Macroscopic Workload Model for Estimating En Route Sector Capacity

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Introduction

- Airspace capacity estimates are key flow management tools
  - Hot topic: complexity and dynamic capacity reductions
- How about ***static, un-reduced*** capacity?
  - The starting point for all dynamic density estimates
  - Should be easily determined
- But we still use subjective estimates to establish max capacity
  - Controllers "declare" parameters based on operational experience
- Unfortunately, controllers don't really know best!
  - Low traffic demand guarantees that many large en route sectors never operate at maximum capacity
  - High local traffic densities limit many small sectors to operate well below their optimistic subjective capacity thresholds
- Fortunately, an existing simple workload model can predict the <u>maximum</u> capacity of any en route sector
  - Its predictions match peak US sector counts exactly

Model Overview

- Uses Schmidt's* simple sector workload equation
- Gives workload as a function of traffic density
  - We choose parameters to minimize complexity
    - No vertical rates
    - Longitudinal flow
  - We set workload to maximum safe level
  - We invert equation to determine corresponding max traffic density
- Sector capacity depends on flow direction and sector geometry
  - Analytical model simplifies fitting to observed peak sector traffic
  - Bounds *maximum* sector traffic counts

* Schmidt, David K., "A Queuing Analysis of the Air Traffic Controller's Work Load", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-8, No. 6, June 1978.

Macroscopic Workload Model

$$G = G_b + G_c + G_r + G_t$$

- G: Sector Workload Intensity
- G_b: Background
- G_c: Conflict — as conflicts arise
- G_r: Recurring — periodic
- G_t: Transition — at sector crossings

