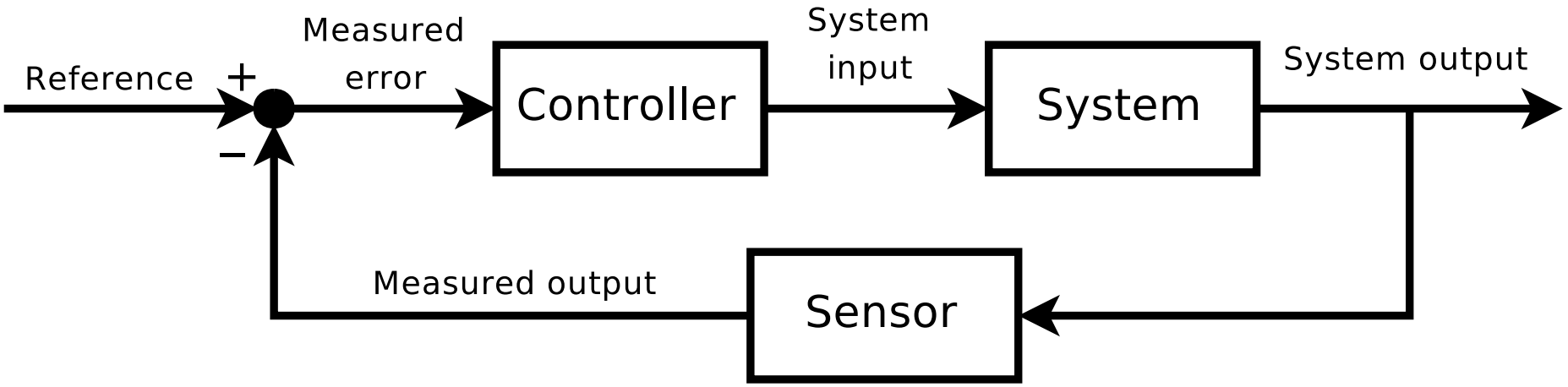
A Brief History of Control



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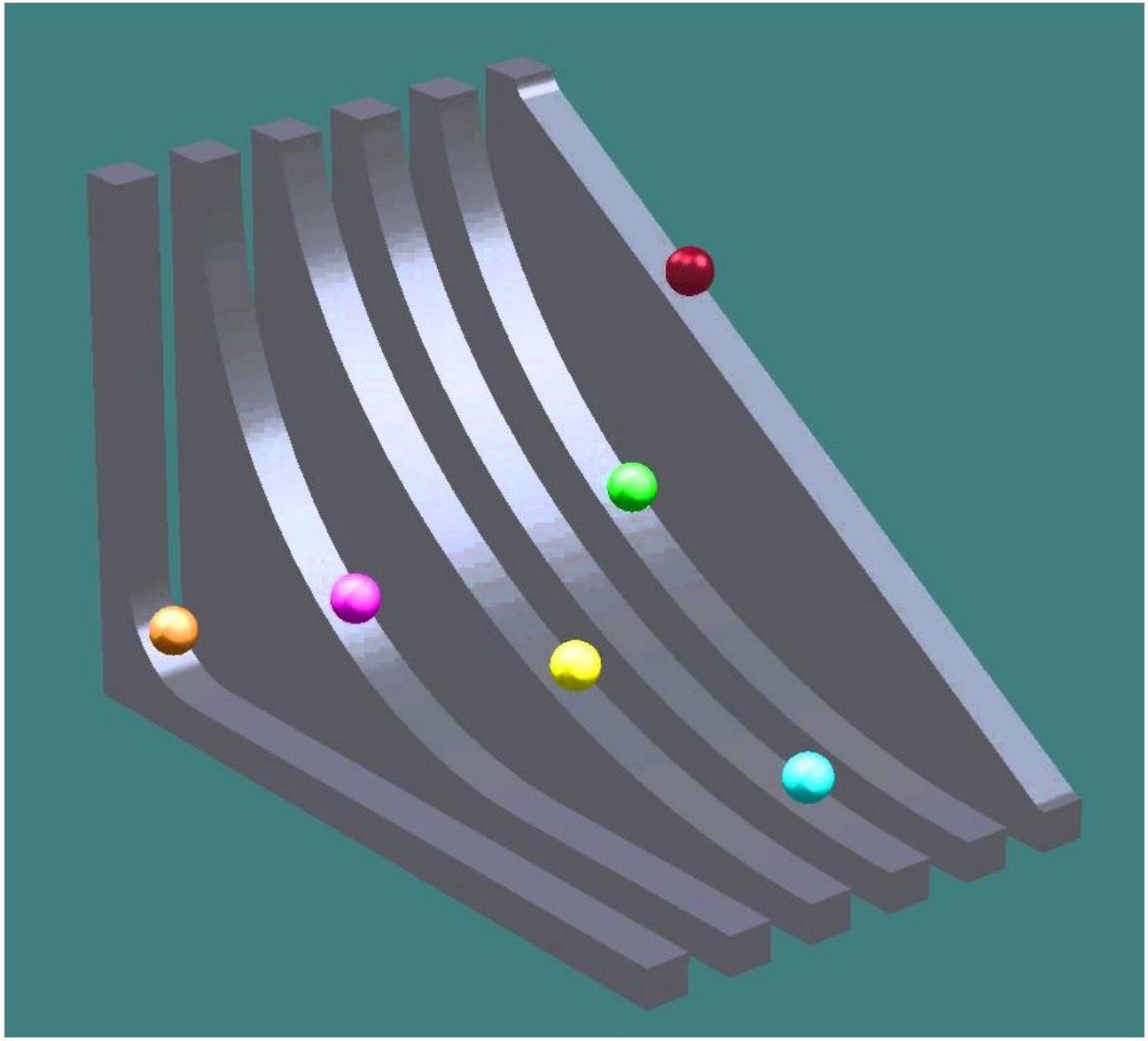
Spring 2024

In The Beginning…



The First Trajectory Optimization Problem

