# Preventing the use of Commercial Aircraft as Weapons

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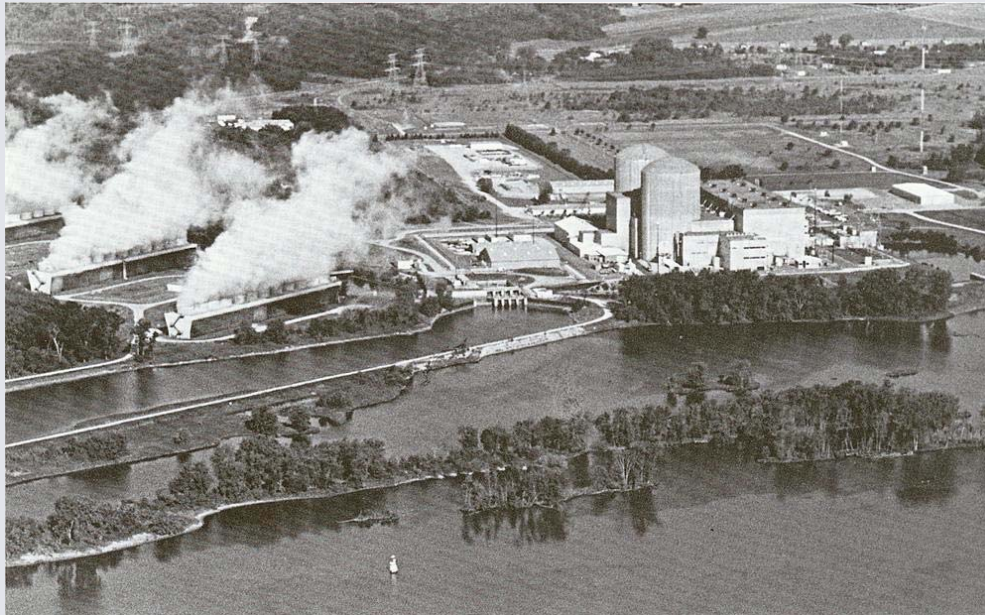
with Xiaojun Liu, Adam Cataldo

Institute of  Transportation Studies Seminar
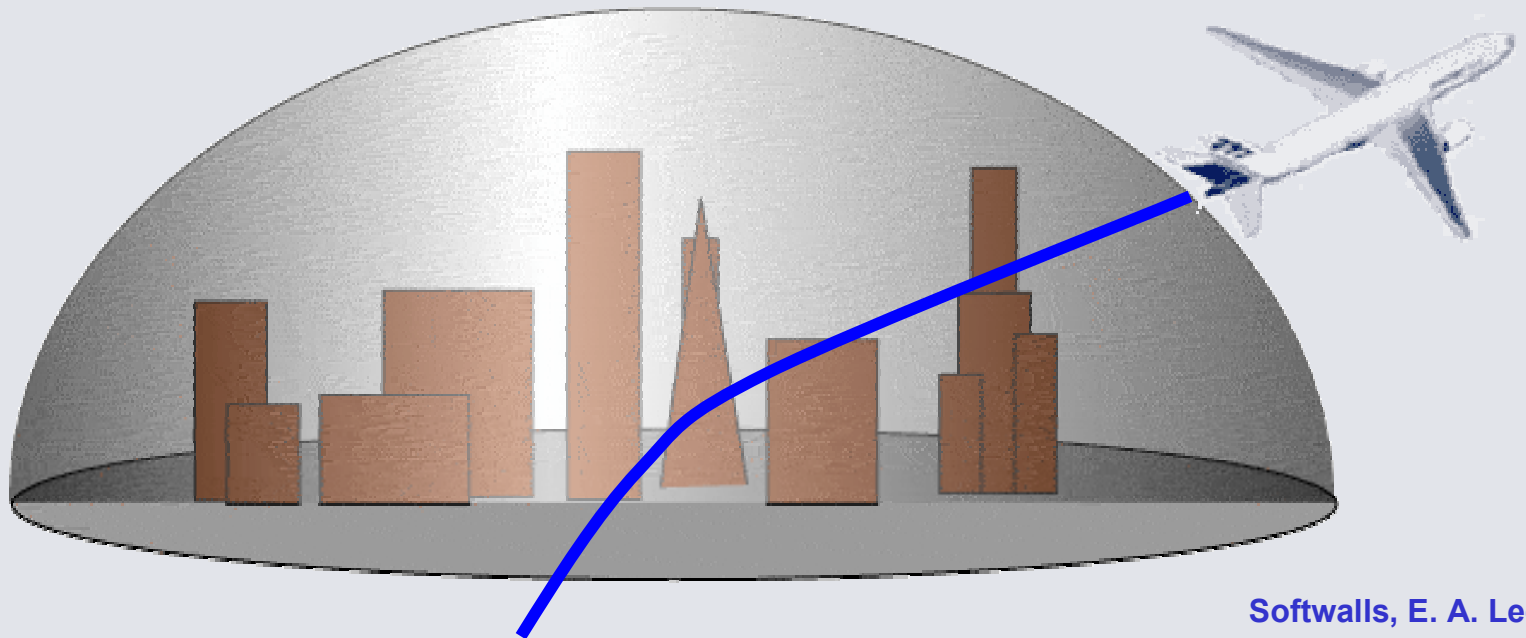February 8, 2002