Gray: original model*
Black: new elements**

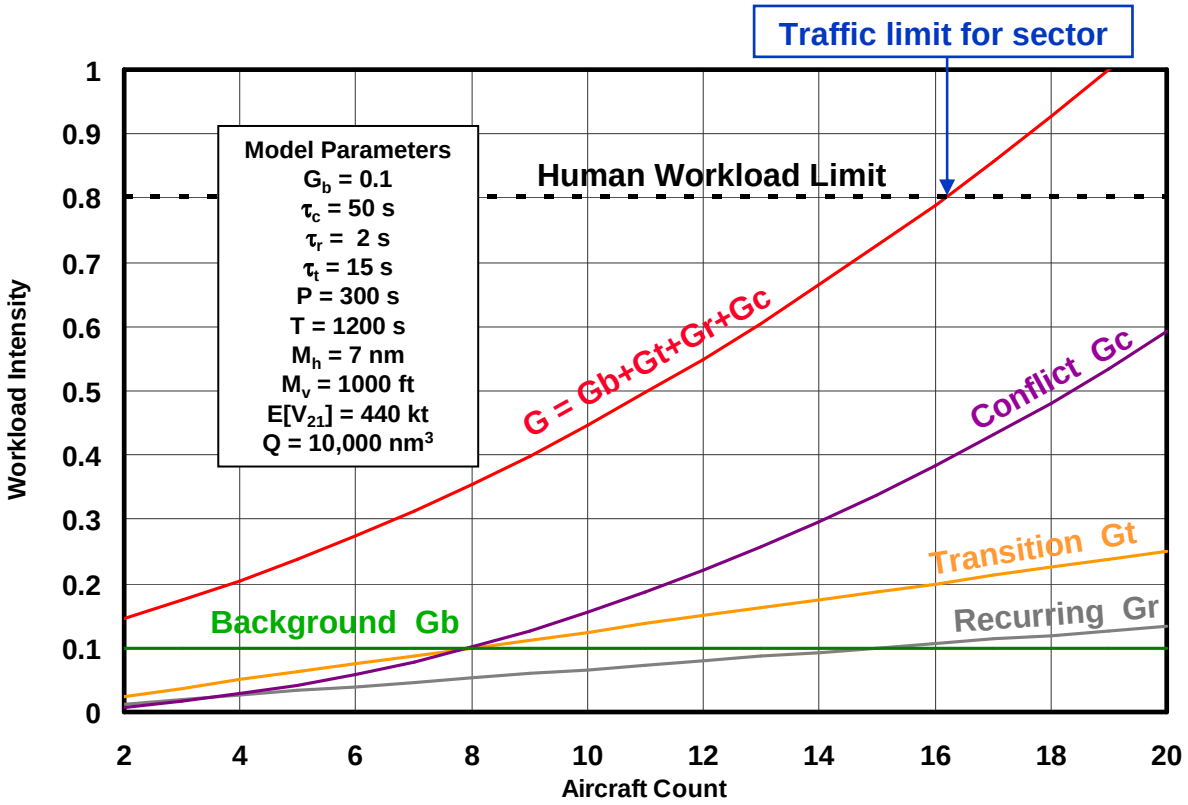
Traffic density *Sector Volume*

$$G_c = \tau_c [B \kappa (\kappa Q + 1)]$$

$$G_r = \tau_r [\kappa Q / P]$$

$$G_t = \tau_t [\kappa Q / T]$$

- service times (*measured*)
- occurrence rates (*calculated from airspace parameters*)



* Schmidt, David K., "A Queuing Analysis of the Air Traffic Controller's Work Load", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-8, No. 6, June 1978.
** Andrews and Welch, "Workload Implications of Free Flight Concepts", 1st USA/EUROCONTROL ATM Seminar, Saclay, France 1997.

Determining Service Time Parameters

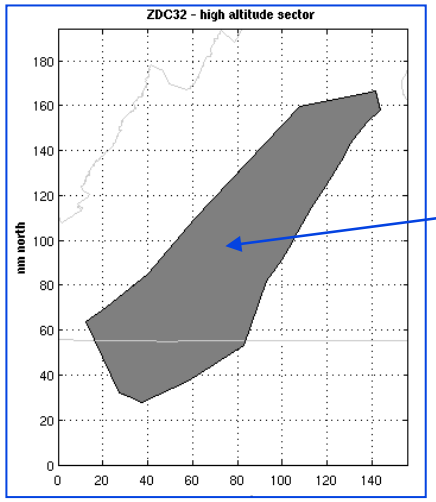
- **Traditional approach**
  - **Observe controller performance times via *real time simulation***

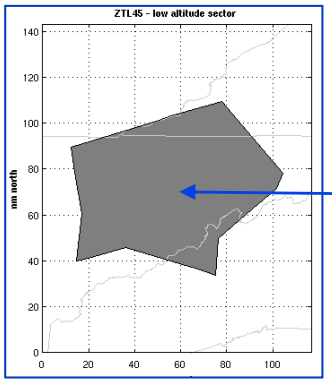
    Schmidt* (τ_c and τ_t), Majumdar (τ_t)**