$$\underset{x(t)}{\text{minimize}} \; T = \int_{P_0}^{P_f} \frac{1}{v}\, ds = \int_{x_0}^{x_f} \frac{\sqrt{1 + (dy/dx)^2}}{\sqrt{2gy}}\, dx$$

$$\frac{1}{2} m v^2 = mgy \implies v = \sqrt{2gy}$$

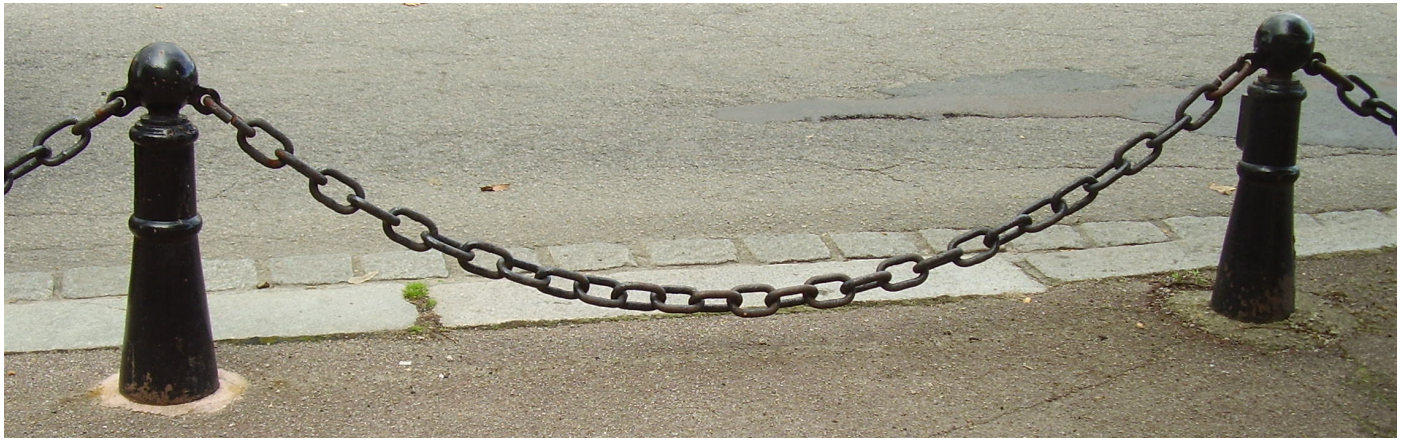
$$ds = \sqrt{dx^2 + dy^2} = \sqrt{1 + (dy/dx)^2}\, dx$$