# A Lethal Weapon?

# Need to Shield

- Major cities
- Government centers
- Chemical and nuclear plants
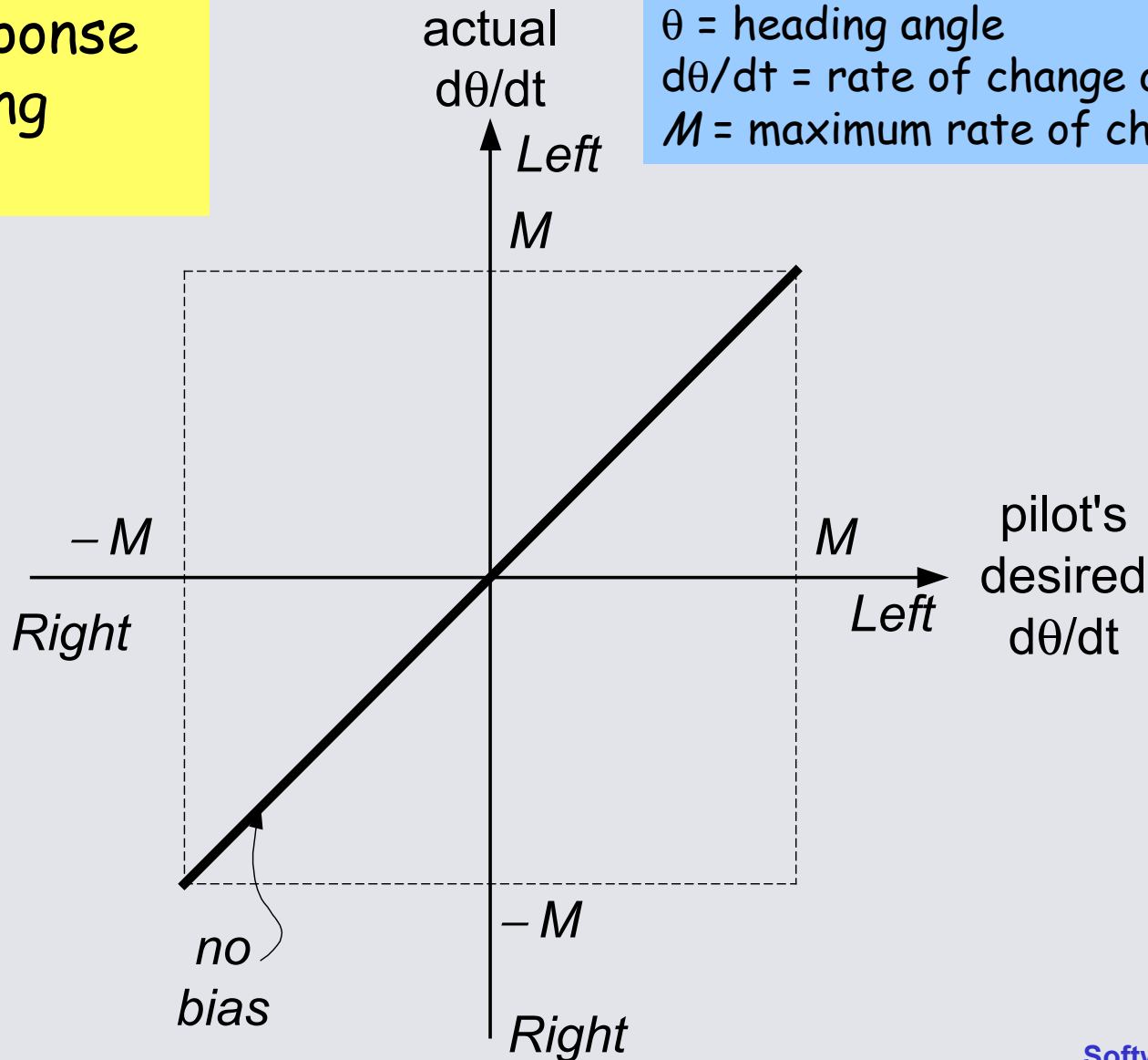- Military installations
- Critical infrastructure

# Softwalls

- Carry on-board a 3-D database with "no-fly-zones"

- Enforce no-fly zones using on-board avionics (aviation electronics)

- Non-networked, non-hackable

# Biasing Pilot Control
# While Maintaining Responsivity

Normal response pilot steering control.

$\theta$ = heading angle
$d\theta/dt$ = rate of change of heading
$M$ = maximum rate of change

actual
$d\theta/dt$

*Left*

$M$

$-M$

*Right*

$M$

pilot's
desired
$d\theta/dt$

*Left*

$-M$

*no bias*

*Right*

# Biasing Pilot Control
# While Maintaining Responsivity

Bias the aircraft to the right.

$\theta$ = heading angle
$d\theta/dt$ = rate of change of heading
$M$ = maximum rate of change

actual $d\theta/dt$

*Left*

$M$

$-M$

*Right*

$M$

*Left*

pilot's desired $d\theta/dt$

$-M$

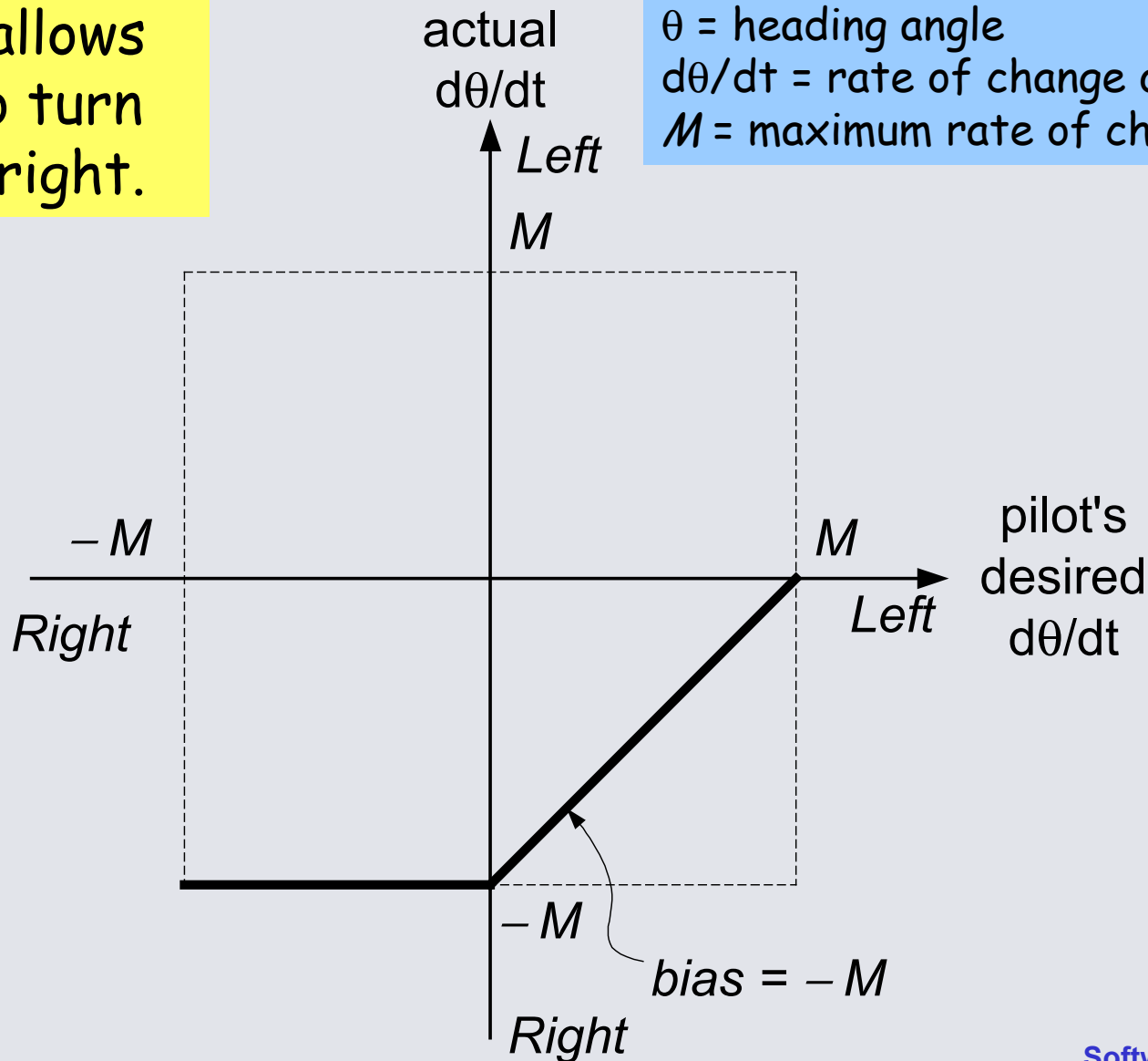*no bias*
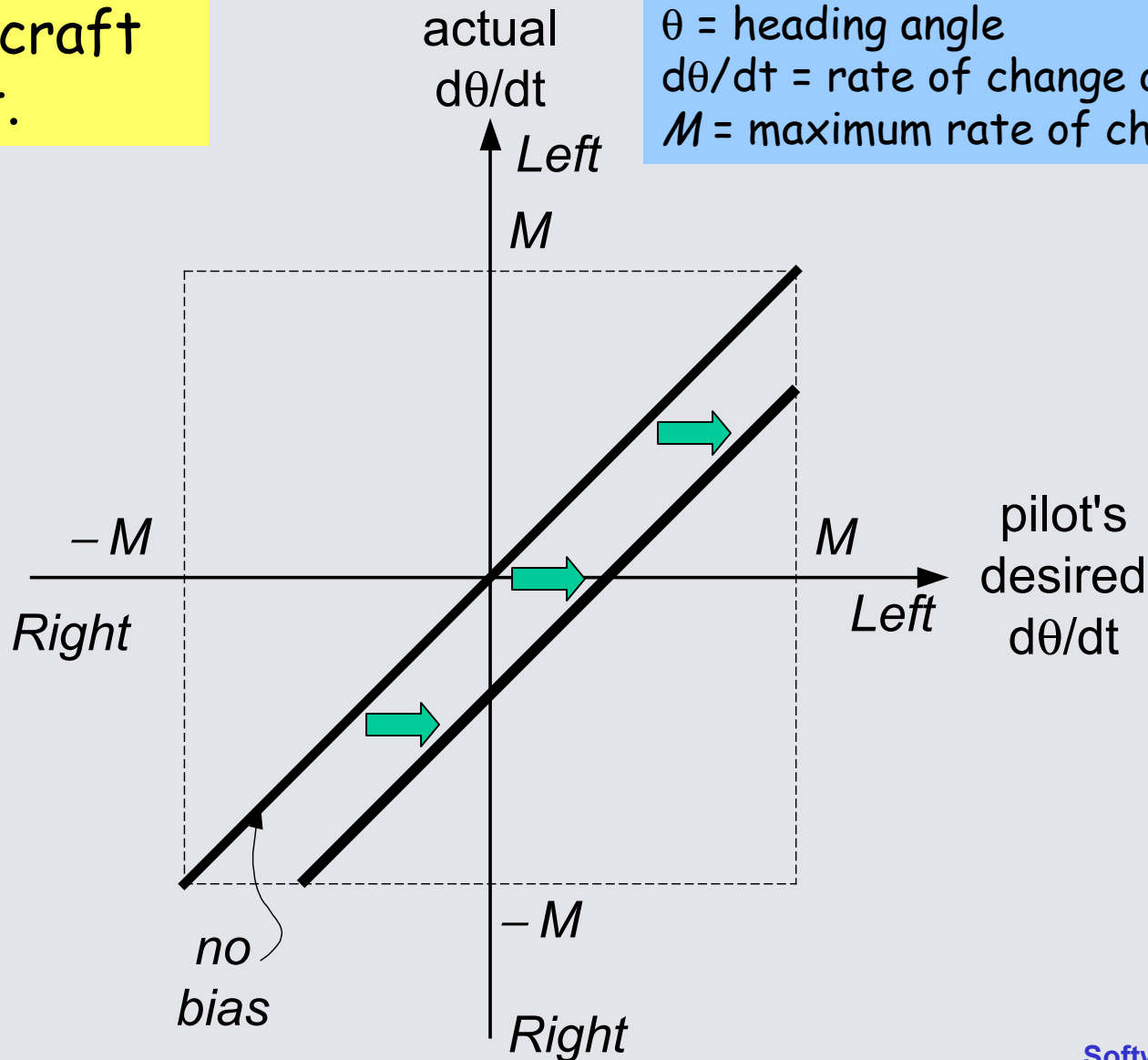
*Right*

