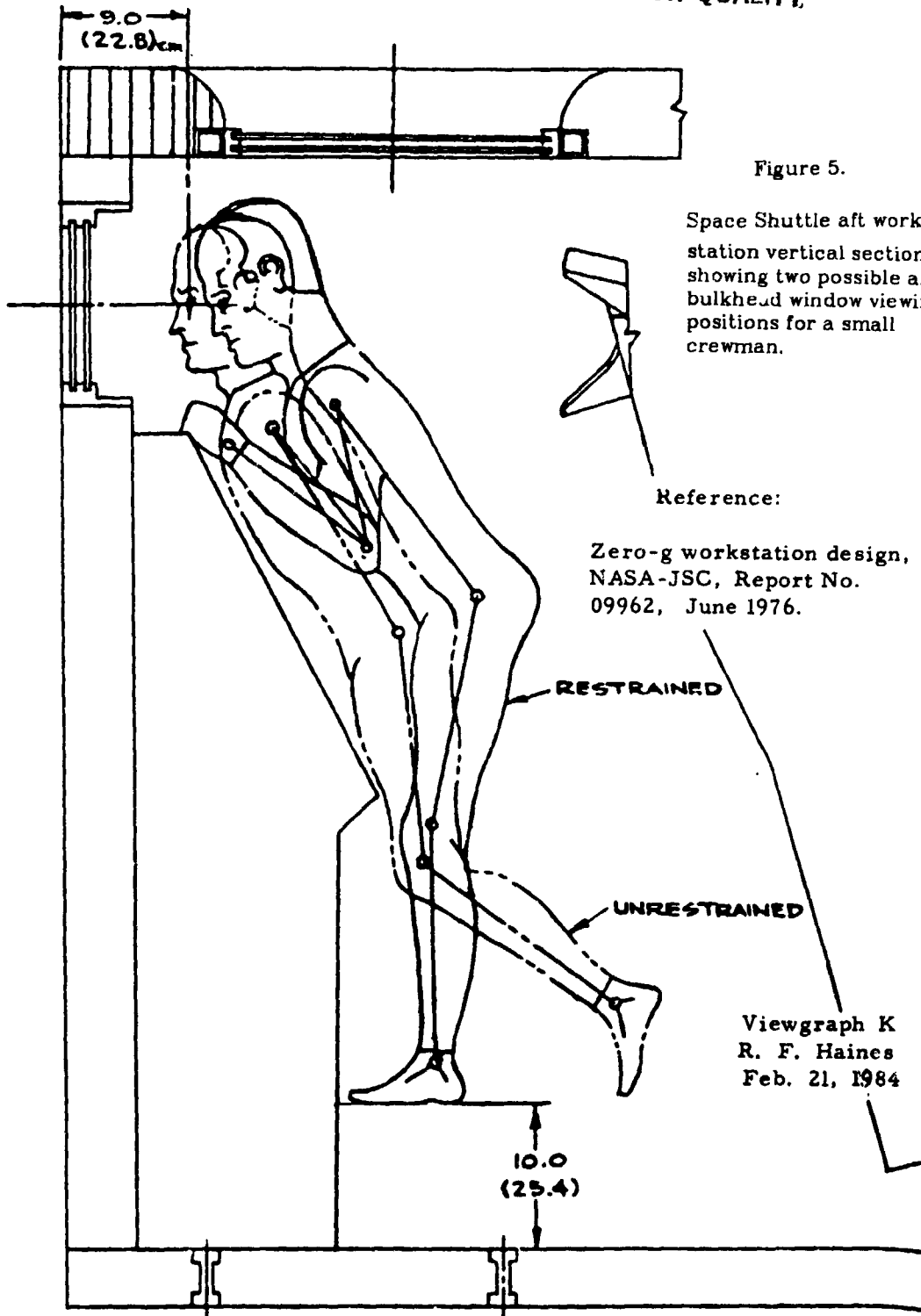


Figure 5.

Space Shuttle aft work station vertical section showing two possible aft bulkhead window viewing positions for a small crewman.

