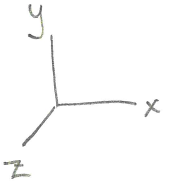
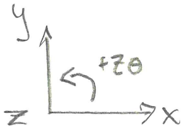
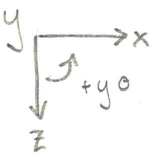
BACKLASH 3D MATH	16 JUL 94	MJT	1/4

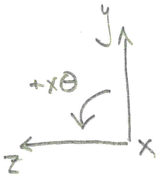
PROPER THREE SPACE DEFINITION

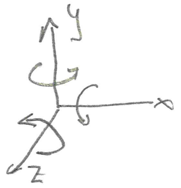


CARTESIAN 3 SPACE
VIEWER LOOKING DOWN
THE -Z AXIS FROM
THE ORIGIN









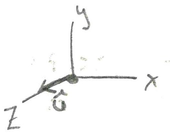
WRITE AND TEST ALL REQUIRED VECTOR / MATRIX ROUTINES

THE MOTHERSHIP MUST MOVE PROPERLY IN 3 SPACE - MAKE SURE THE MATH IS CORRECT

ROTATION ABOUT X AND Y REQUIRED; TWO STEP METHOD

1) PITCH - ROTATE ABOUT X-AXIS
2) YAW - ROTATE ABOUT Y-AXIS

<u>ALL</u>! NATIVE ORIENTATIONS SHOULD BE 0 DEGREES OF ROTATION ABOUT ALL AXES - PLACING FACING DOWN THE POSITIVE Z AXIS



PITCH = 0°
YAW = 0°

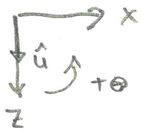
$\hat{u} = \langle 0, 0, 1 \rangle$

MAINTAIN ORIENTATIONS - REGENERATE XFORMS ON CHANGES

ALL ANGLES SHOULD BE MAINTAINED 0-360.0° WITH ASSERTION FOR OUT OF RANGE ANGLES

ON POSSIBLE OVER / UNDERFLOW OF ANGLES - SUPPLY NORMALIZATION

ROTATION OF VECTORS ABOUT Y AXIS - YAWING



$\hat{u} = <0,0,1>$ $\theta_y = 0°$

$$U'_x = u_x \cdot \cos\theta + u_z \cdot \sin\theta$$
$$u'_y = U_y$$
$$U'_z = -U_x \cdot \sin\theta + u_z \cdot \cos\theta$$

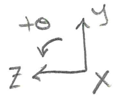
TEST CASES:

	θ_y	$\vec{V}$	$\vec{V}'$	
✓	45°	<0,0,1>	<.707, 0, .707>	
✓	135°	<0,0,1>	<.707, 0, -.707>	
✓	225°	<0,0,1>	<-.707, 0, -.707>	
✓	315°	<0,0,1>	<-.707, 0, .707>	
✓	150°	<0,0,1>	<0.5, 0, -0.866>	
✓	45°	<.707,0,.707>	<1,0,0>	
✓	60°	<0.5, 0, -0.866>	<-0.5, 0, -0.866>	

* NOTE - THIS DIFFERS FROM CURRENT IMPLEMENTATION

ROTATION OF VECTORS ABOUT X AXIS - PITCHING

$$\hat{u} = u_x \hat{i} + U_y \hat{j} + U_z \hat{k}$$



$$u_x = U_x$$
$$u_y = U_y \cdot \cos\theta - U_z \sin\theta$$
$$u_z = -U_y \cdot \sin\theta + U_z \cos\theta$$

$\vec{V}$	θ_y	$\vec{V}'$	
✓ <0,0,1>	45°	<0, -.707, .707>	
✓ <0,0,1>	135°	<0, -0.707, -0.707>	
✓ <0,0,1>	225°	<0, 0.707, -0.707>	
✓ <0,0,1>	315°	<0, .707, .707>	
✓ <0, -.707, .707>	135°	<0, 0, -1>	
✓ <0,0,1>	210°	<0, 0.5, -0.866>	
✓ <0, 0.5, -0.866>	195°	<0, -0.707, 0.707>	