# Biasing Pilot Control
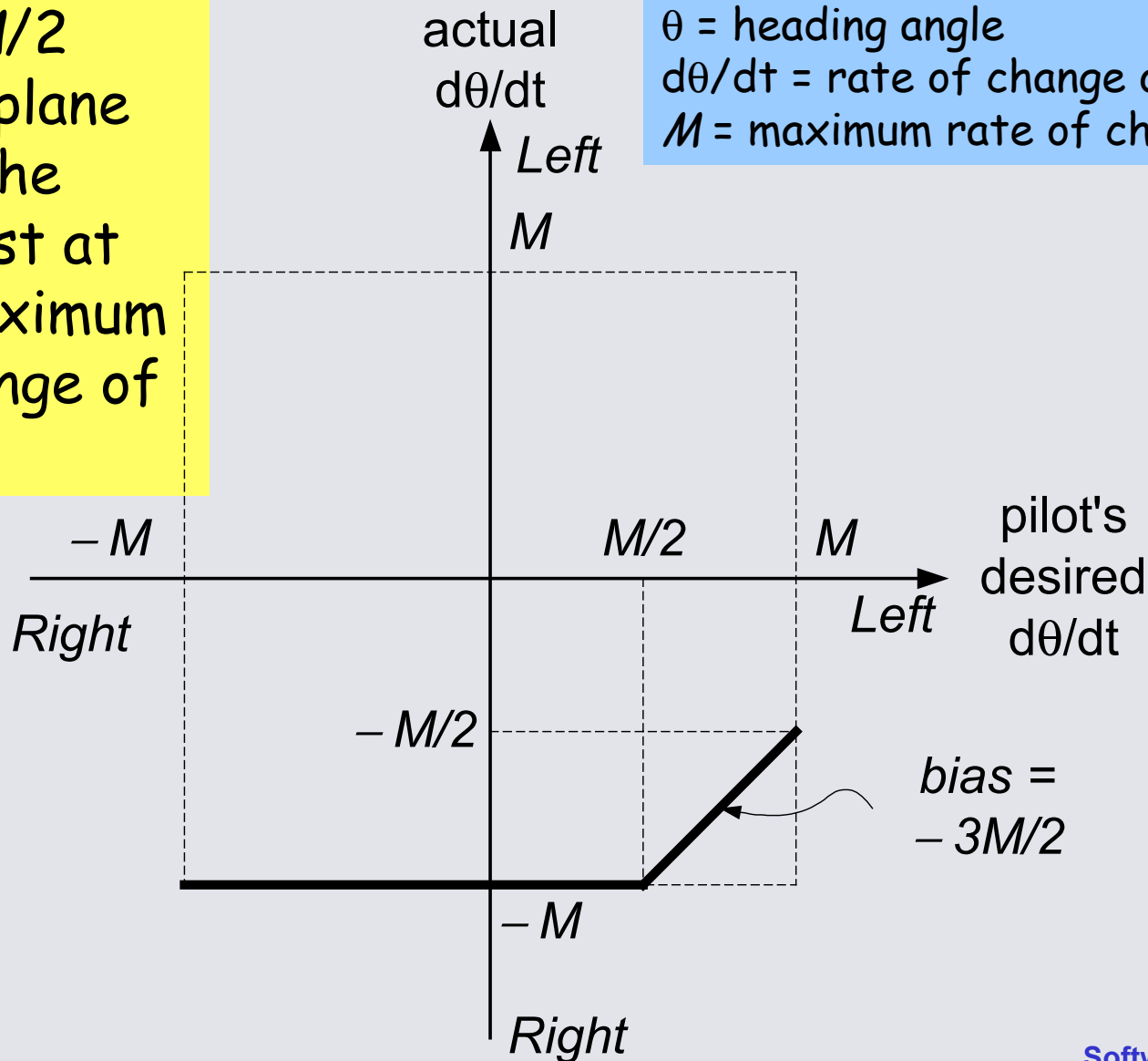# While Maintaining Responsivity

Bias of $-M$ allows the plane to turn only to the right.

