Envisioning Artificial Gravity

The Artificial Gravitational Field

"If our designs for private houses are to be correct, we must at the outset take note of the countries and climates in which they are built."
— Vitruvius (1st century B.C.)

Comfort in artificial gravity favors a large floor radius (R_f) and tangential velocity (V_t). Economics pushes in the opposite direction, toward a short radius and low tangential velocity, to save mass and kinetic energy. In designing such a habitat, it's essential to take note of the gravitational distortions due to Coriolis accelerations that accompany relative motion in a rotating environment, and to avert them as much as possible.

The design gravity is the centripetal acceleration ($\mathbf{A}_{cent}$), always directed toward the center of rotation. The Coriolis acceleration ($\mathbf{A}_{Cor}$) is a vector product of the habitat's angular velocity ($\mathbf{W}$) and the inhabitant's relative velocity ($\mathbf{v}$). The net apparent gravity is the vector sum of all of the acceleration components ($\mathbf{A}$). This vector defines the sense of "up".
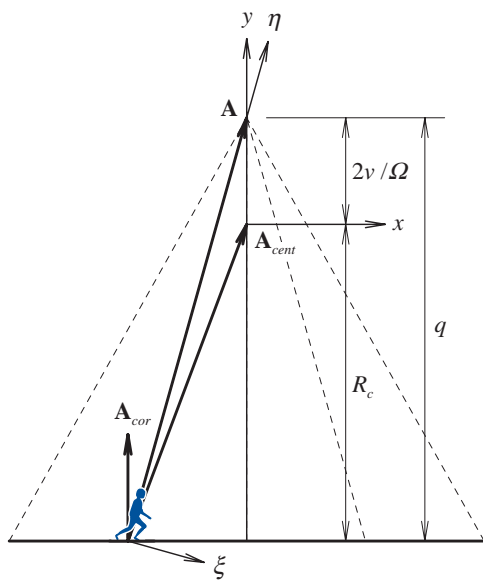
If the habitat is a linear element with a flat floor, the inhabitant will perceive a slope as he walks from end to end. The same is true for ascending or descending a ladder, and for any other motion along a straight chord in the plane of rotation. The apparent slope follows the form of a catenary arch:
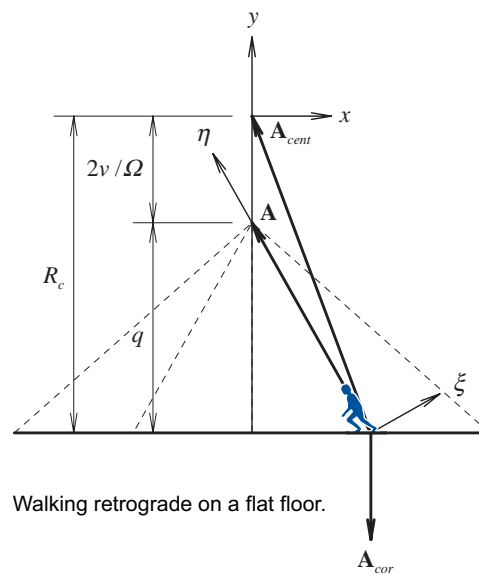
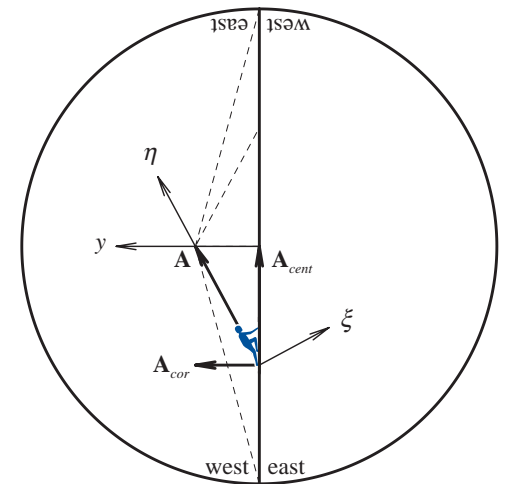$$(\eta/q) = -\cosh(\xi/q)$$

where:

$$q = R_c \pm 2v/\Omega$$
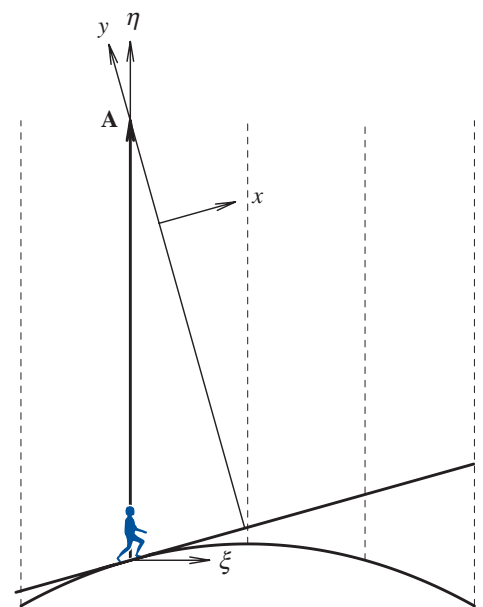$$R_c = \text{radius to midpoint of chord}$$

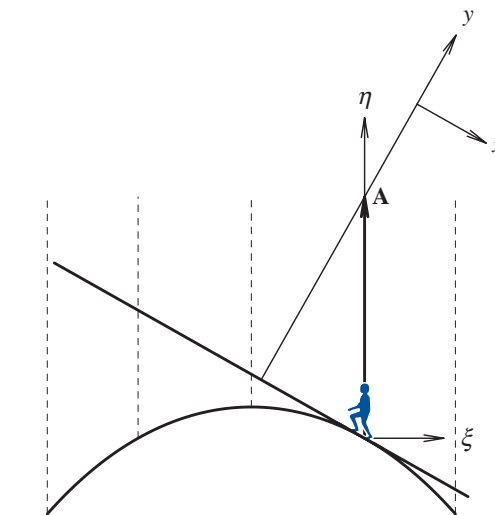Walking prograde on a flat floor in a rotating habitat.
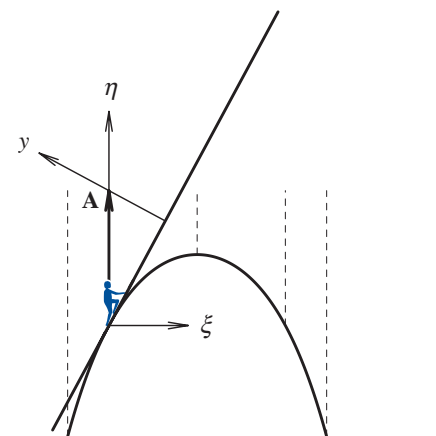

Walking retrograde on a flat floor.

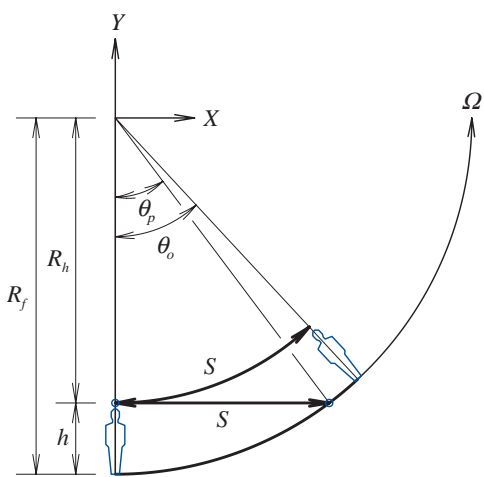Climbing a ladder in a rotating habitat.

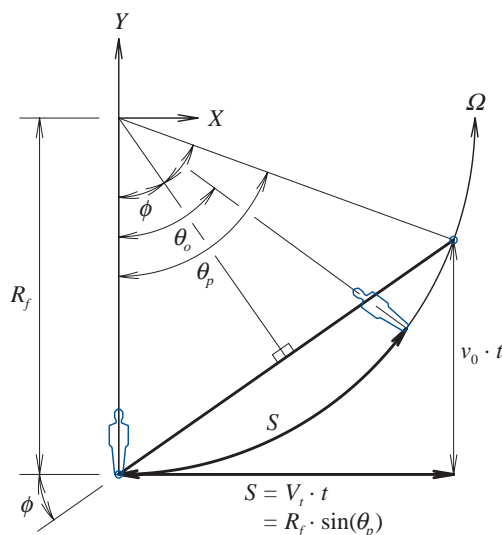Apparent slope of floor and strength of gravity.