* MATCHES CURRENT IMPLEMENTATION

TRANSFORMATION MATRIX

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

TRANSLATION

ROTATIONAL COMPONENTS

USE MATRIX ON LEFTSIDE OF THE PRODUCT

$$\begin{bmatrix} M \end{bmatrix} \times \begin{bmatrix} \vec{V} \end{bmatrix} = \begin{bmatrix} \vec{V}' \end{bmatrix}$$

ROTATION ABOUT X-AXIS - PITCH

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix}$$ yields

$$V_x' = V_x$$
$$V_y' = V_y \cos\theta - V_z \sin\theta$$
$$V_z' = V_y \sin\theta + V_z \cos\theta$$

ROTATION ABOUT Y-AXIS - YAW

$$\begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix}$$ yields

$$V_x' = V_x \cos\theta + V_z \sin\theta$$
$$V_y' = V_y$$
$$V_z' = -V_x \sin\theta + V_z \cos\theta$$

THIS MATCHES PAGE 2

TRANSLATION IS STORED IN THE RIGHTMOST COLUMN - A TRANSLATION SHOULD BE PEFORMED PRIOR TO ROTATION

THE ROTATION SECTION IS STORED AS FIXUNIT NUMBERS
THE TRANSLATION SECTION IS STORED AS FIX24 NUMBERS

TRANSLATION VALUES ARE ADDED TO THE TARGET VECTOR

$$\begin{bmatrix} 1 & 0 & 0 & T_x \\ 0 & 1 & 0 & T_y \\ 0 & 0 & 1 & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \\ 1 \end{bmatrix} = \begin{bmatrix} V_x + T_x, & V_y + T_y, & V_z + T_z \end{bmatrix}$$

VIEW TRANSFORMS WILL INVOLE NEGATING THE PLAYER WORLD POSITION

ie PLAYER $\begin{bmatrix} 50 \\ 75 \\ 100 \\ 1 \end{bmatrix}$ OBJ $\begin{bmatrix} -10 \\ 20 \\ 40 \\ 1 \end{bmatrix}$ XF = $\begin{bmatrix} 1 & 0 & 0 & -50 \\ 0 & 1 & 0 & -75 \\ 0 & 0 & 1 & -100 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ → OBJ' = $\begin{bmatrix} -60 \\ -55 \\ -60 \\ 1 \end{bmatrix}$

BACKLASH
3D MATH | 16 JUL 94 | MJT | 4/4

TRANSFORMS SHOULD BE STORED AS 3 ROW x 4 COLUMNS

$$\begin{bmatrix} x_1 & x_2 & x_3 & T_x \\ y_1 & y_2 & y_3 & T_y \\ z_1 & z_2 & z_3 & T_z \end{bmatrix}$$

VECTORS AS 3x1 ARRAYS THAT ARE ROW OR COLUMN VECTORS WITH TRANSPOSING IMPLIED BY USE.

APPENDING TRANSFORMATIONS

$$\begin{bmatrix} XF00 & XF01 & XF02 \\ XF10 & XF11 & XF12 \\ XF20 & XF21 & XF22 \end{bmatrix} \begin{bmatrix} \text{ROT} \\ \text{MATRIX} \end{bmatrix}$$

APPEND TRANSLATION BY SUMMING COMPONENTS

ROTATION ABOUT X AXIS APPENDED

$$\begin{bmatrix} XF00 & XF01 & XF02 \\ XF10 & XF11 & XF12 \\ XF20 & XF21 & XF22 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} = \begin{bmatrix} XF'00 & XF'01 & XF'02 \\ XF'10 & XF'11 & XF'12 \\ XF'20 & XF'21 & XF'22 \end{bmatrix}$$

$XF'00 = XF00$

$XF'01 = XF01$

$XF'02 = XF02$

$XF'10 = \cos\theta \cdot XF10 - \sin\theta \cdot XF20$

$XF'11 = \cos\theta\, XF11 - \sin\theta\, XF21$

$XF'12 = \cos\theta \cdot XF12 - \sin\theta\, XF22$

$XF'20 = \sin\theta\, X10 + \cos\theta\, X20$

$XF'21 = \sin\theta\, X11 + \cos\theta\, X21$

$XF'22 = \sin\theta\, X12 + \cos\theta\, X22$

ROTATION ABOUT Y AXIS APPENDED

$$\begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} XF00 & XF01 & XF02 \\ XF10 & XF11 & XF12 \\ XF20 & XF21 & XF22 \end{bmatrix} = \begin{bmatrix} XF'00 & XF'01 & XF'02 \\ XF'10 & XF'11 & XF'12 \\ XF'20 & XF'12 & XF'22 \end{bmatrix}$$