$\theta$ = heading angle
$d\theta/dt$ = rate of change of heading
$M$ = maximum rate of change

actual
$d\theta/dt$

*Left*

$M$

$-M$

*Right*

$M$

pilot's
desired
$d\theta/dt$

*Left*

$-M$

bias = $-M$

*Right*

# Biasing Pilot Control
# While Maintaining Responsivity

Bias of $-3M/2$ forces the plane to turn to the right at least at half the maximum rate of change of heading.

$\theta$ = heading angle
$d\theta/dt$ = rate of change of heading
$M$ = maximum rate of change

actual
$d\theta/dt$

*Left*

$M$

$-M$     $M/2$     $M$     pilot's desired $d\theta/dt$

*Right*     *Left*

$-M/2$
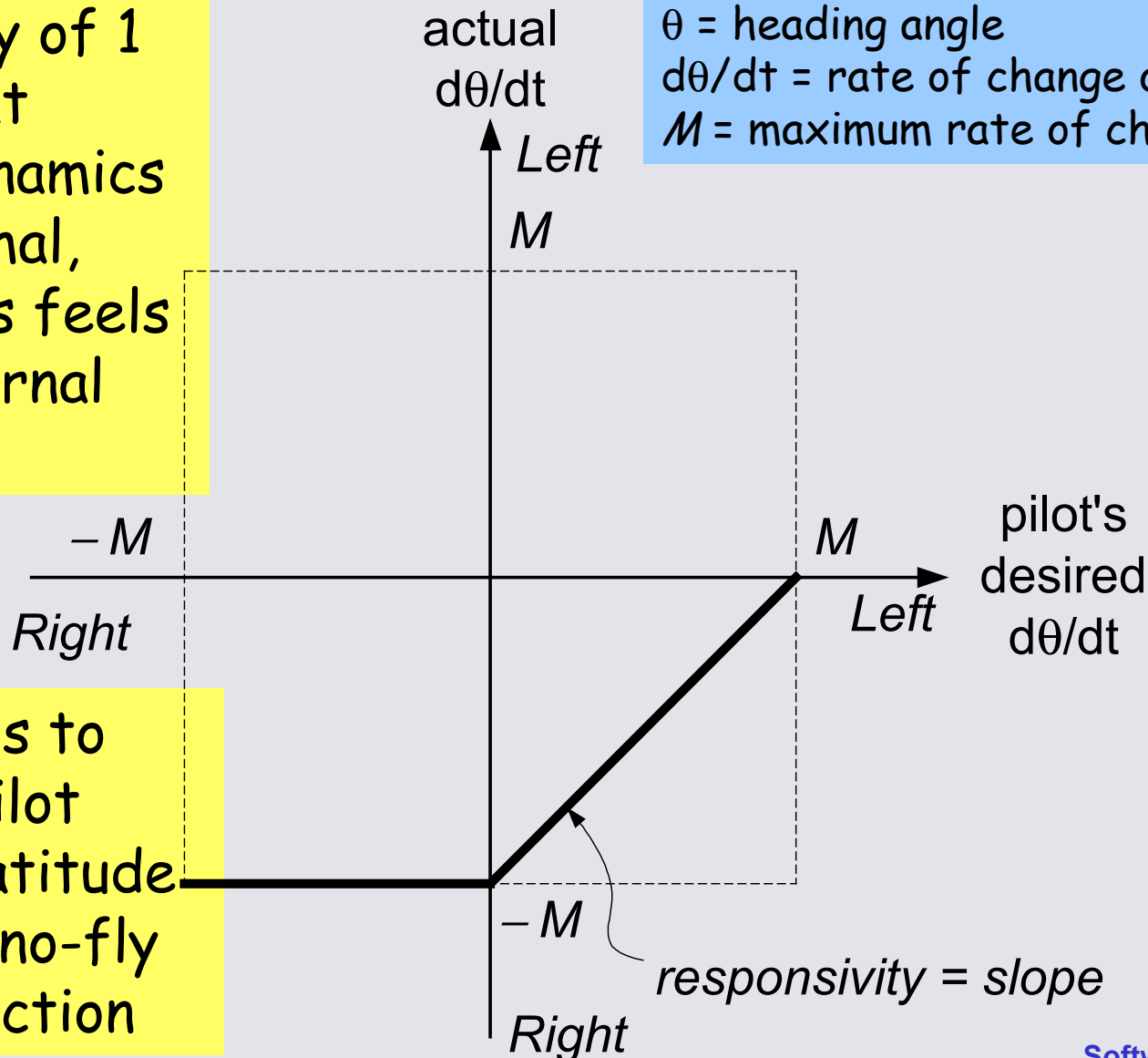
$bias = -3M/2$

$-M$

*Right*

# Responsivity

Responsivity of 1 ensures that aircraft dynamics appear normal, and the bias feels like an external force.

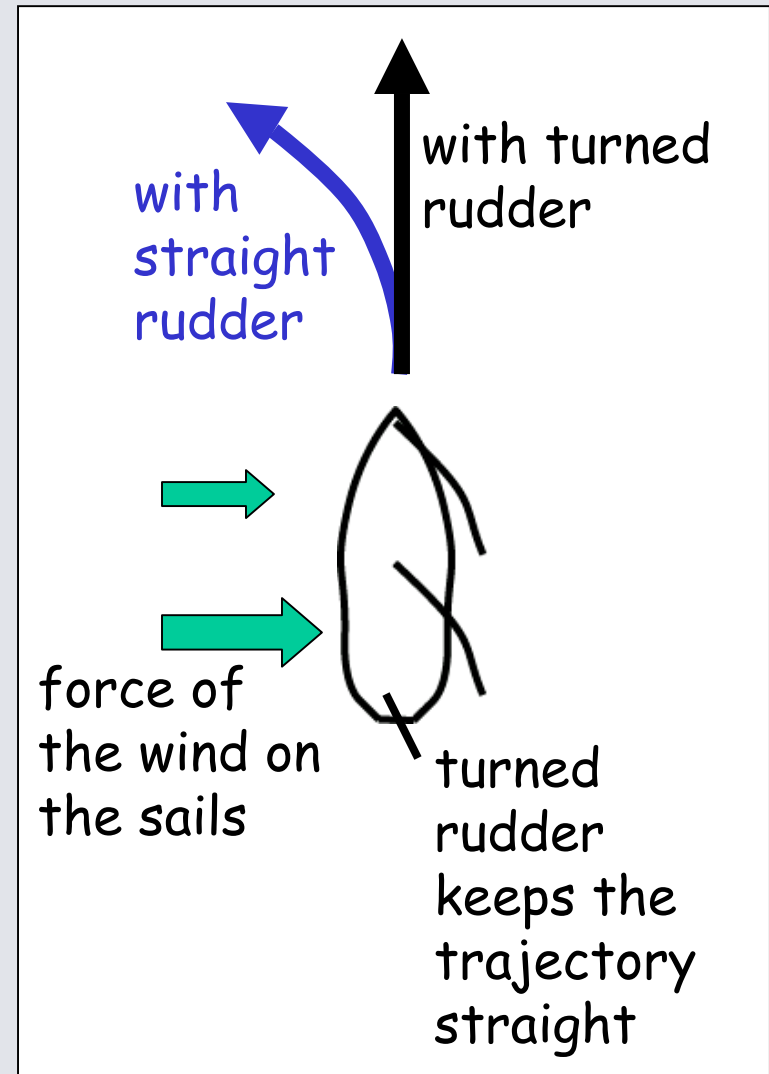Objective is to allow the pilot maximum latitude subject to no-fly zone restriction