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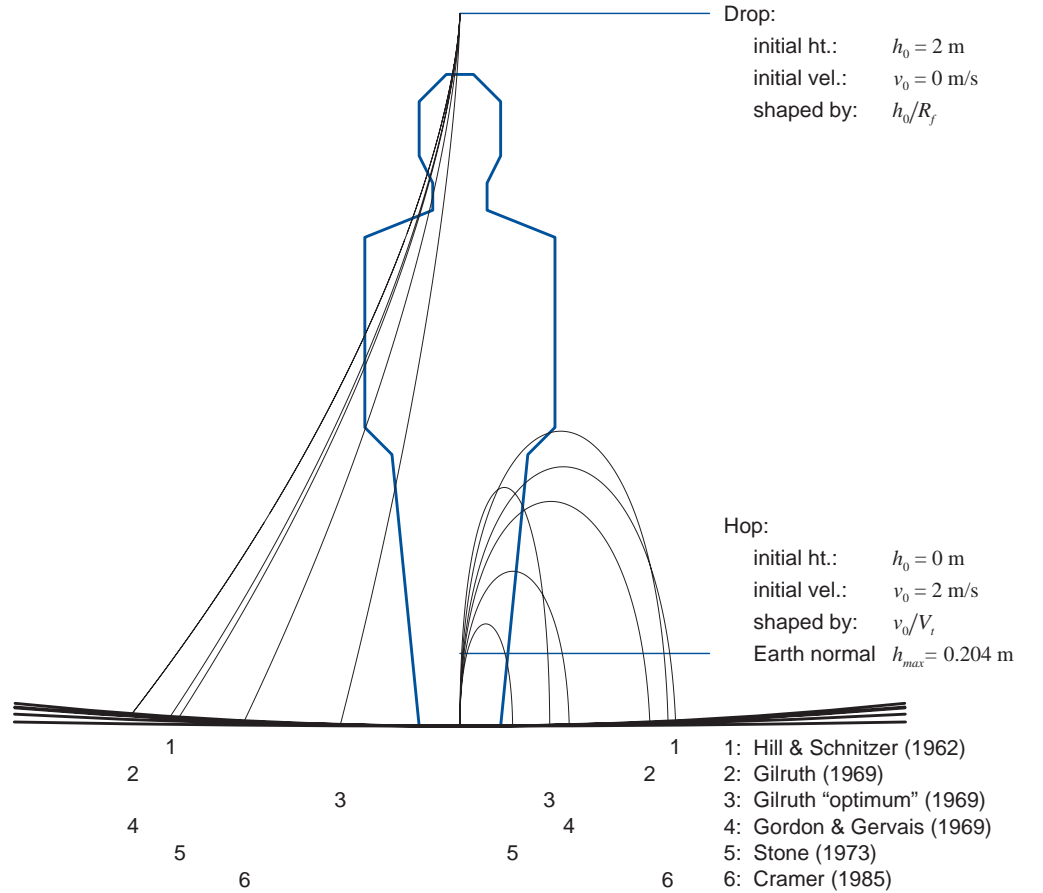Apparent slope of ladder and strength of gravity.

A dropping particle in artificial gravity (inertial view).

$$S = V_t \cdot t$$
$$= R_f \cdot \sin(\theta_p)$$

A hopping particle in artificial gravity (inertial view).

As iron filings sprinkled on a sheet of paper can reveal the shape of a magnetic field, so free-falling particles reveal the shape of a gravitational field. Relative to the rotating inhabitant, dropping particles always deflect to the west (retrograde), and hopping particles always deflect to the east (prograde).