$XF'10 = XF10$

$XF'11 = XF11$

$XF'12 = XF12$

$XF'00 = XF00\cos\theta + XF20\sin\theta$

$XF'01 = XF01\cos\theta + XF21\sin\theta$

$XF'02 = XF02\cos\theta + XF22\sin\theta$

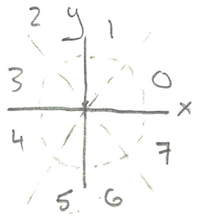
$XF'20 = -XF00\sin\theta + XF20\cos\theta$

$XF'21 = -XF01\sin\theta + XF21 \cdot \cos\theta$

$XF'22 = -XF02\sin\theta + XF22\cos\theta$

BACKLASH
SPECIAL VECTOR FUNCTIONS | 16 JUL 94 | MICHAEL J. TERRY | 1/1

ARC TANGENT



ARCTANGENT FOR THE UNIT CIRCLE CAN BE GENERATED USING THE LARGER AND SMALLER VECTOR COMPONENTS

EIGHT OCTANTS ARE DEFINED 0 – 7

0	$x >= 0$	$y >= 0$	$\|x\| >= \|y\|$
1	$x >= 0$	$y >= 0$	$\|x\| < \|y\|$
2	$x < 0$	$y > 0$	$\|x\| < \|y\|$
3	$x < 0$	$y > 0$	$\|x\| >= \|y\|$
4	$x < 0$	$y < 0$	$\|x\| >= \|y\|$
5	$x < 0$	$y < 0$	$\|x\| < \|y\|$
6	$x > 0$	$y < 0$	$\|x\| < \|y\|$
7	$x > 0$	$y < 0$	$\|x\| >= \|y\|$

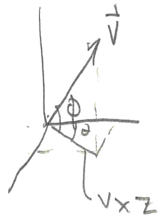
IN ODD OCTANTS, THE ARCTAN IS DECREASING; INCREASING IN EVEN OR 0 OCTANTS

A LOOKUP TABLE IS USED FOR THE FORTYFIVE DEGREES IN THE OCTANTS - THE VALUES REPEAT

MAGNITUDE

LIMITATIONS OF FIXED POINT NUMBERS REQUIRE CREATIVE EFFORT TO AVOID OVERFLOW WHEN GENERATING MAGNITUDES OF VECTORS. COSTLY SQUARES AND SQUARE ROOTS ARE ALSO AVOIDED. LOOK-UPS OF TRANSCENDENTAL FUNCTIONS ARE USED.

$$|V| = \sqrt{V_x^2 + V_y^2 + V_z^2}$$



$$\Theta = \text{ARCTAN}\left(\frac{\text{SMALLER}}{\text{LARGER}}\right) \qquad V_{xz} = \text{LARGER}/\cos\Theta$$
$$|x|, |z|$$

$$\phi = \text{ARCTAN}\left(\frac{\text{SMALLER}}{\text{LARGER}}\right) \qquad |V| = \text{LARGER}/\cos\phi$$
$$|V_{xz}|, |y|$$

BACKLASH
SPACE DEFINITIONS

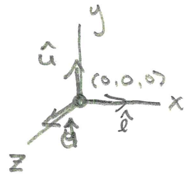
17 JUL 94

MJT

1/3

1) OBJECT SPACE : OBJECT CENTERED AT (0,0,0)
2) WORLD SPACE : GENERAL SPACE FOR OBJECT INTERACTION
3) VIEW SPACE : WORLD SPACE TRANSFORMED WITH RESPECT TO VIEWER
4) SCREEN SPACE : VIEW SPACE PROJECTED TO TWO DIMENSIONS

OBJECT SPACE



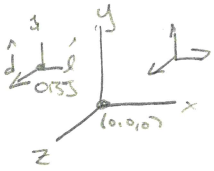
OBJECT CENTER IS AT (0,0,0)

$\hat{d}$ = DIRECTION VECTOR OF OBJECT - DETERMINES WHERE THE OBJECT IS GOING; OPTIONAL - ONLY NEEDED FOR OBJECTS THAT MOVE IN SPACE