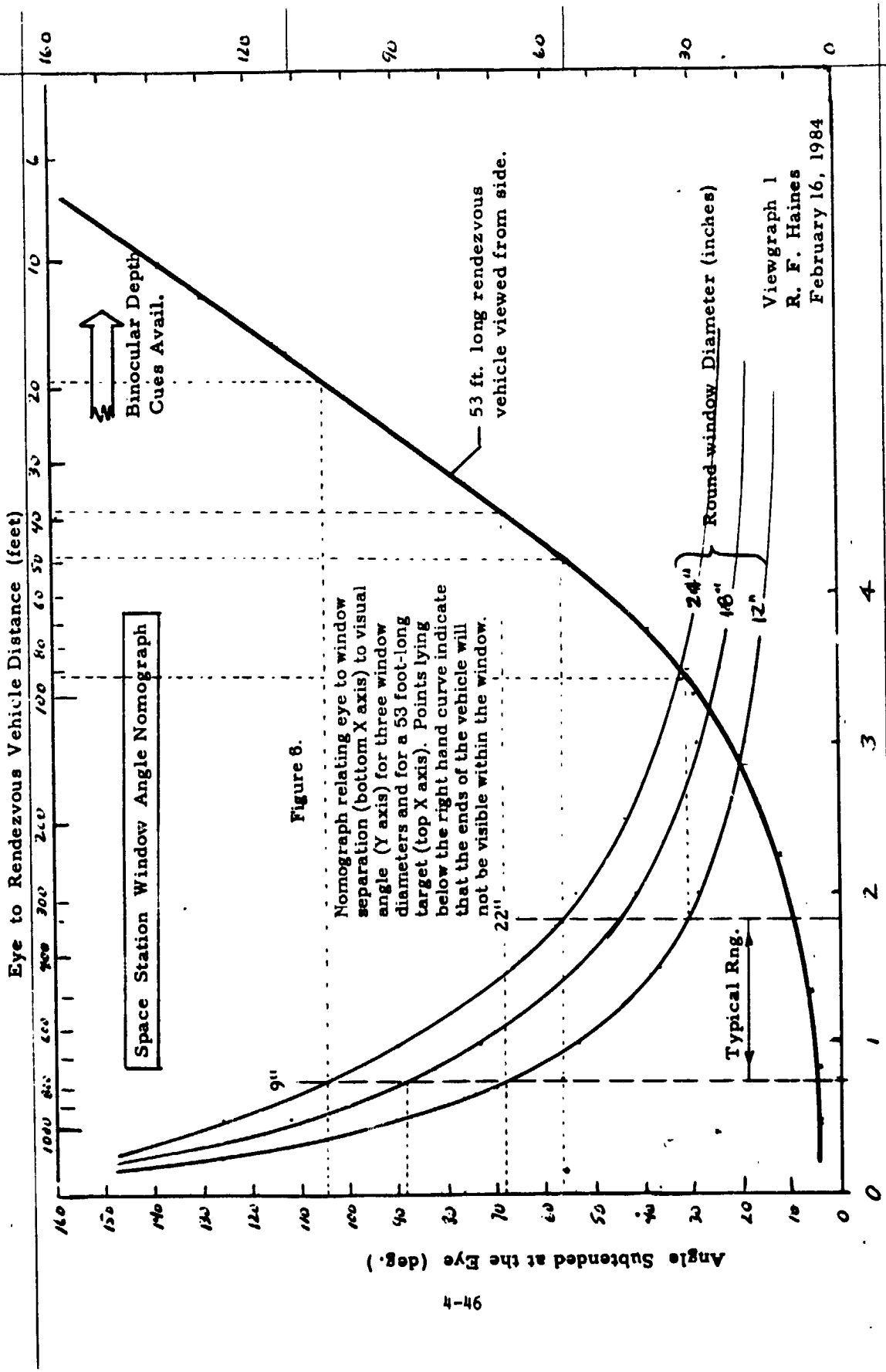
Reference:

Zero-g workstation design, NASA-JSC, Report No. 09962, June 1976.

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Viewgraph K  
R. F. Haines  
Feb. 21, 1984



AUTOFF'S EQUAL AREA PROJECTION OF THE SPHERE  
MATHS OF PROJECTED SPHERICAL FIGURES AND BY INVENTOR  
AFT WINDOW FIELD-OF-VIEW

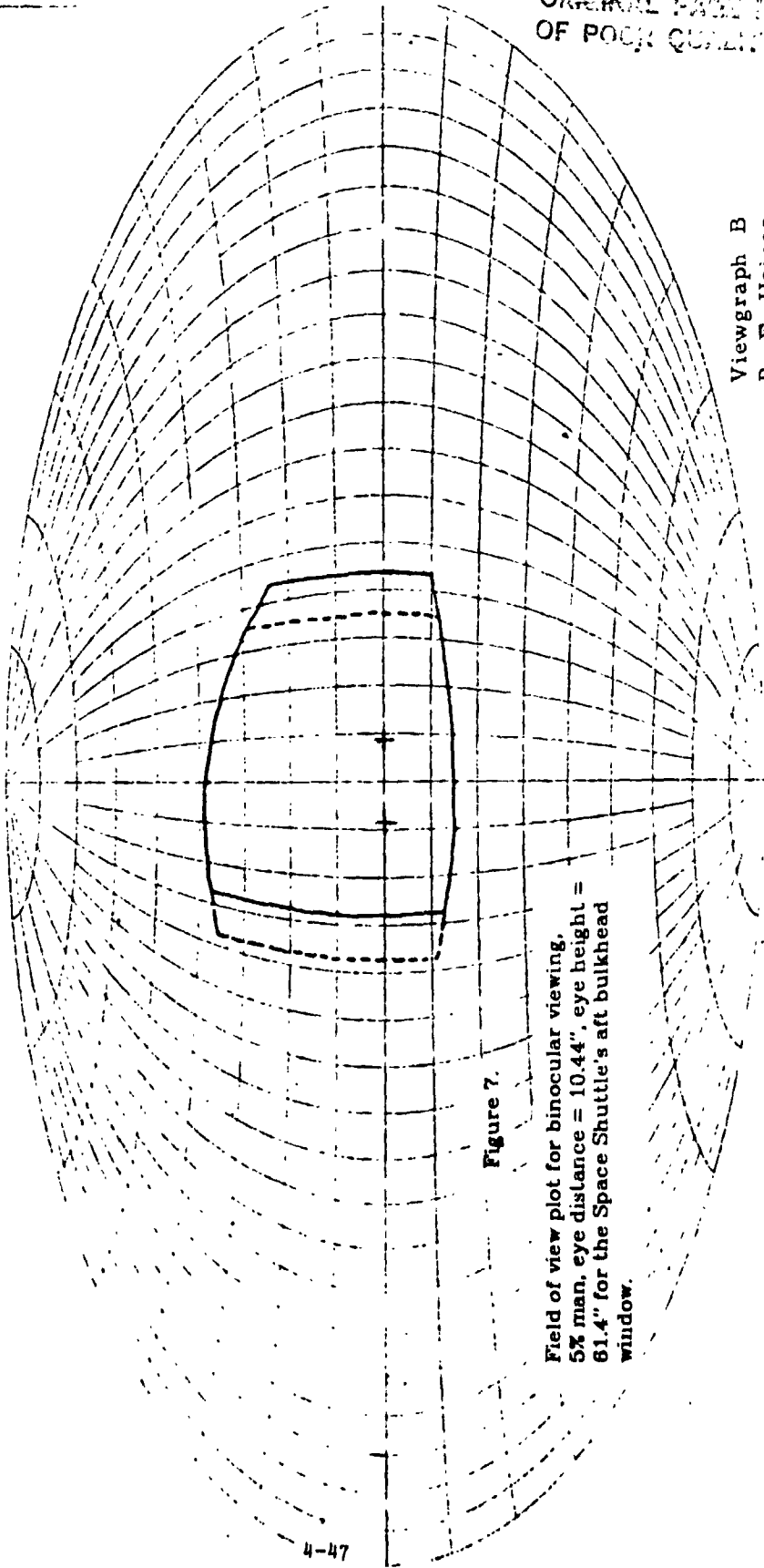


Figure 7.