$\theta$ = heading angle
$d\theta/dt$ = rate of change of heading
$M$ = maximum rate of change

actual $d\theta/dt$

*Left*

$M$

$-M$

*Right*

$M$

pilot's desired $d\theta/dt$

*Left*

$-M$

*responsivity = slope*

*Right*

# Sailing Analogy – Weather Helm

Even with weather helm, the craft responds to fine-grain control as expected.

with straight rudder

with turned rudder

force of the wind on the sails

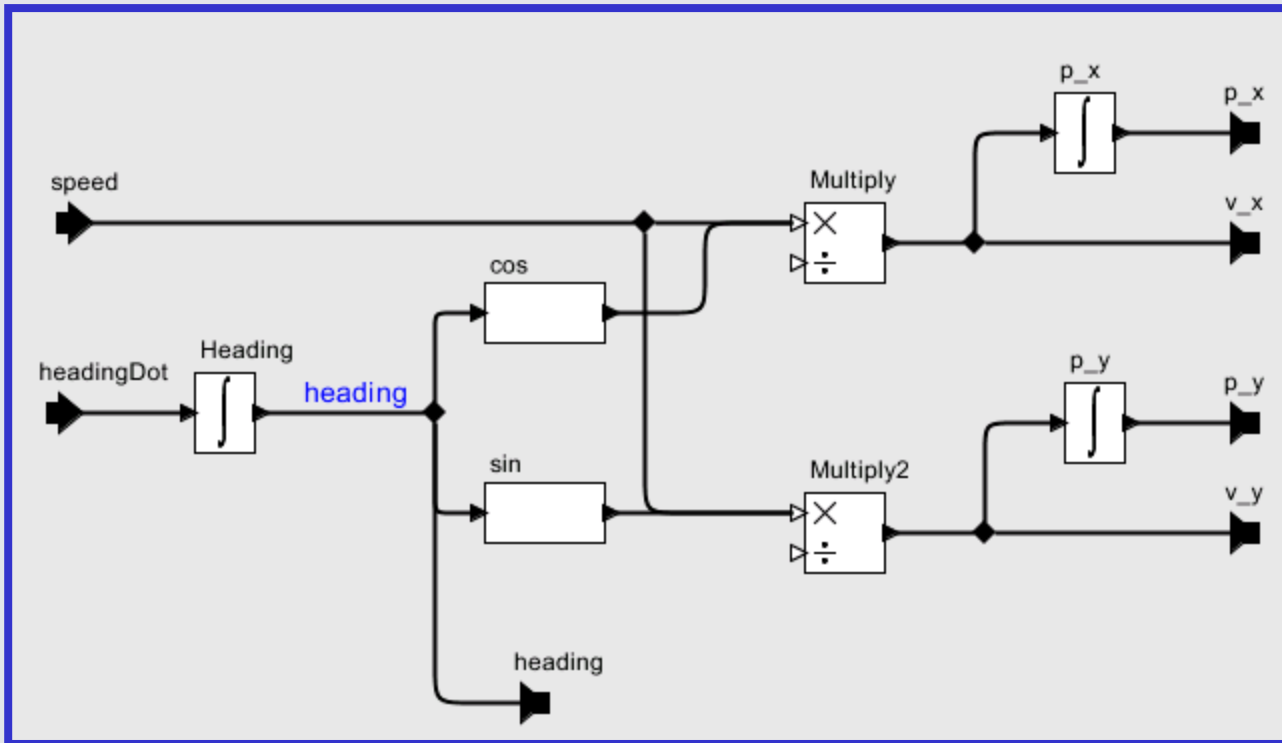turned rudder keeps the trajectory straight

# A Preliminary Candidate Control Strategy

due to Xiaojun Liu

# Two-Dimensional Aircraft Model

- speed $s$
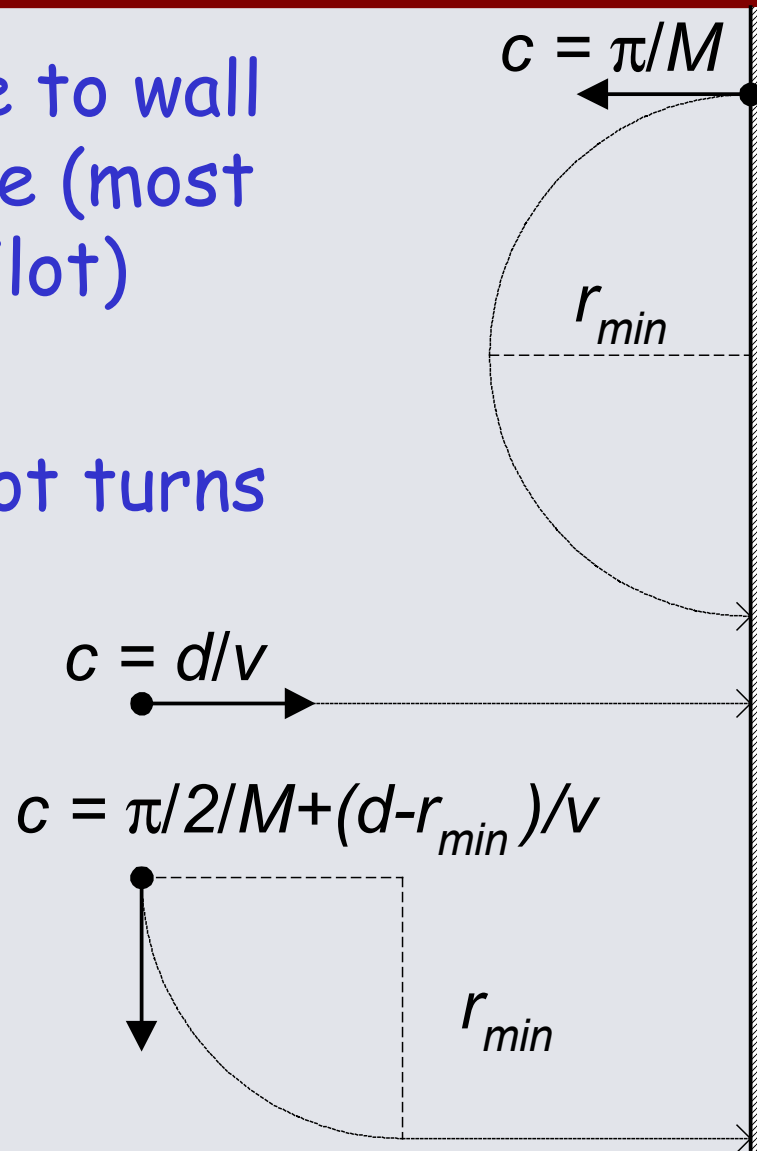- position $p$
- heading $\theta$
- time $t$