$\hat{u}$ = UP VECTOR OF OBJECT - DETERMINES WHICH WAY IS THE TOP OF THE OBJECT - USED BY POLY-VIEW OBJECTS TO SELECT A VIEW - OPTIONAL

$\hat{\ell}$ = LEFT VECTOR OF OBJECT - $\hat{\ell} = \hat{u} \times \hat{d}$ - POINTS TO LEFT SIDE OF OBJECT - NOT USED

WORLD SPACE



WORLD SPACE IS THE UNIVERSAL COORDINATE SYSTEM
COORDINATES ARE FIXED POINT 24.8
COORDINATE RANGES ARE ± 8,388,607

WITH FASTEST OBJECT AT 100.00 UNITS PER SECOND THIS YIELDS A RANGE OF 83,886 FRAMES AT 30FPS - THIS YIELDS 46.6 MINUTES TO SPAN THE COORDINATE RANGE

OBJ2WORLD TRANSFORM - OBJECT SPACE IS TRANSLATED TO WORLD SPACE. ROTATIONS ARE NOT REQUIRED AS THE OBJECT CENTER IS THE ONLY THING MOVED. MOVEMENT IN WORLD SPACE IS PERFORMED BY MULTIPLYING SPEED (SCALAR) BY THE DIRECTION VECTOR $\hat{d}$ AND ADDING THE RESULT TO THE WORLD SPACE POSITION

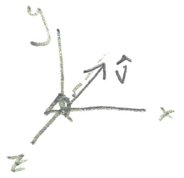
ANY OBJECT APPROACHING THE BOUNDARIES OF WORLD SPACE SHOULD BE TOSSED

THE MOTHERSHIP SHOULD BE TRACKED IN THE X-Z PLANE WITH IT ALLOWED TO MOVE WITH PITCH AND YAW ACTION

PITCH MAY BE RESTRICTED FOR VIEW CONSIDERATIONS

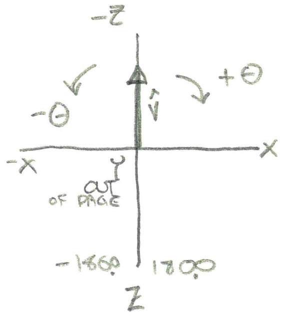
BACKLASH
SPACE DEFINITIONS | 17 JUL 94 | MJT | 2/3

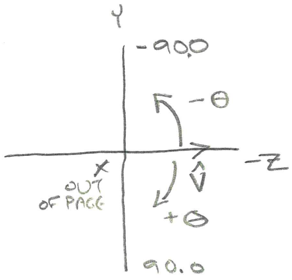
VIEW SPACE



VIEW SPACE IS THE REPRESENTATION OF WORLD SPACE WITH RESPECT TO A VIEWER.

IN VIEWSPACE, THE VIEWER IS AT THE ORIGIN, LOOKING DOWN THE NEGATIVE Z AXIS.

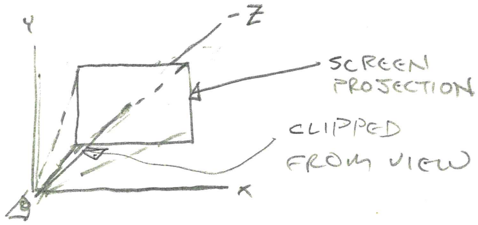




MEASUREMENT OF VIEW ORIENTATION DIFFERS FROM THE CONVENTIONAL AS THE BASE VIEWING VECTOR $\hat{V}$ IS <0, 0, -1>

A VIEW TRANSFORM IS GENERATED FROM THE VIEWER'S WORLD POSITION AND VIEWER'S ORIENTATION AS DESCRIBED ABOVE.

SCREEN SPACE



SCREEN SPACE IS THE 2D PROJECTION OF VIEW SPACE

OBJECTS INFRONT OF VIEW PROJECTION ARE TOSSED

SCALING IS BASED ON DISTANCE TO OBJECT (MAGNITUDE OF VIEW SPACE VECTOR POSITION)

PROJECTIONS ARE SUPPLIED FOR POINTS AND RECTANGULAR IMAGES (RASTERS)
POINT PROTECTION

$$S_x = V_x \cdot \underbrace{\frac{\text{PROJ RATIO}}{\text{DISTANCE}}}_{\text{SCALING FACTOR}} \qquad S_y = V_y \cdot \frac{\text{PROJ RATIO}}{\text{DISTANCE}}$$

THE SCALING FACTOR IS A 16,16 FIXED POINT NUMBER TO REDUCE THE ROUND OFF ERROR.