Calculus of Variations

$$\underset{x(t)}{\text{minimize}} \; J(x(t)) = \int_{t_0}^{t_f} L(t, x(t), \dot{x}(t))\, dt$$

Lots of Applications:

Statics (Catenary)
Optics (Fermat's Principle)
Classical Mechanics (Hamilton's Principle)
Finite-Element Methods (Weak formulation)
General Relativity (Einstein-Hilbert Action)
Quantum Mechanics (Feynman Path Integral)



Feedback Systems

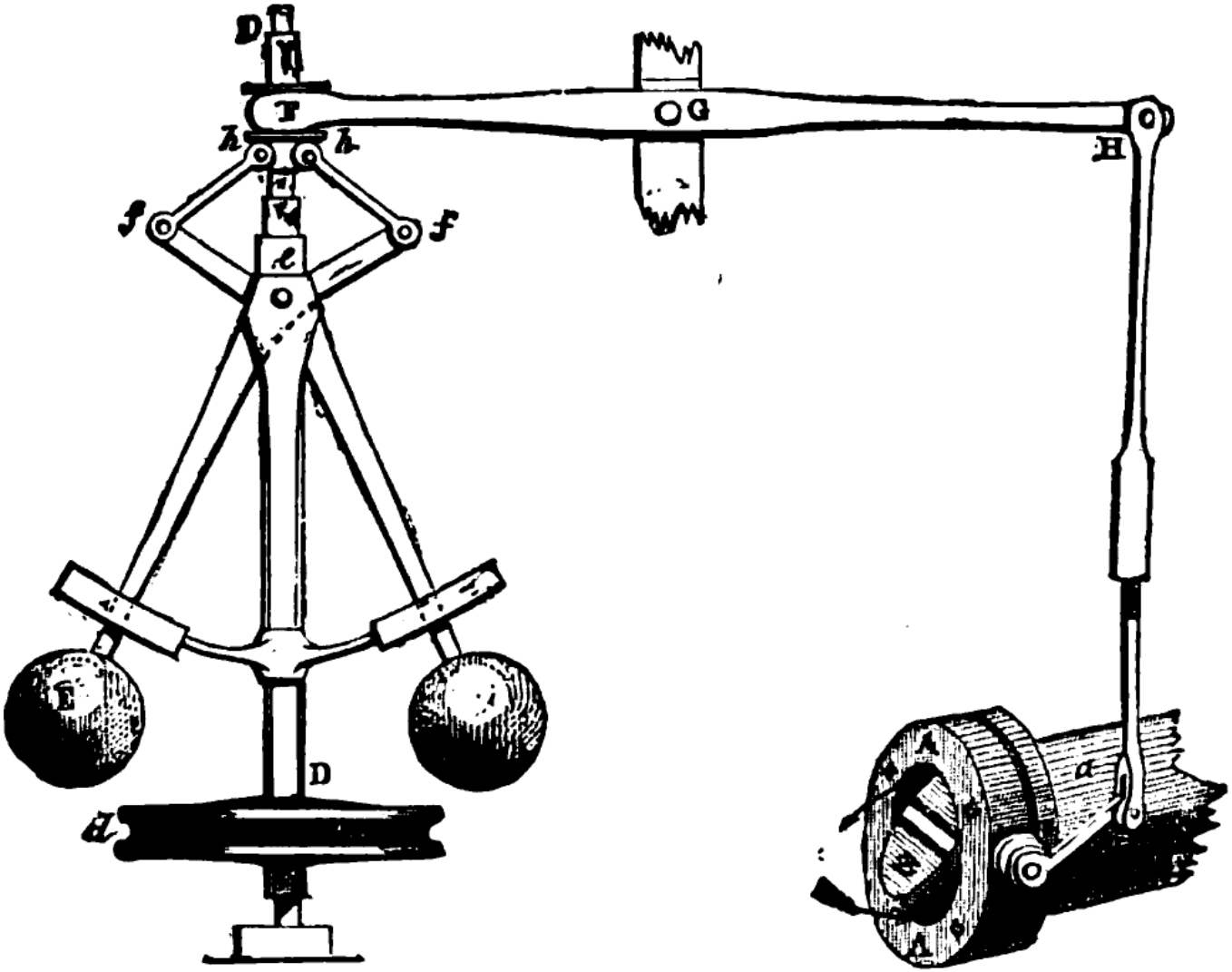
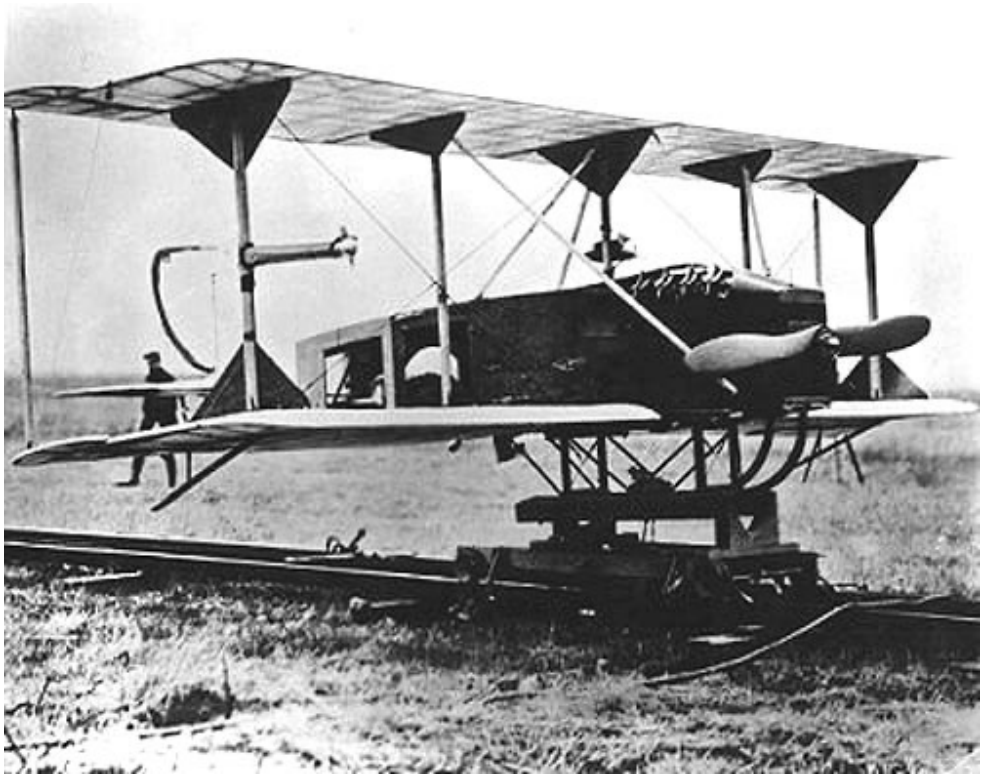
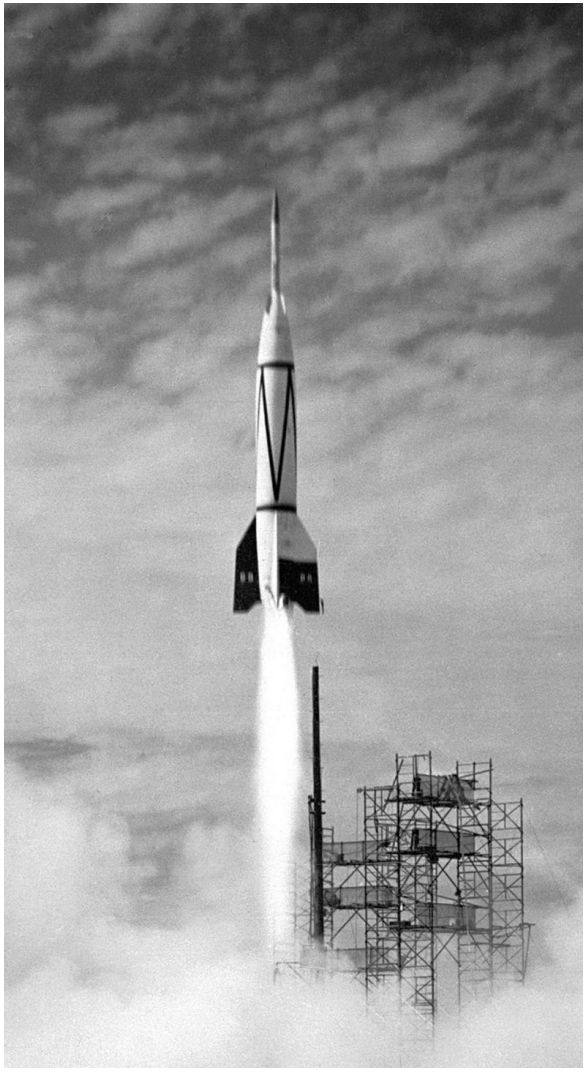