The figure to the right shows the deflections of particles in rotating habitats having the minimum floor radius (R_f) and tangential velocity (V_t) within the "comfort zone" for rotation, as proposed by several authors. Clearly, conformance to the comfort zone does not guarantee an "Earth-normal" gravity environment!

Drop:
initial ht.: $h_0 = 2$ m
initial vel.: $v_0 = 0$ m/s
shaped by: h_0/R_f

Hop:
initial ht.: $h_0 = 0$ m
initial vel.: $v_0 = 2$ m/s
shaped by: v_0/V_t
Earth normal $h_{max} = 0.204$ m

1: Hill & Schnitzer (1962)
2: Gilruth (1969)
3: Gilruth "optimum" (1969)
4: Gordon & Gervais (1969)
5: Stone (1973)
6: Cramer (1985)

Apparent deflections of "dropping" and "hopping" particles in minimal "comfortable" artificial-gravity environments.
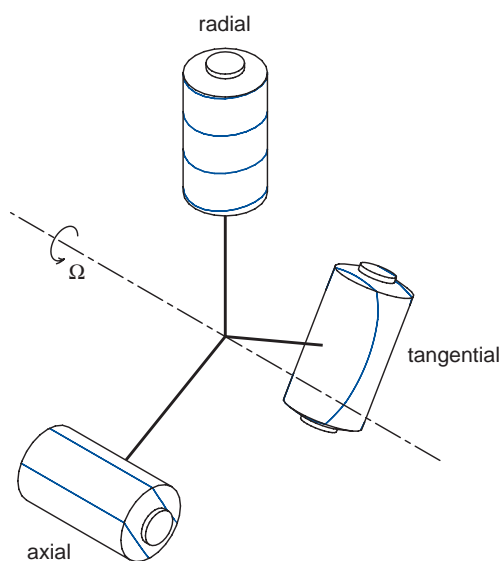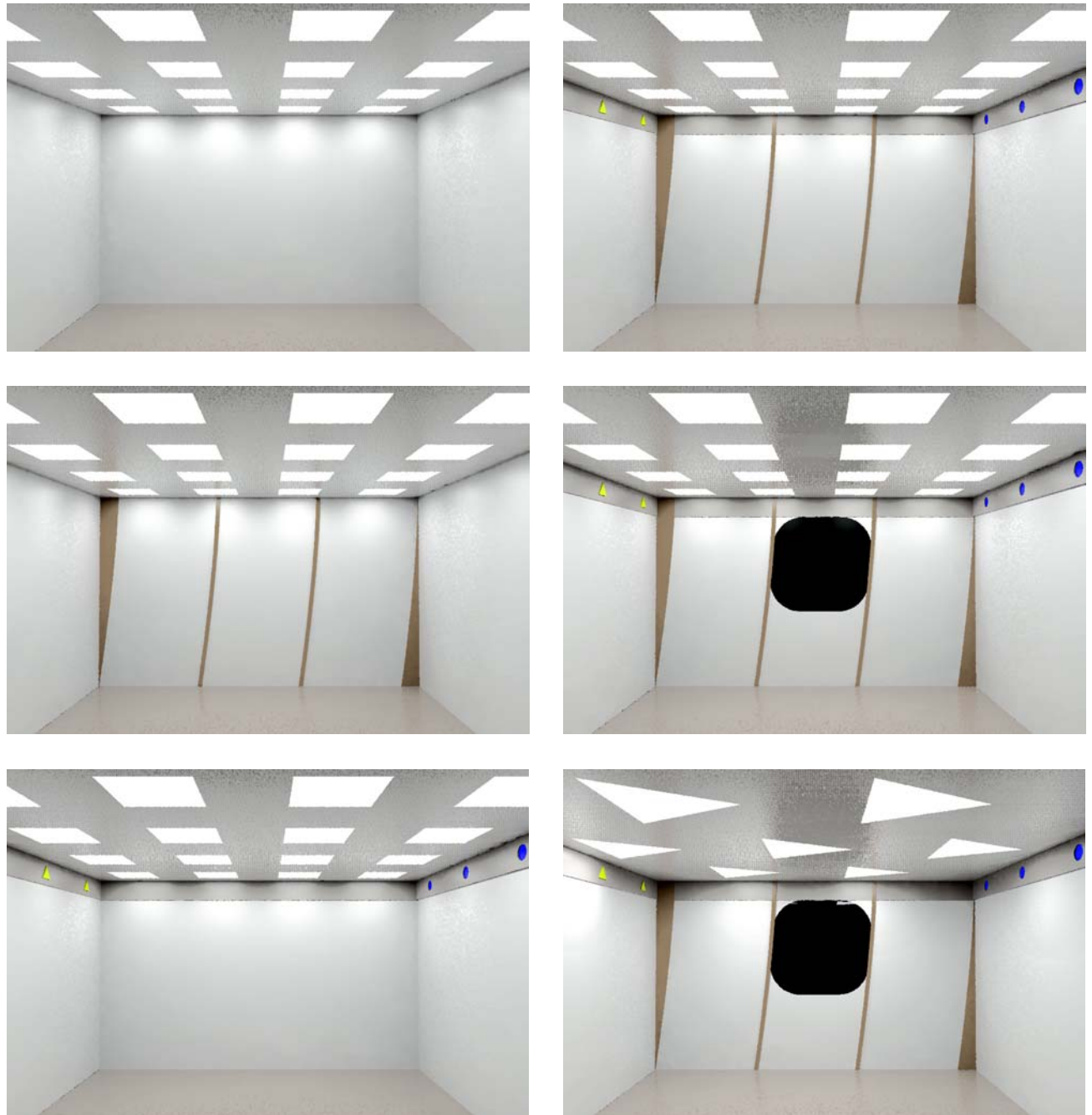
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Adapting to Artificial Gravity