A BIT-MAP PROJECTION CALCULATES THE SCREEN POSITIONS OF THE FOUR CORNERS OF THE BIT-MAP.

ORIENTATION OF THE IMAGE (320:200 ASPECT) IS COMPENSATED FOR IN THE HEIGHT/WIDTH CALCULATIONS.

GLOBAL DEFINITIONS

VIEWORIENT - VIEW ORIENTATION - ANGLES DEFINING DIRECTION OF THE VIEW. USED TO GENERATE THE ROTATIONAL COMPONENT OF THE VIEW TRANSFORM

VIEWPOS - VIEW POSITION - WORLD SPACE VIEW POSITION - USED FOR THE TRANSLATIONAL COMPONENT OF THE VIEW TRANSFORM

VIEWXFORM - VIEW TRANSFORM - COMBINATION OF VIEW ORIENTATION AND VIEW POSITION.

SHIP DEFINITIONS

SHIPORIENT - MOTHERSHIP ORIENTATION - ANGLES DESCRIBING DIRECTION OF THE MOTHERSHIP IN WORLD SPACE

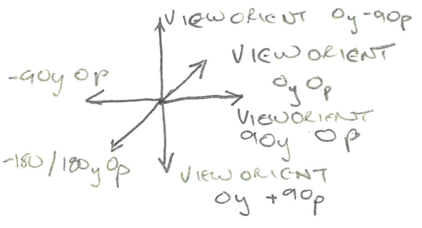
SHIP DIR - MOTHERSHIP DIRECTION - UNIT VECTOR DESCRIBING DIRECTION OF MOTHERSHIP IN WORLD SPACE

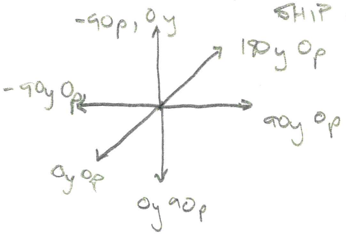
SHIP SPEED - MOTHERSHIP SPEED - SCALER 24.8 FIXED POINT NUMBER DESCRIBING RATE AT WHICH MOTHERSHIP IS TRAVELLING IN THE SHIP DIRECTION.

TURRET DEFINITIONS

TURRORIENT - TURRET ORIENTATION - ANGLES DESCRIBING TURRET ORIENTATION IN WORLD SPACE

TURRDIR - TURRET DIRECTION IN WORLD SPACE - MADE FROM ORIENTATION, A UNIT VECTOR - USED TO GENERATE DIRECTIONS FOR SHOTS





SHIP ORIENTATIONS/TURRET ORIENTATIONS

SHIP ORIENTATION - WORLD SPACE

TURRET ORIENTATION - OBJECT SPACE OF THE MOTHERSHIP

TURRET AND SHIP ORENTATIONS ARE COMBINED TO MAKE A UNIFIED VIEW ORIENTATION THAT MUST BE CONVERTED TO A VIEW SPACE TRANSFORMATION

$\Theta_W = \Theta_S + \Theta_T$ NET WORLD YAW = SHIP YAW + TURRET YAW LIMIT (0-360°)