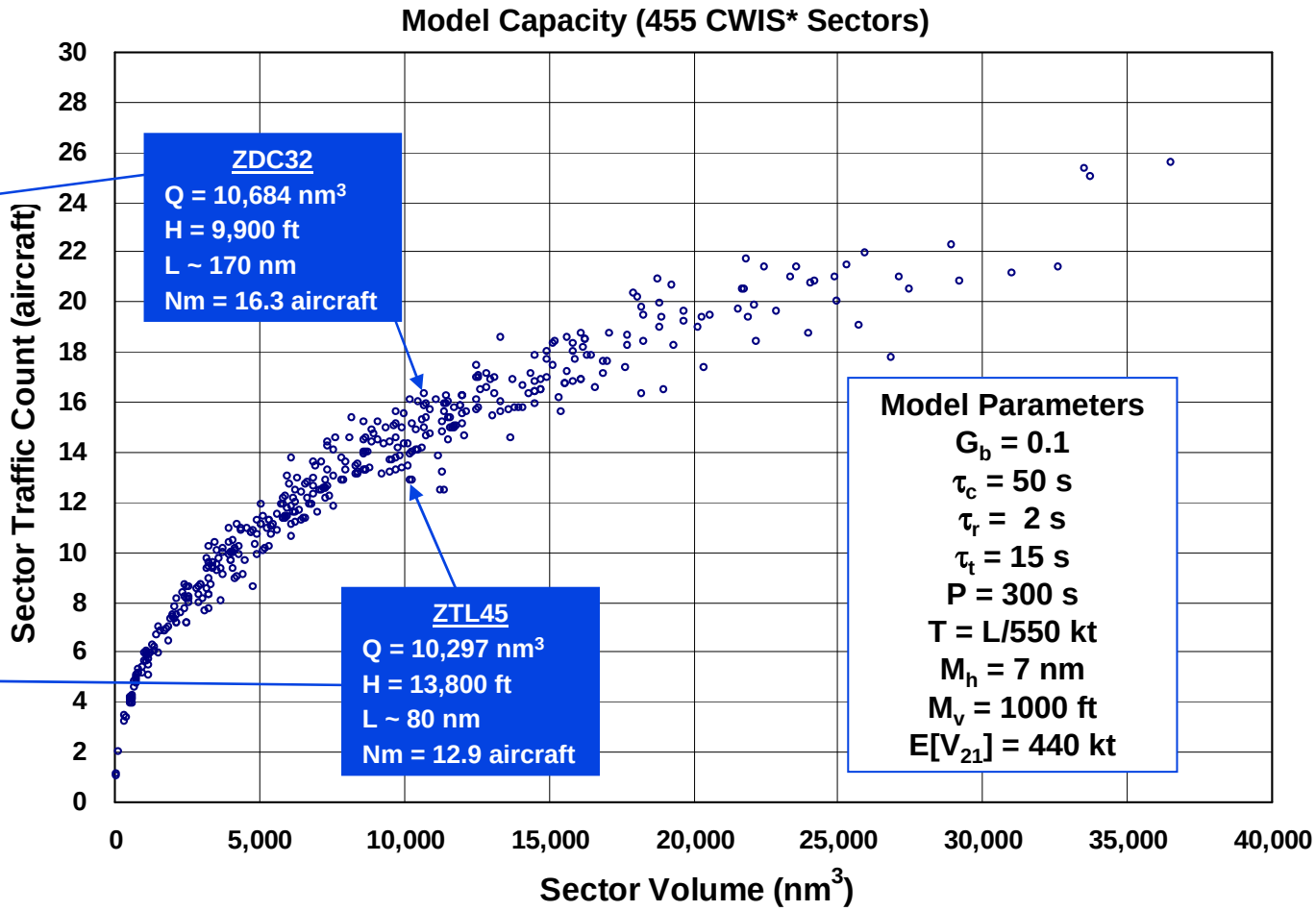
- **Macroscopic approach**
  - **Invert workload equation to calculate capacity bound N_{max}**
  - **Calculate N_{max} for a large number of sectors**
  - **Fit service times to match N_{max} to observed peak sector traffic**

* Schmidt, David K., "A Queuing Analysis of the Air Traffic Controller's Work Load", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-8, No. 6, June 1978.
** Majumdar, Arnab and Ploak, John, ""Estimating Capacity of Europe's Airspace Using a Simulation Model of Air Traffic Controller Workload", Transportatoin Research Record 1744, Paper No. 01-3250, 2001