$$\dot{p}(t) = (s(t)\cos(\theta(t)), s(t)\sin(\theta(t)))$$
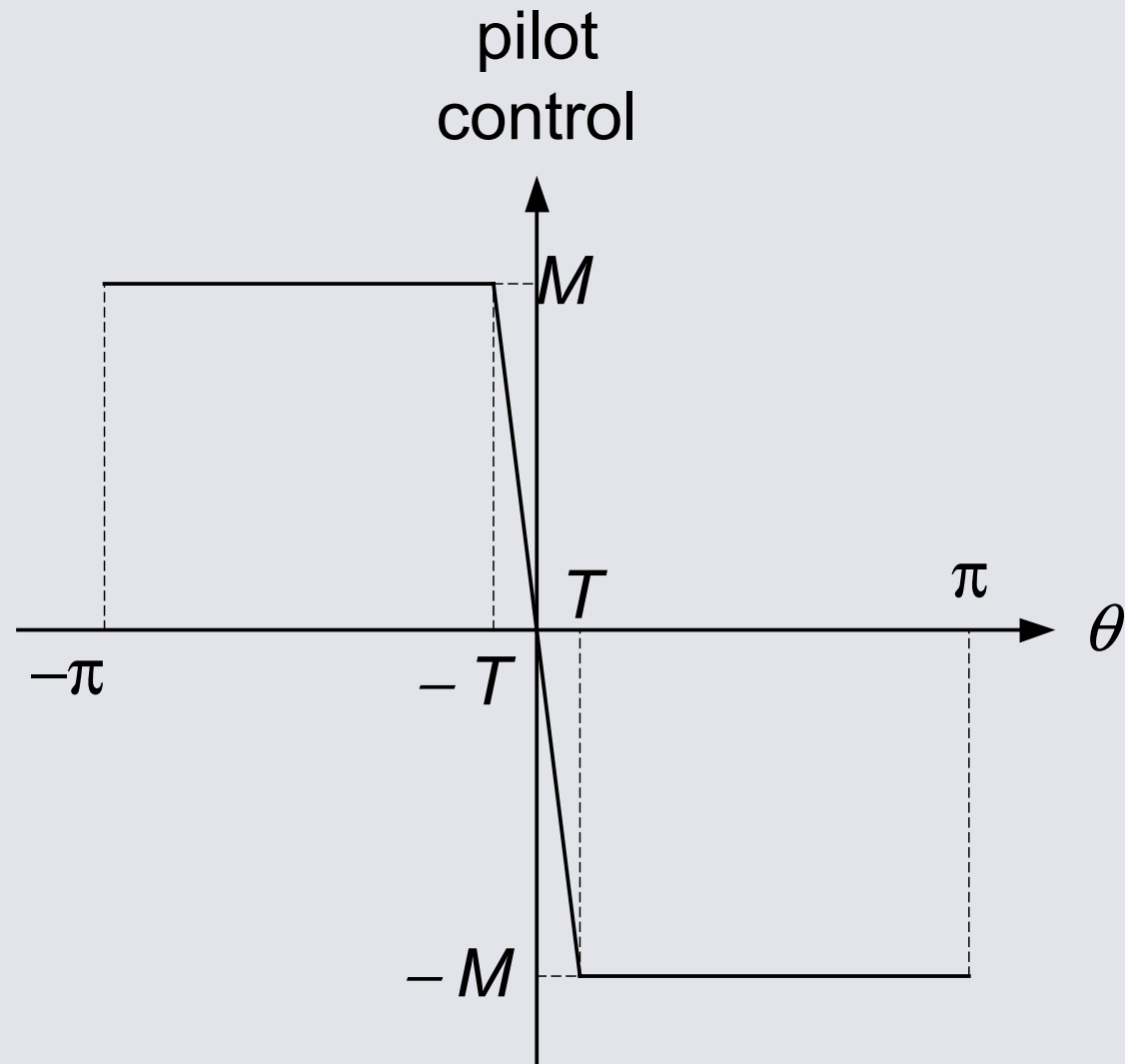
# Criticality – Time to Wall

- Measure of time to wall in the worst case (most uncooperative pilot)