$\Theta_V = 180.0 - \Theta_W$ FOR $\Theta_W <= 180.0$ Θ_V = VIEWORIENT[T] - YAW

$-(\Theta_W - 180.0)$ FOR $\Theta_W > 180.0$

PITCH DOES NOT REQUIRE CONVERSION

BACKLASH
OBJECT PROCESSING

18 JUL 84

MJT

SUMMARY OF SPACE PROCESSING FOR OBJECTS OF DIFFERENT CLASSES AND ACTIONS WITHIN SPACES

OBJECT TYPE	OBJECT SPACE	OBJ 2 WORLD	WORLD SPACE	WORLD 2 VIEW	VIEW SPACE	VIEW 2 SCREEN
STARS	N/A	N/A	POSITION FIXED	ROT XFORM W/ BN BAND REDUCTION	POSITION	POS PROJECT
STATIC SCENERY	N/A	N/A	POSITION FIXED	ROT XFORM	POSITION	POS PROJECT
DEBRIS	N/A	N/A	POSITION FIXED	XFORM	POSITION	POS PROJECT MAGN IMAGE SELECTION
DYNAMIC SCENERY	N/A	N/A	POSITION FIXED	XFORM	POSITION	PERSPECTIVE PROJECT
SHIPS (POLY VIEW)	DIRECTION VECTOR UP VECTOR	XFORM	POSITION NOT-FIXED DIRECTION	XFORM	POSITION DIRECTION & UP VECTORS	PERSPECTIVE PROJECT
SHOTS, EXPL, DRONES	DIRECTION	XFORM	POSITION NOT FIXED	XFORM	POSITION	PERSPECTIVE PROJECT

STARS

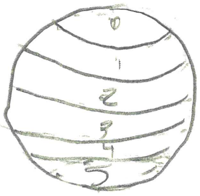
DUE TO THE SMALL VIEW ANGLES USED IN THE GAME, THE AREA OF VISIBLE SPACE IS RELATIVELY SMALL AND TRICKS ARE REQUIRED TO GENERATE SUFFICIENT STAR DENSITIES FOR THE BACKGROUND

THE 3D TRANSFORMATIONS FOR THE STARS ARE EXPENSIVE IN TIME TO THE POINT WHERE THEY SIGNIFICANTLY STRAP MACHINE PROCESSING.

THE FOLLOWING ALGORITHM IS USED TO REDUCE THE NUMBER OF POINTS THAT MUST BE TRANSFORMED BY THE PROGRAM PER FRAME

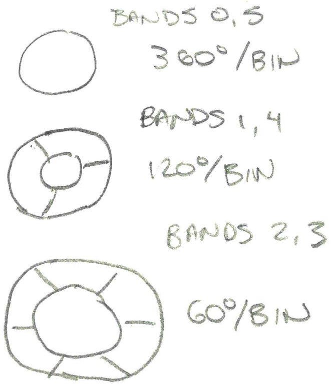
STARS ARE PLACED ON THE INNER SURFACE OF A SPHERE 5000 UNITS FROM THE CENTER OF THE VIEWER. THE STARS ARE FIXED IN SPACE WITH RESPECT TO DISTANCE FROM THE VIEWER.

THE SPHERE IS SLICED INTO 6 BANDS - EACH 30° ACROSS AS SHOWN BELOW: THESE BANDS ARE NUMBERED 0-5 FROM TOP DOWN.



DEPENDING ON THE ORIENTATION OF THE VIEWER HE WILL BE SEEING PARTS OF 1 OR 2 OF THESE BANDS.

BANDS ARE FURTHER DIVIDED INTO BINS (1 OR MORE) EACH BIN IS APPROXIMATELY THE VIEWING WIDTH AT THE BAND'S PITCH.



THE EDGES OF THE VIEW ARE CAST TO INTERSECT BANDS /AND BINS. BETWEEN 1 AND 4 BINS WILL BE HIT BY THE CAST. STARS WITHIN THOSE BINS ARE TRANSFORMED AND DRAWN IF IN VIEW.

ALL OTHER STARS ARE OUTSIDE OF THE VIEW AND CAN BE IGNORED.

AS EACH BIN REPRESENTS EQUAL (APPROXIMATION) VIEW SPACE, EACH BIN IS SEEDED WITH THE SAME NUMBER OF STARS TO GENERATE A RANDOM BUT EVEN STAR DENSITY.

AS ONLY ROTATION IS APPLIED DURING VIEW TRANSFORMATION, MATH ONLY NEEDS TO BE APPLIED WHEN THE VIEW ORIENTATION CHANGES. IF TURRET ORIENTATION AND SHIP ORIENTATION ARE CONSTANT, THE STARS DON'T NEED TO MOVE.

STATIC SCENERY

STATIC SCENERY WORKS LIKE THE STARS WITHOUT THE TRANSFORM REDUCTIONS. THE OBJECTS ARE PLACED AT VIEW ANGLES AND REMAIN FIXED AGAINST VIEW SPACE TRANSLATION.