Field of view plot for binocular viewing,  
5% man, eye distance = 10.44", eye height =  
61.4" for the Space Shuttle's aft bulkhead  
window.

ORIGINAL FACSIMILE  
OF POOR QUALITY

Viewgraph B  
R. F. Haines  
Feb. 21, 1984

Space Shuttle

COPY OF ORIGINAL  
OF POOR QUALITY

AITOFF'S EQUAL AREA PROJECTION OF THE SPHERE  
TABLES OF PROJECTED SPHERE POINTS AND DISTANCES  
AFT WINDOW FIELD-OF-VIEW

EYE POINT Y= 13.75

NOMINAL EYE  
X= 565  
Y= 475  
R= 484

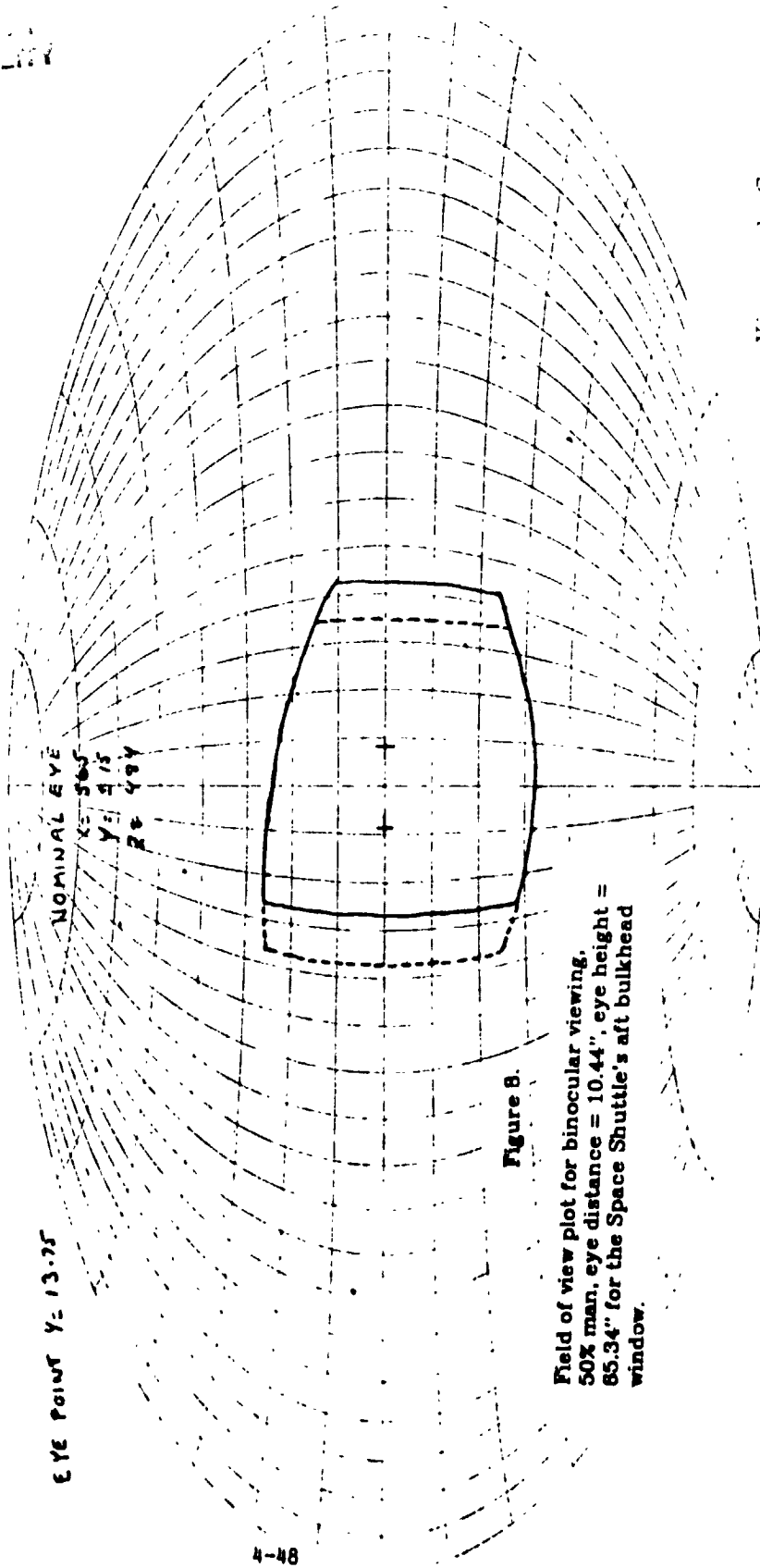


Figure 8.

Field of view plot for binocular viewing.  
50% man, eye distance = 10.44", eye height =  
85.34" for the Space Shuttle's aft bulkhead  
window.