Coriolis effects are proportional to off-axis relative motion in a rotating environment. While stationary, an inhabitant doesn't experience these distortions and may lose track of their orientation, only to be rudely reminded when turning his head or rising from his chair. Anything that helps him to maintain his orientation with respect to the spin may allow him to prepare himself for the consequences of his actions.

Natural planetary gravity distinguishes three principal directions: up, down, and horizontal. Architectural grammar responds with three principal elements: ceiling, floor, and wall. The walls are not gravitationally distinct. Architecture may isolate the inhabitants from any cue to cardinal orientation (north, south, east, west), but it cannot isolate them from gravity.

Artificial gravity, due to Coriolis effects, distinguishes at least five principal directions: up (centripetal), down (centrifugal), east (prograde), west (retrograde), and north-south (axial). How should architecture respond?

The figures to the right represent simple experiments with architectural forms in artificial gravity. Starting with an unadorned room and the elements of ceiling, floor, and wall, forms are added or modified to express the rotation of the room in space and the consequent distinction between east and west. The involute curves on the back wall trace the path of a particle dropped from ceiling height, assuming a floor radius of 250 meters (similar to the "Bernal Sphere" space colony concept). The frieze is punctuated with recessed blue circles on the eastwall and raised yellow triangles on the westwall. The scene through the window would appear to rotate clockwise at about 1.9 RPM.

If the habitat is composed of right circular cylinders, then its internal form depends greatly on the orientation of the cylinder with respect to the rotation. The figure above illustrates the three principal orientations. Each has implications for crew comfort as well as dynamic stability.

Axial: Considering only the internal gravity environment, ideally the geometric axis of the cylinder should be aligned with the rotation axis. There are no Coriolis effects associated with motion parallel to the axis, nor any need for floor curvature in that dimension. Unfortunately, this is the least dynamically stable orientation.

Tangential: This is more dynamically stable, but may require substantial floor curvature (or apparent floor slope) unless the rotational radius is large with respect to the cylinder length. This is the most commonly proposed orientation. In particular, toroids are rings of tangential modules.

Radial: This is dynamically stable, but may be the least comfortable orientation of all. It forces off-axis motion between decks at different gravity levels, occupies the hands for climbing, and increases the risk of falling. It also presents a circular plan that's indifferent to the gravitational distinctions between the prograde and retrograde directions.

A fountain in artificial gravity.