Sector Capacities from Model



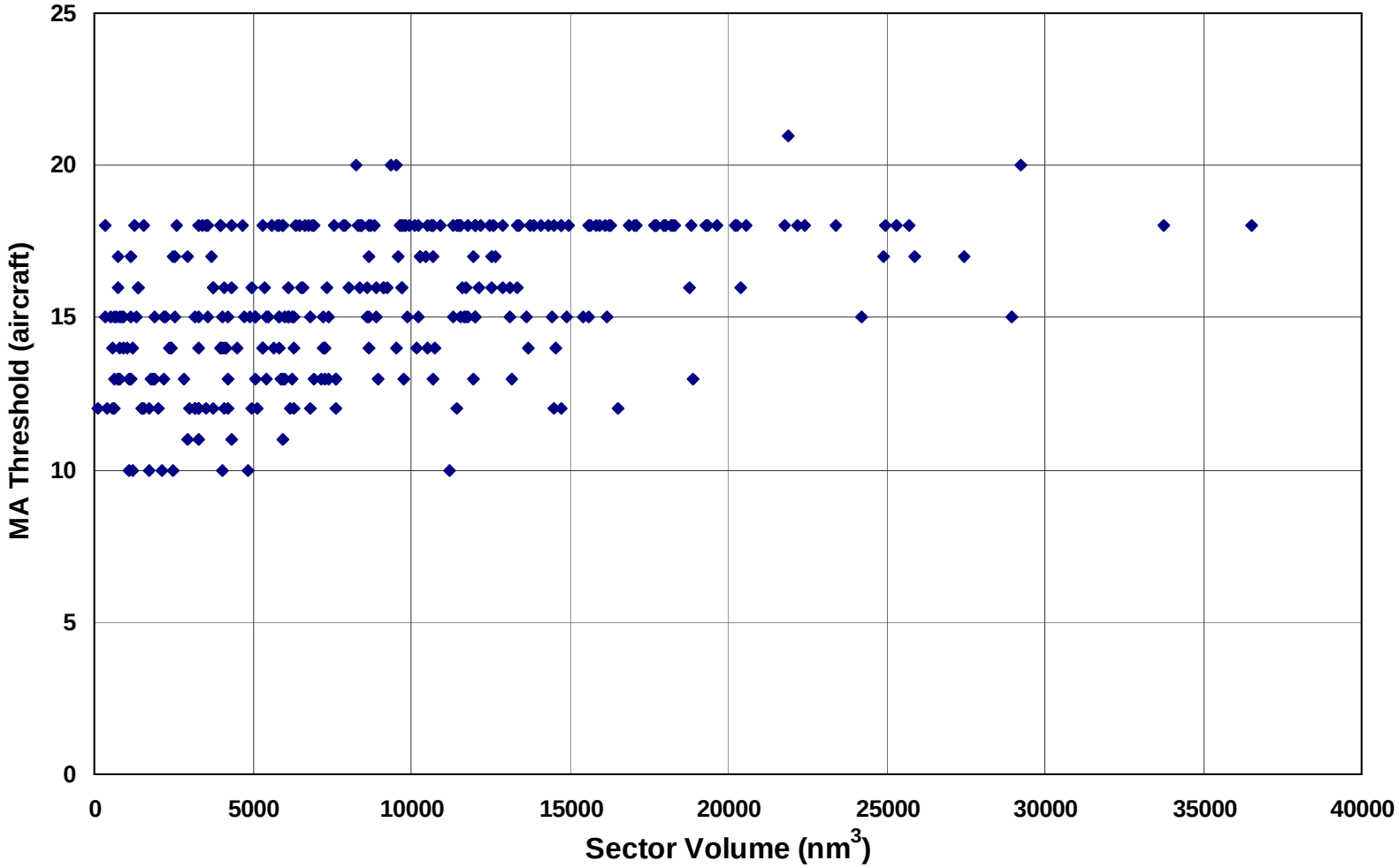




Capacity varies as ~ (sector volume)$^{1/2}$
At a given volume, elongated sectors have higher capacity

* Corridor Integrated Weather System Domain in Northeast US

FAA Monitor Alert Parameters - CIWS Sectors



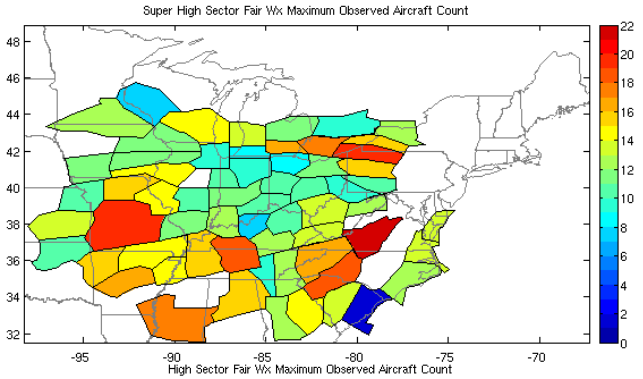
Monitor Alert Parameter ~ independent of sector volume