Space Shuttle

Viewgraph C  
R. F. Haines  
Feb. 21, 1954

AITOFF'S EQUAL AREA PROJECTION OF THE SPHERE  
TABLE OF PROJECTED SQUARE DEGREES ON DIAMETER  
AFT WINDOW FIELD-OF-VIEW

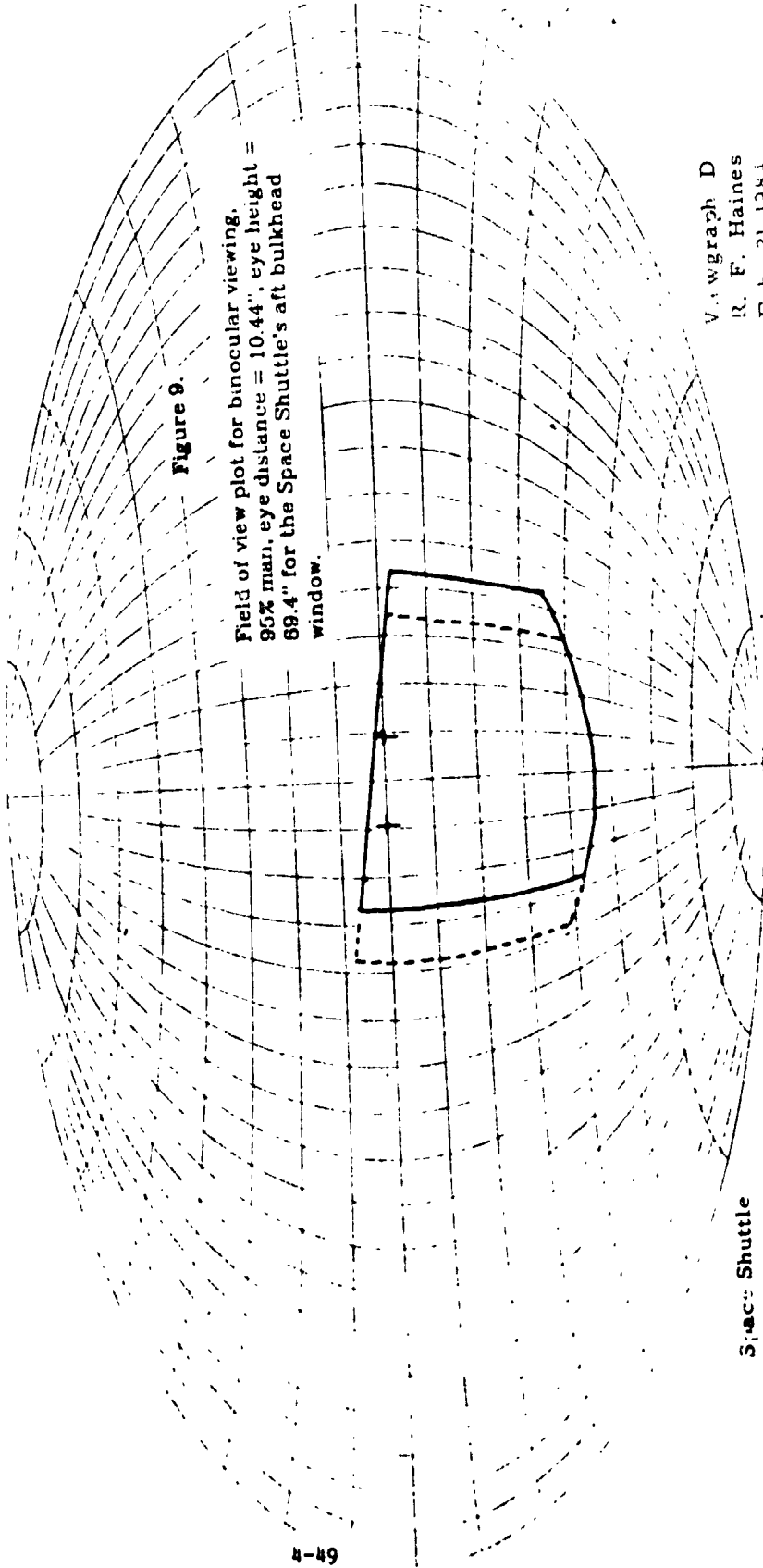


Figure 9.

Field of view plot for binocular viewing.  
95% man, eye distance = 10.44", eye height =  
89.4" for the Space Shuttle's aft bulkhead  
window.