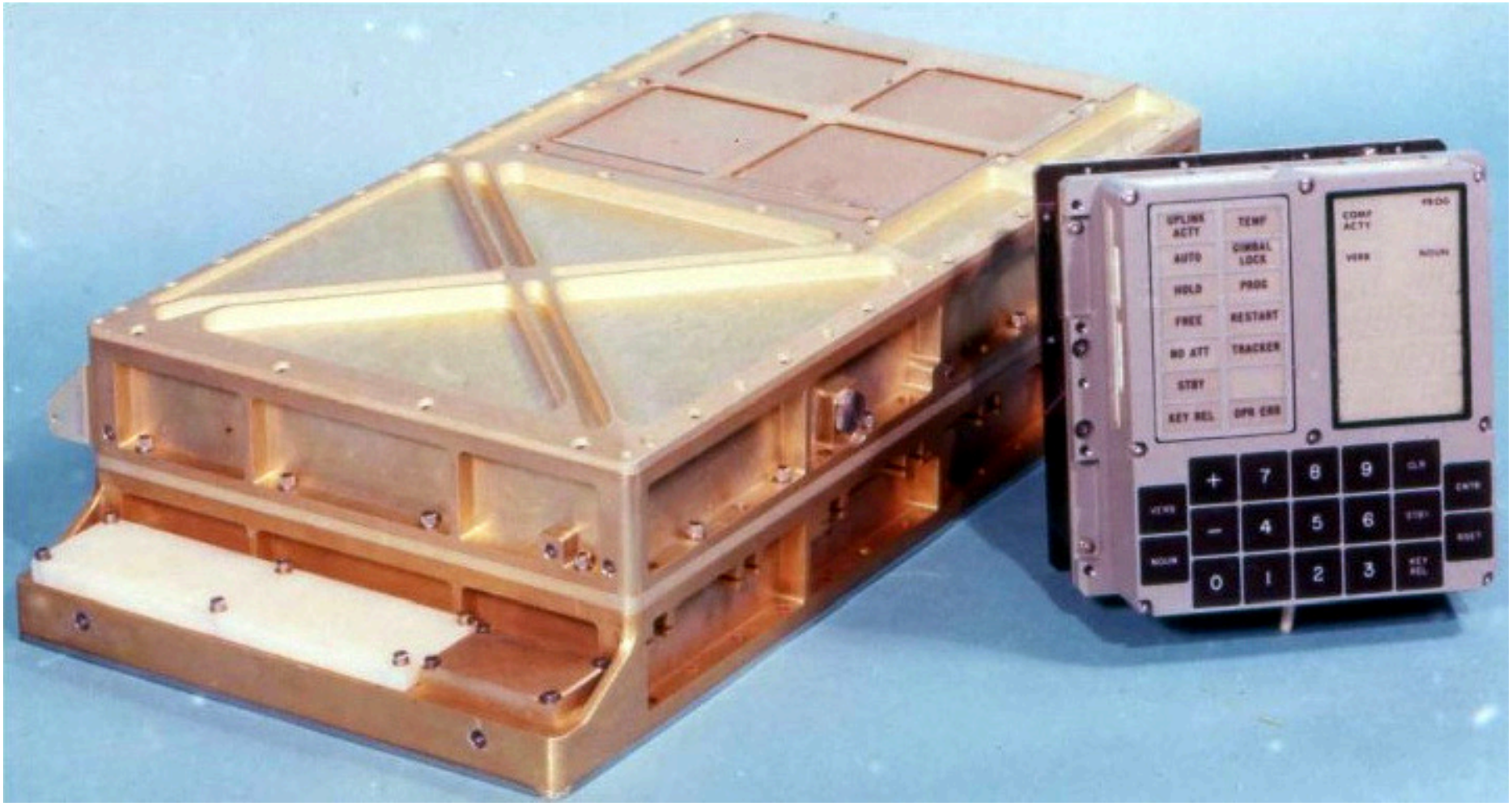
FIG. 4.—*Governor and Throttle-Valve.*

“Classical Control” (1910-1960)





“Modern Control” (Post-1960)



Adaptive Control and RL (1950s-Present)

Robust Control (1980s-Present)

Guaranteed Margins for LQG Regulators

JOHN C. DOYLE

Abstract—There are none.

Introduction

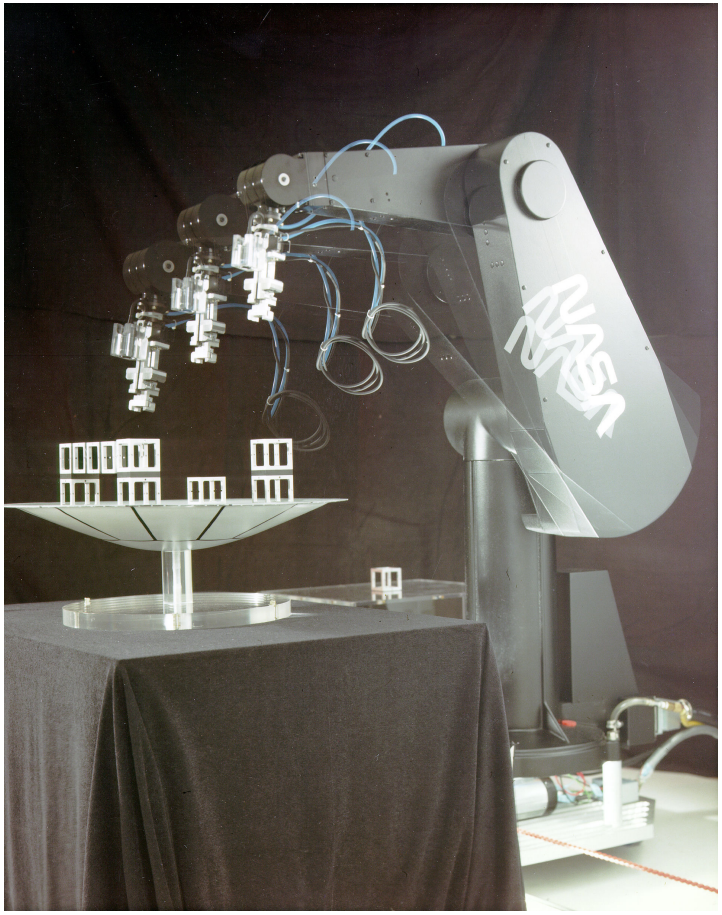
Considerable attention has been given lately to the issue of robustness of linear–quadratic (LQ) regulators. The recent work by Safonov and Athans [1] has extended to the multivariable case the now well-known guarantee of 60° phase and 6 dB gain margin for such controllers. However, for even the single-input, single-output case there has remained the question of whether there exist any guaranteed margins for the full LQG (Kalman filter in the loop) regulator. By counterexample, this note answers that question; there are none.