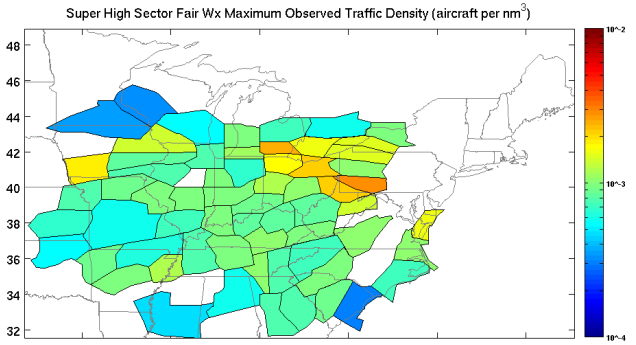
CIWS Sector Peak Traffic

Aircraft Count

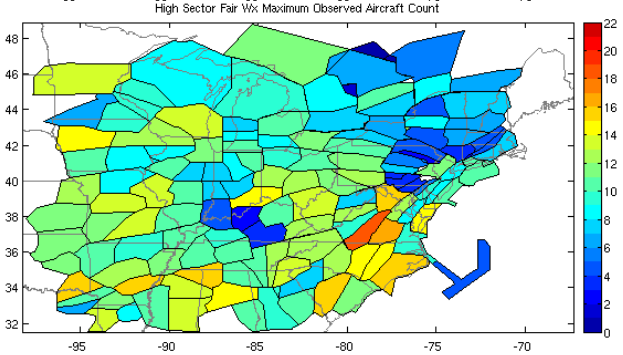
Aircraft Density

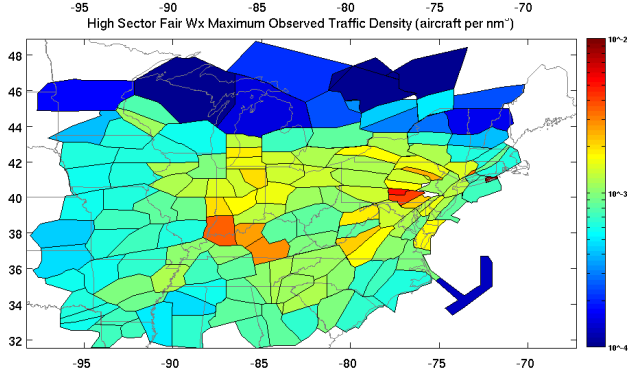