Space Shuttle

Viewgraph D  
R. F. Haines  
Feb. 21, 1981

AITOFF'S EQUAL AREA PROJECTION OF THE SPHERE  
RADIUS OF PROJECTED SPHERE EQUALS ONE DECIMETER

Space Shuttle  
Rear Bulkhead Window

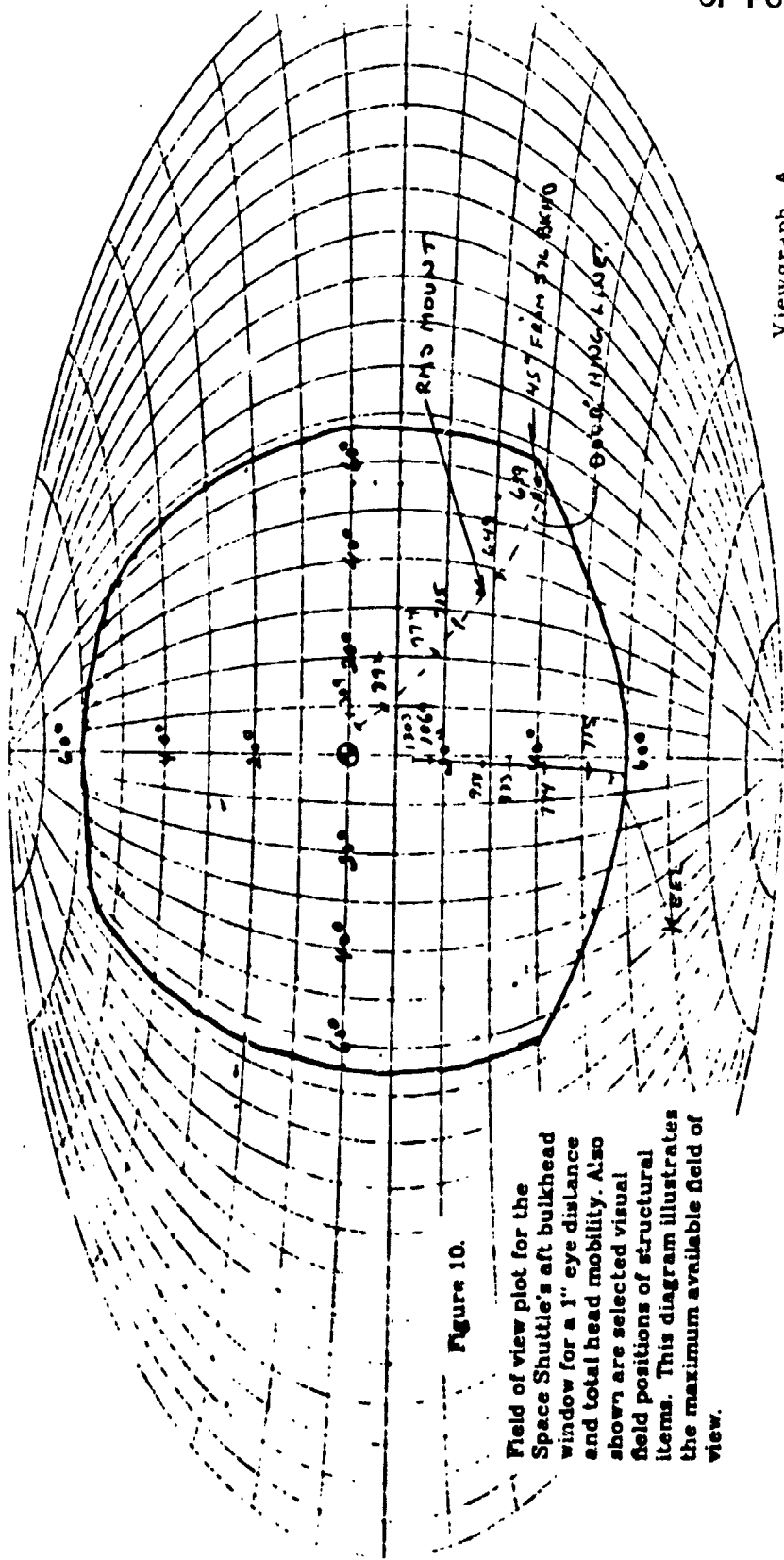


Figure 10.

Field of view plot for the Space Shuttle's aft bulkhead window for a 1" eye distance and total head mobility. Also shown are selected visual field positions of structural items. This diagram illustrates the maximum available field of view.

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Feb. 21, 1964

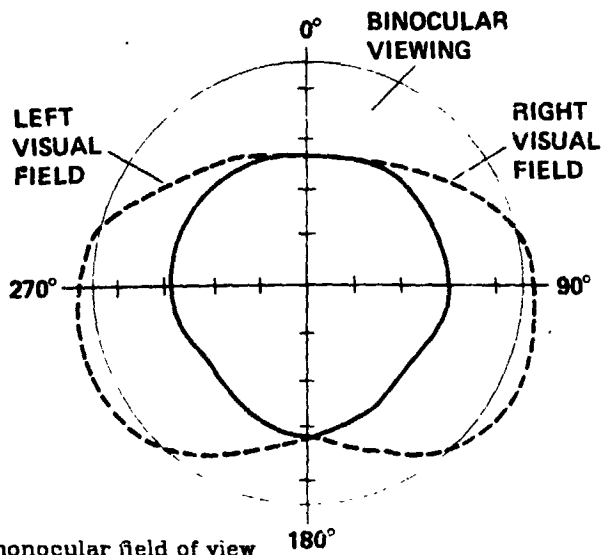


Figure 1.

Total binocular and monocular field of view of the human. The intersection of the horizontal and vertical lines is the line of sight. Each tick = 20°. The central area is the binocular visual field where both eyes receive corresponding images.

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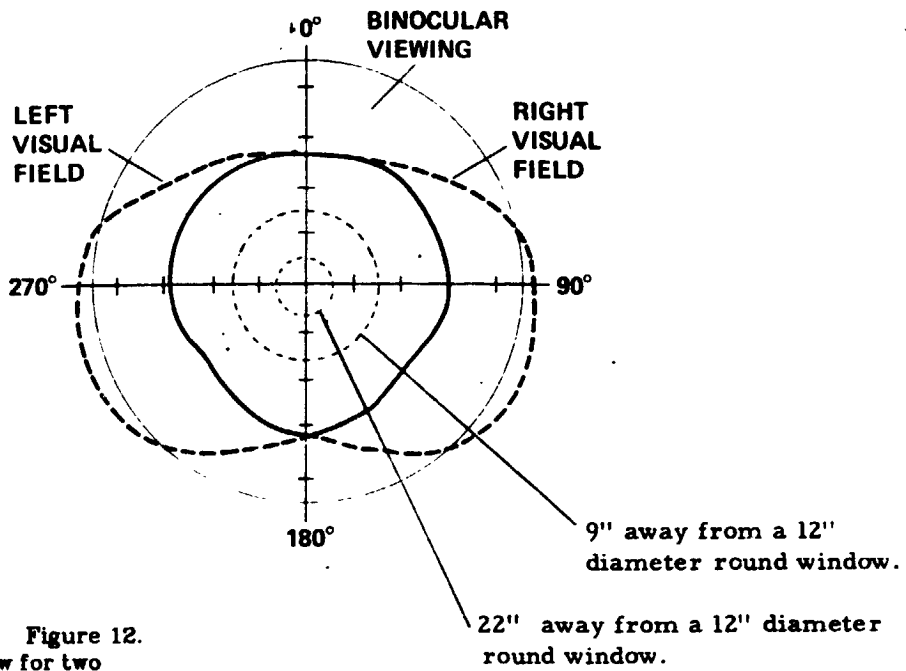


Figure 12.  
Field of view for two  
viewing distances and a 12"  
diameter round window relative  
to the binocular visual field.