- Assumes the pilot turns toward the wall at the maximum rate

$c = \pi/M$
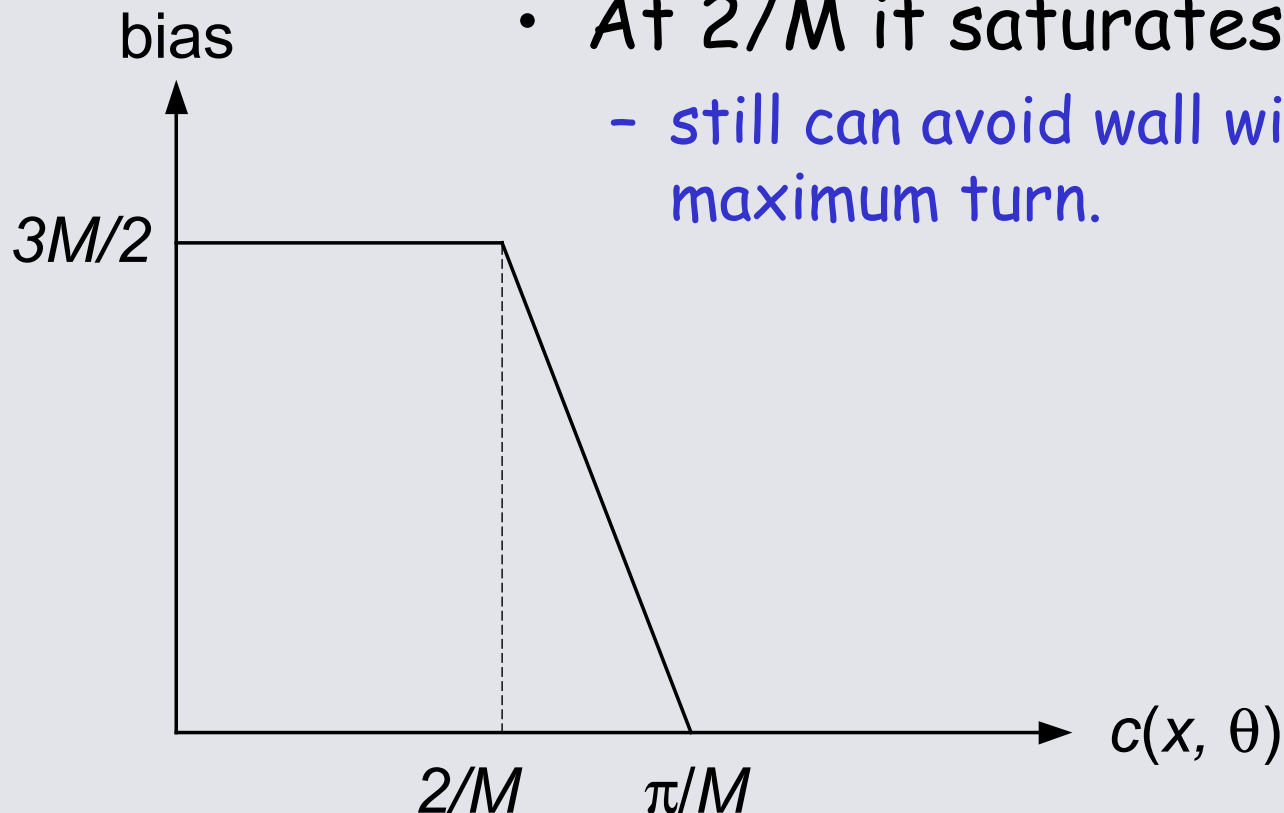
$r_{min}$

$c = d/v$

$c = \pi/2/M+(d-r_{min})/v$

$r_{min}$

# Maximally Uncooperative Pilot

- Assume $\theta = 0$ is heading towards the wall

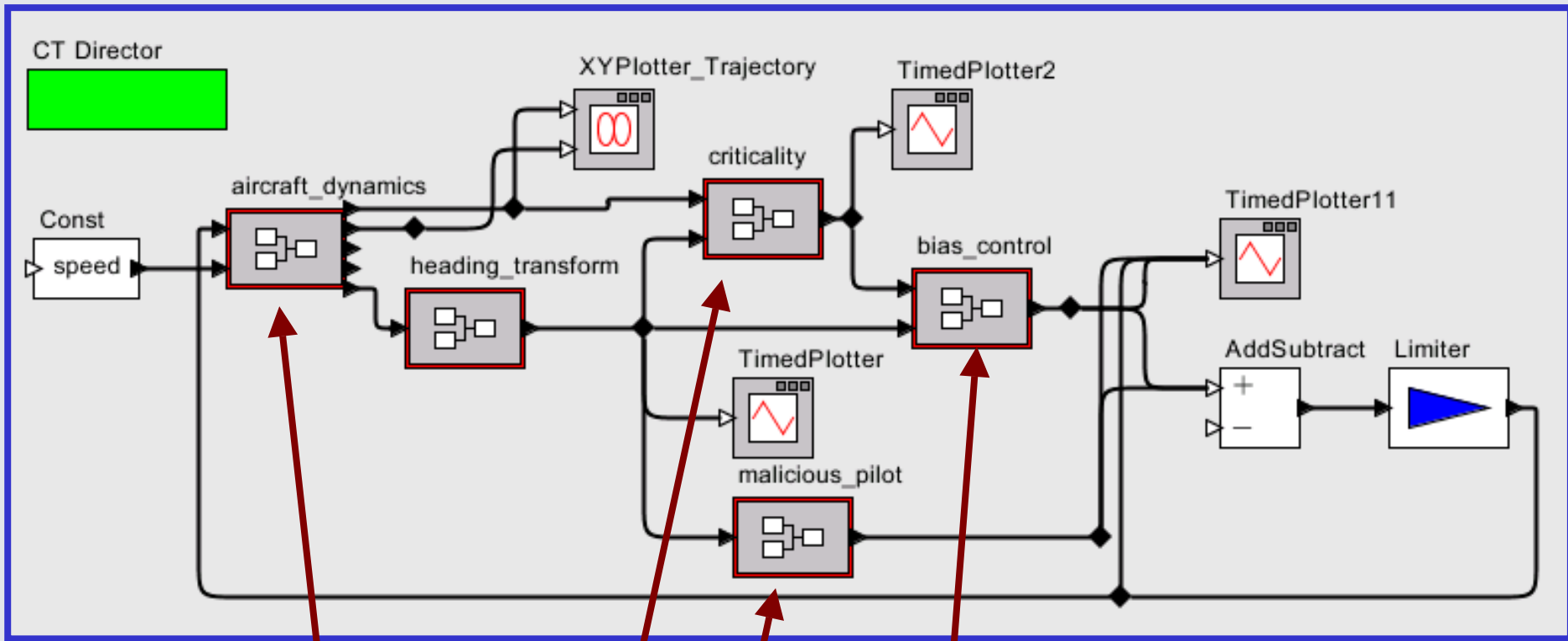- This pilot steers maximally towards the wall

pilot control

# Bias from Criticality-Based Controller

- If time to wall is less than $\pi/M$, the bias rises
  - at the wall, heading away is OK
- At 2/M it saturates.
  - still can avoid wall with half-maximum turn.

bias

3M/2

2/M      $\pi/M$

$c(x, \theta)$

# Simulation Model

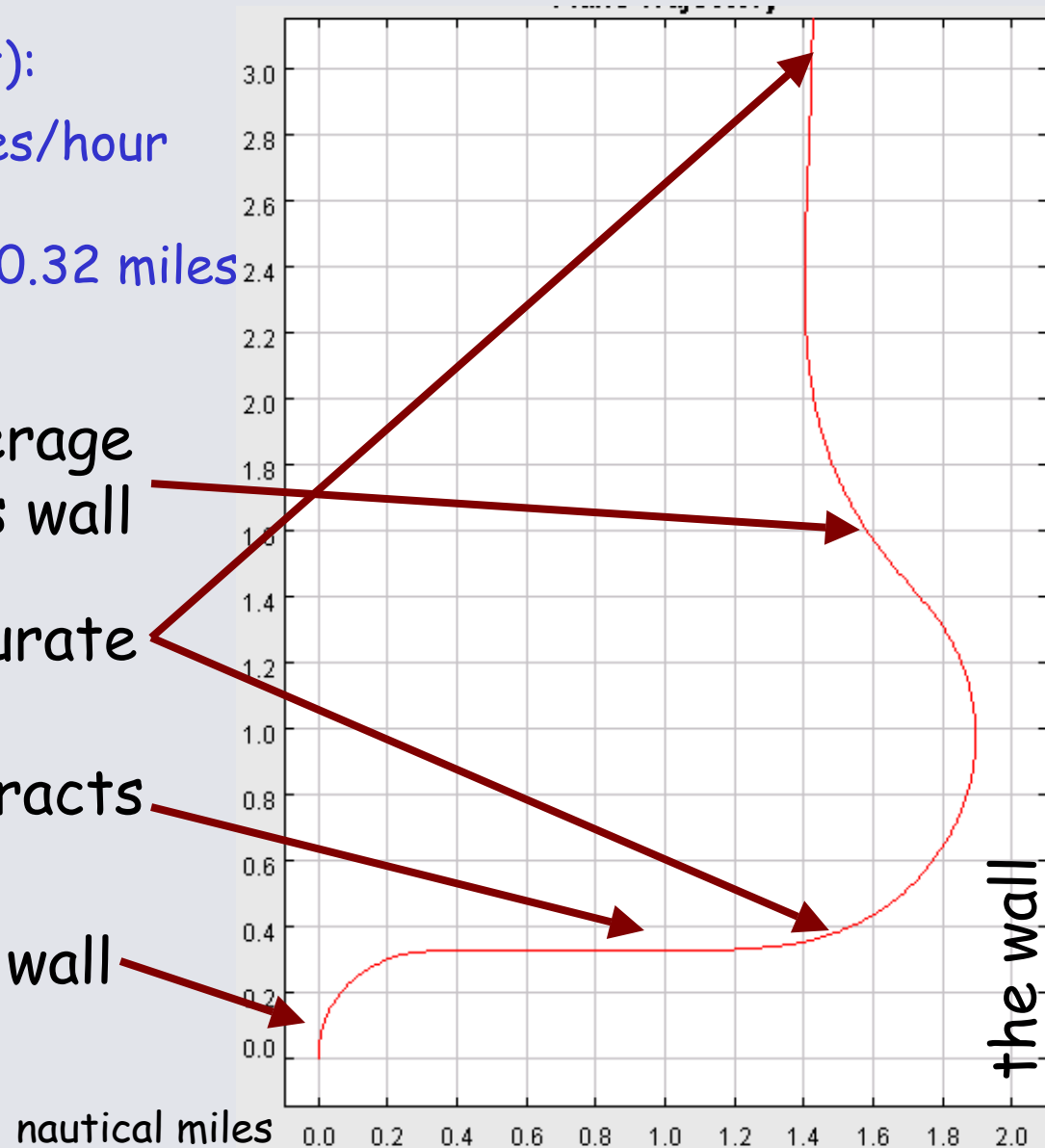# Simulation – Maximally Uncooperative Pilot