A standard two-state single-input single-output LQG control problem is posed for which the resulting closed-loop regulator has arbitrarily small gain margin.

Model Predictive Control (1970s-Present)

Robotic Manipulators: (1970s-80s)

$$u = B(q)^{-1}\left(M(q)\ddot{q} + C(q,\dot{q})\right)$$

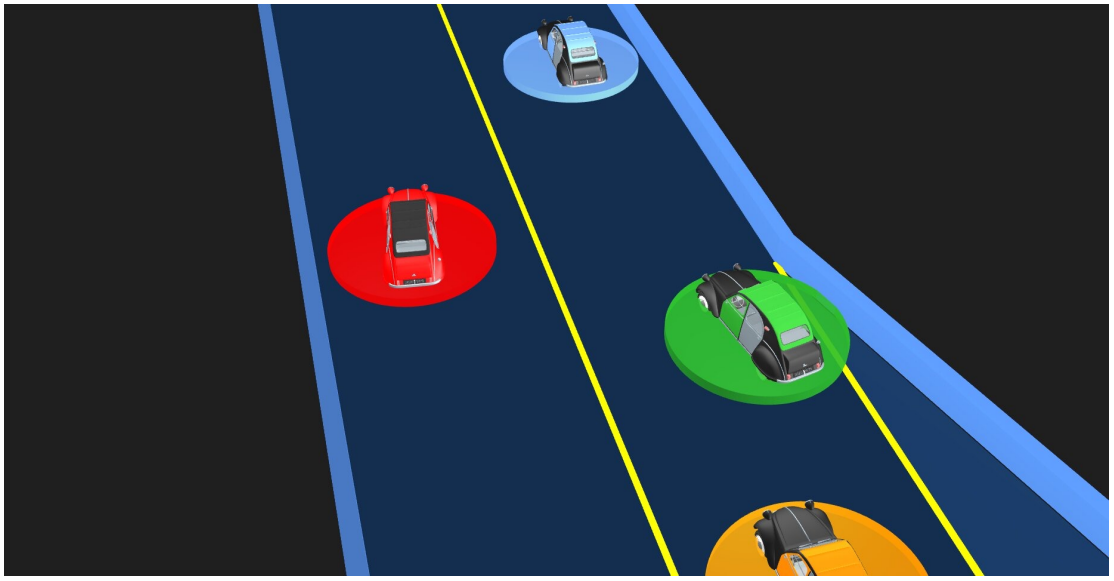


Legged Robots: (1980s-Present)

Legged Robots: (1980s-Present)

Challenges for the Future?

- General theory for dealing with contact
- Bridging the gap between model-based control and RL
- Making RL more data efficient by incorporating prior knowledge
- Safety guarantees for uncertain nonlinear systems
- Dealing with other (possibly adversarial) agents



Questions?
Comments?