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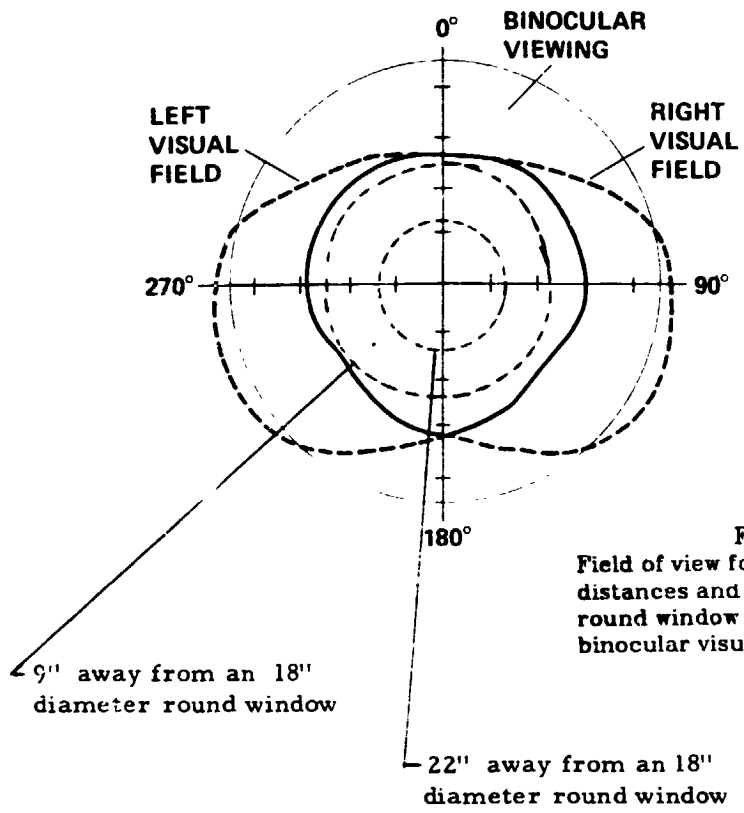


Figure 13.  
Field of view for two viewing distances and an 18" diameter round window relative to the binocular visual field.

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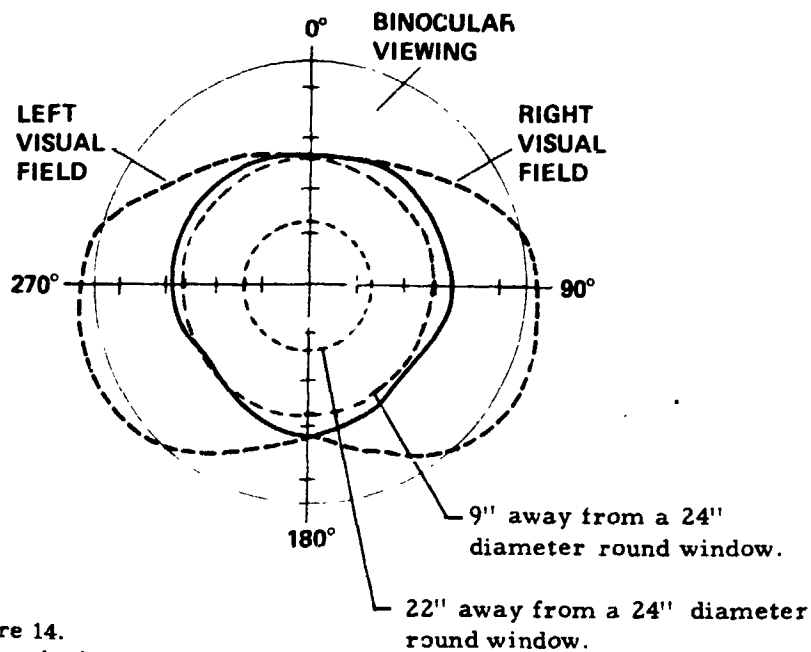


Figure 14.  
Field of view for two viewing distances  
and a 24" diameter round window relative  
to the binocular visual field.

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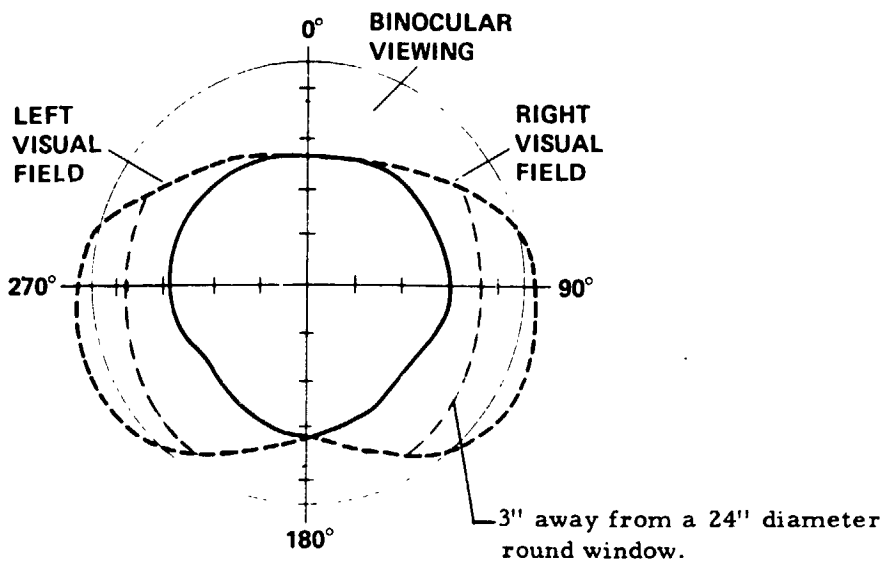
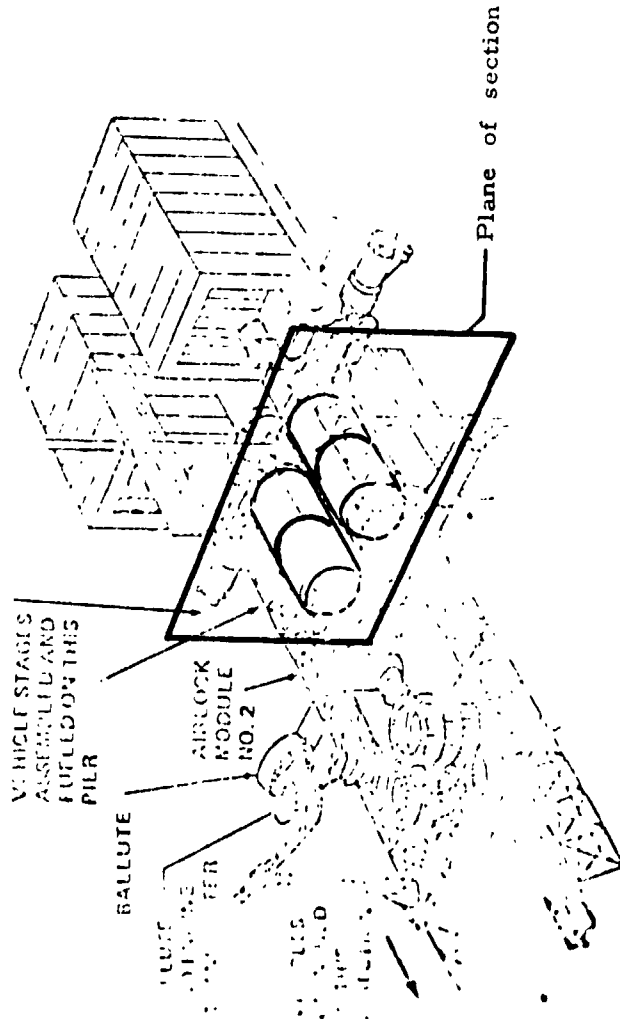