**Assumptions** (pulled out of a hat):

- speed: 0.1 miles/sec = 360 miles/hour
- M: $2\pi/20$ radians/sec
- min turning radius: speed/M = 0.32 miles

pilot regains steerage towards wall

pilot controls saturate

bias starts, pilot counteracts

pilot turns towards the wall

the wall

nautical miles

# Related Methods

- Ground proximity warning systems
- Automatic ground avoidance systems
- TCAS & ACAS – collision avoidance
- Potential field methods for air-traffic control
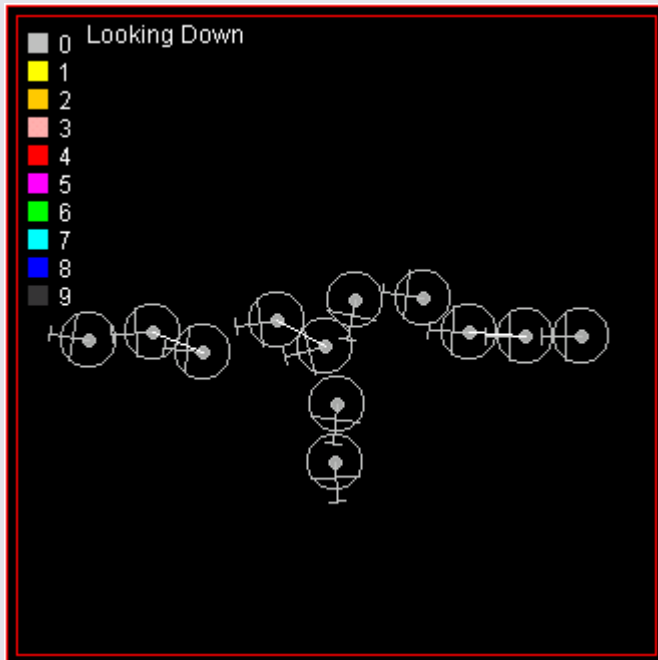


Honeywell
TCAS

Rockwell conflict resolution

# Objections

- Reducing pilot control is dangerous
  - reduces ability to respond to emergencies

# Is There Any Aircraft Emergency Severe Enough to Justify Trying to Land on Fifth Ave?

# Objections

- Reducing pilot control is dangerous
  - reduces ability to respond to emergencies
- There is no override
  - switch in the cockpit

# No-Fly Zone with Harsher Enforcement



DHAULAGIRI

There is no override in the cockpit that allows pilots to fly through this.

# Objections

- Reducing pilot control is dangerous
  - reduces ability to respond to emergencies
- There is no override
  - switch in the cockpit
- Localization technology could fail
  - GPS can be jammed

# Localization Issues

- GPS
- Inertial navigation





"Localization" is the technology for reliably and accurately knowing the location of an object.

# Objections

- Reducing pilot control is dangerous
  - reduces ability to respond to emergencies
- There is no override
  - switch in the cockpit
- Localization technology could fail
  - GPS can be jammed
- Deployment could be costly
  - how to retrofit older aircraft?

# Deployment

- Fly-by-wire aircraft
  - a software change
- Older aircraft
  - autopilot level
- Phase in
  - prioritize airports

# Objections

- Reducing pilot control is dangerous
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  - how to retrofit older aircraft?
- Deployment could take too long
  - software certification

# Not Like Air Traffic Control



1942-1962
Denver ARTCC  Stapleton Airport

This seems entirely independent of air traffic control, and could complement safety methods deployed there. Self-contained on a single aircraft.

# Objections

- Reducing pilot control is dangerous
  - reduces ability to respond to emergencies
- There is no override
  - switch in the cockpit
- Localization technology could fail
  - GPS can be jammed
- Deployment could be costly
  - how to retrofit older aircraft?
- Deployment could take too long
  - software certification
- Fully automatic flight control is possible
  - throw a switch on the ground, take over plane

# UAV Technology
## (Unoccupied Air Vehicle)



e.g. Global Hawk
(Northrop Grumman)

Technology Support Working Group (TSWG), office of the Secretary of Defense, has reportedly decided against recommending any partial control approach. Their feeling is that there is only one feasible strategy: a single trigger, either on-board or remote control, that would assume complete control and take the plane to a safe base.

Northrop Grumman has such a system in the Global Hawk UAV that some believe can be dropped-in to passenger airliners.

# Potential Problems with Ground Control

- Human-in-the-loop delay on the ground
  - authorization for takeover
  - delay recognizing the threat

- Security problem on the ground
  - hijacking from the ground?
  - takeover of entire fleet at once?
  - coup d'etat?

- Requires radio communication
  - hackable
  - jammable

# Open Questions

- Technical issues
  - Geometry constraints on no-fly zones?
  - Can localization without GPS be accurate enough?
  - Can the database be secure?
  - Can areas near urban airports be protected?
  - How to prove safety?
  - Robustness with partial system failures?

- Policy issues
  - Definition of no-fly zones
  - Centralized vs. decentralized control

# Acknowlegements

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- Paul Yang

# Discussion

- Absent terrorism, does this make flying safer?
- Is it better to have F-16's enforcing no-fly zones?
- Are pilots willing to give up some control?
- Can the technique be phased in?
- Are there other, simpler approaches?
- …