Figure 15.  
Field of view for a 3" eye to window viewing distance and a 24" diameter round window relative to the binocular visual field.

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BOEING CONCEPT - OVERALL CONFIGURATION

Figure 18.  
Illustration of plane cutting two  
parallel cylindrical modules.



ORIGINAL PLANE  
OF POOR QUALITY

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February 21, 1984

EXTERNAL VISIBILITY OVERLAP  
(Each Circle Represents Module Section)

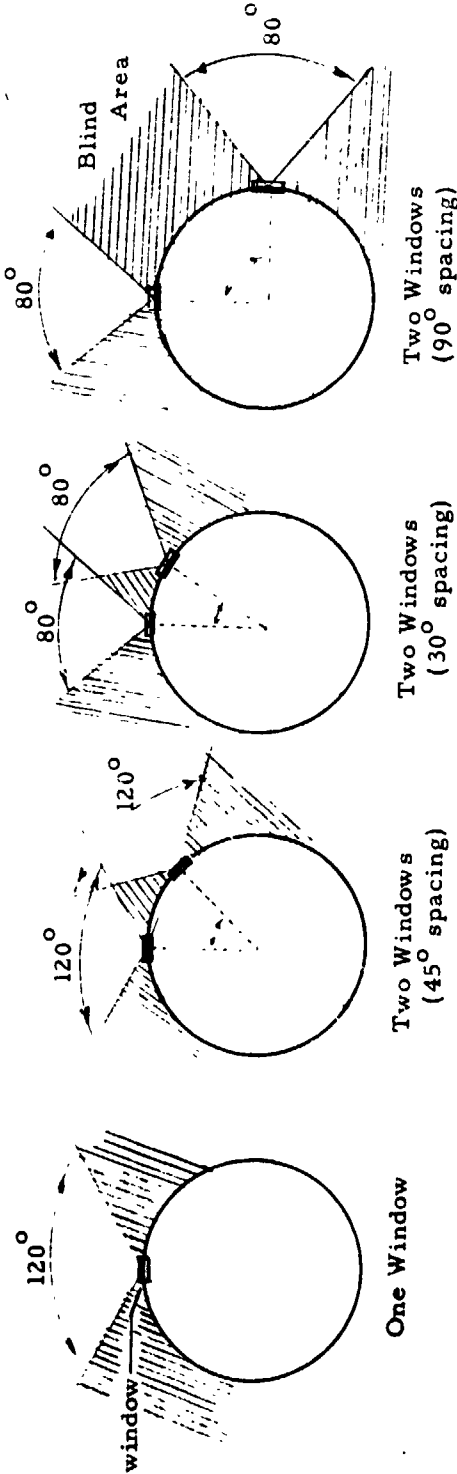


Figure 17.  
Diagram to illustrate overlapping fields of view for various window angular widths and spacings. Note that the two factors may be traded off with each other to minimize blind areas (cross-hatched).

To minimize blind areas:  
Increase field of view angle per window  
Decrease window to window spacing  
Both of the above

Note: Field of view angle is not directly related to window area.

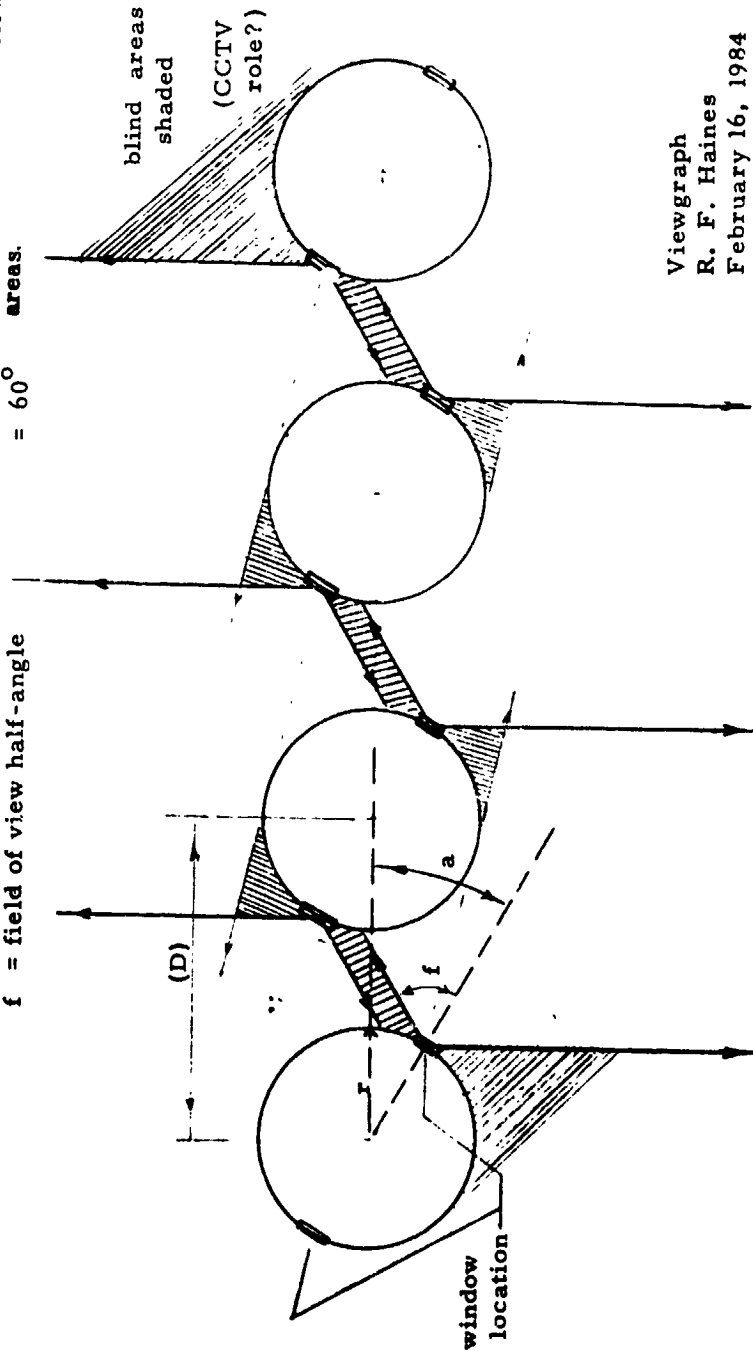
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R. F. Haines  
February 16, 1984

**WINDOW FIELDS OF VIEW FOR IN-LINE MODULES**  
 (Each Circle Represents a Module Section)

**Key Variables:**

- $D$  = Intermodule spacing
- $a$  = window orientation angle off axis
- $r$  = module radius
- $f$  = field of view half-angle

**Figure 18.**  
 Diagram of four in-line modules each having two windows  $180^\circ$  apart as shown. Four design variables are also indicated. Closed circuit TV may be useful to "see" into otherwise blind areas.



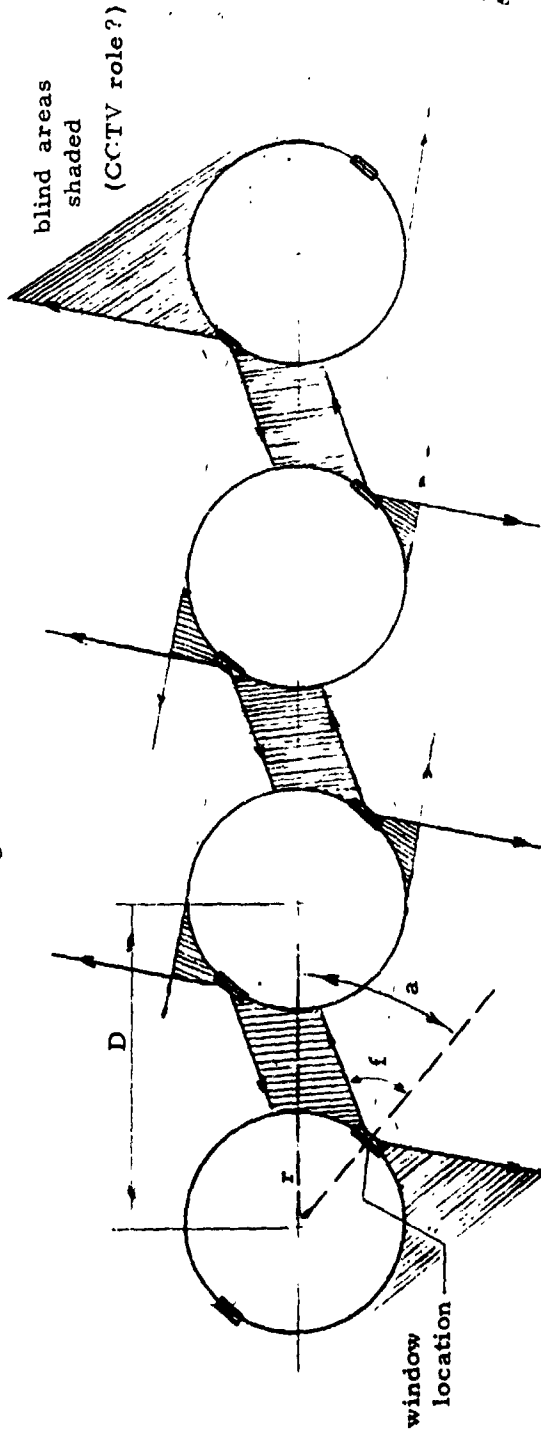
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 February 16, 1984

WINDOW FIELDS OF VIEW FOR IN-LINE MODULES  
 ( Each Circle Represents a Module Section)

Key Variables:

- D = intermodule spacing =  $3r$
- a = window orientation angle off axis =  $45^\circ$
- r = module radius =  $r$
- f = field of view half-angle =  $60^\circ$

Figure 19  
 Diagram of four in-line modules each having two windows  $180^\circ$  apart as shown. Compare this field of view configuration with that of Figure 18.



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 February 16, 1984

SEMINAR ON SPACE STATION HUMAN PRODUCTIVITY  
HUMAN FACTORS ISSUES IN SPACE STATION ARCHITECTURE  
March 1, 1984

JOHNSON SPACE CENTER CONFIGURATIONS

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