Super High



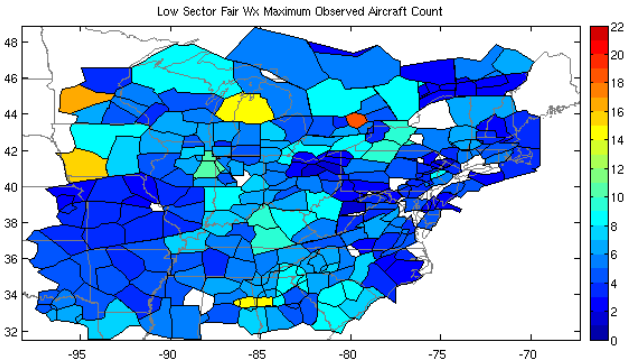


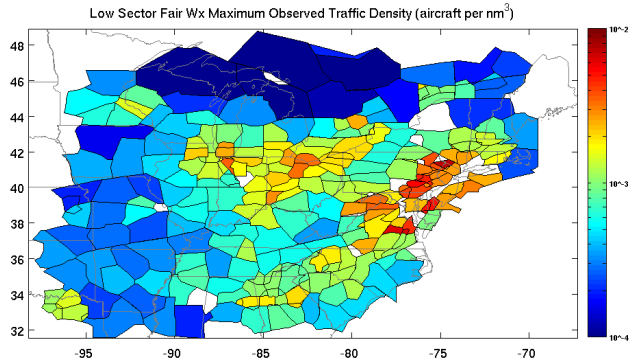
High



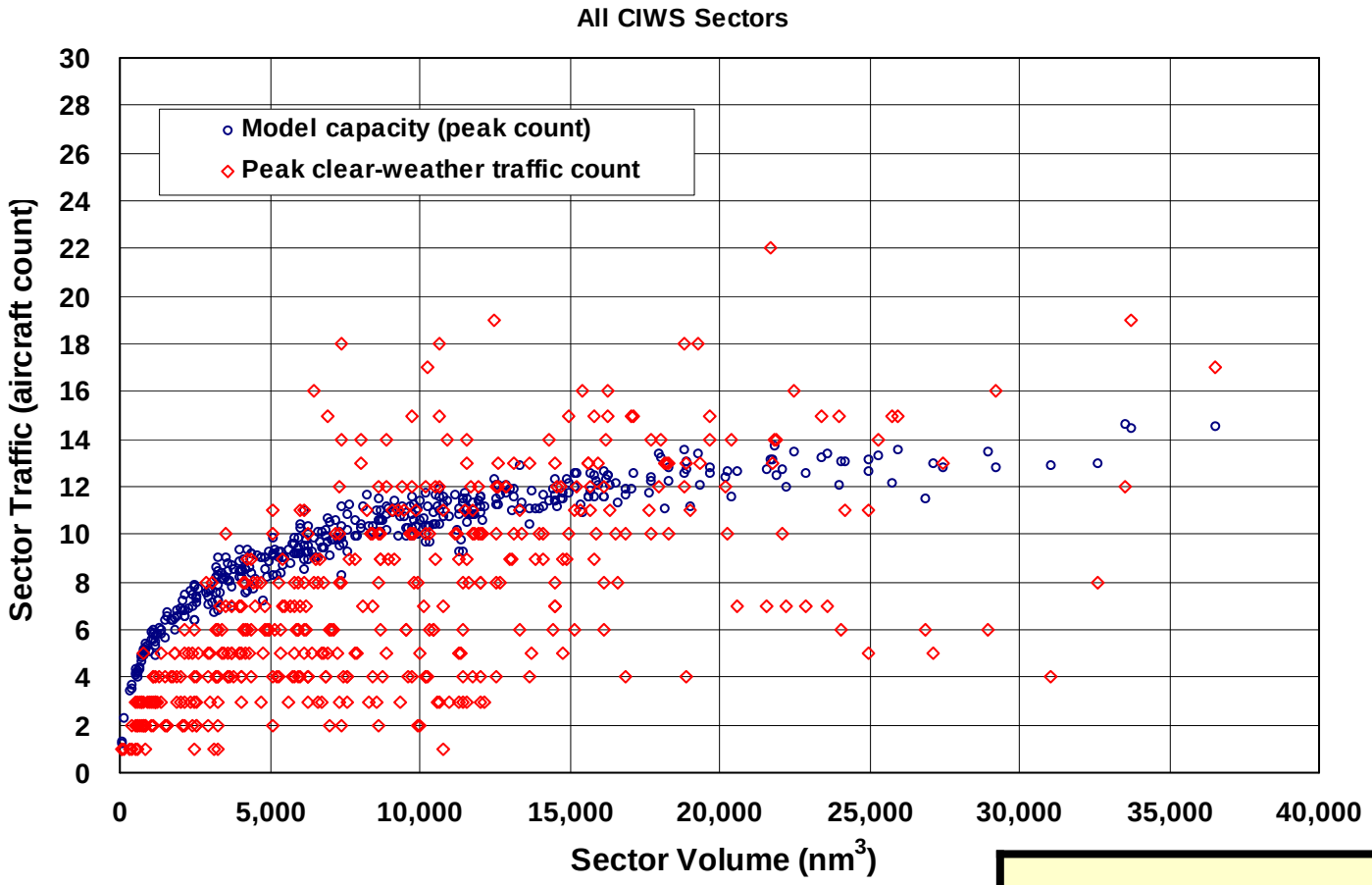


Low





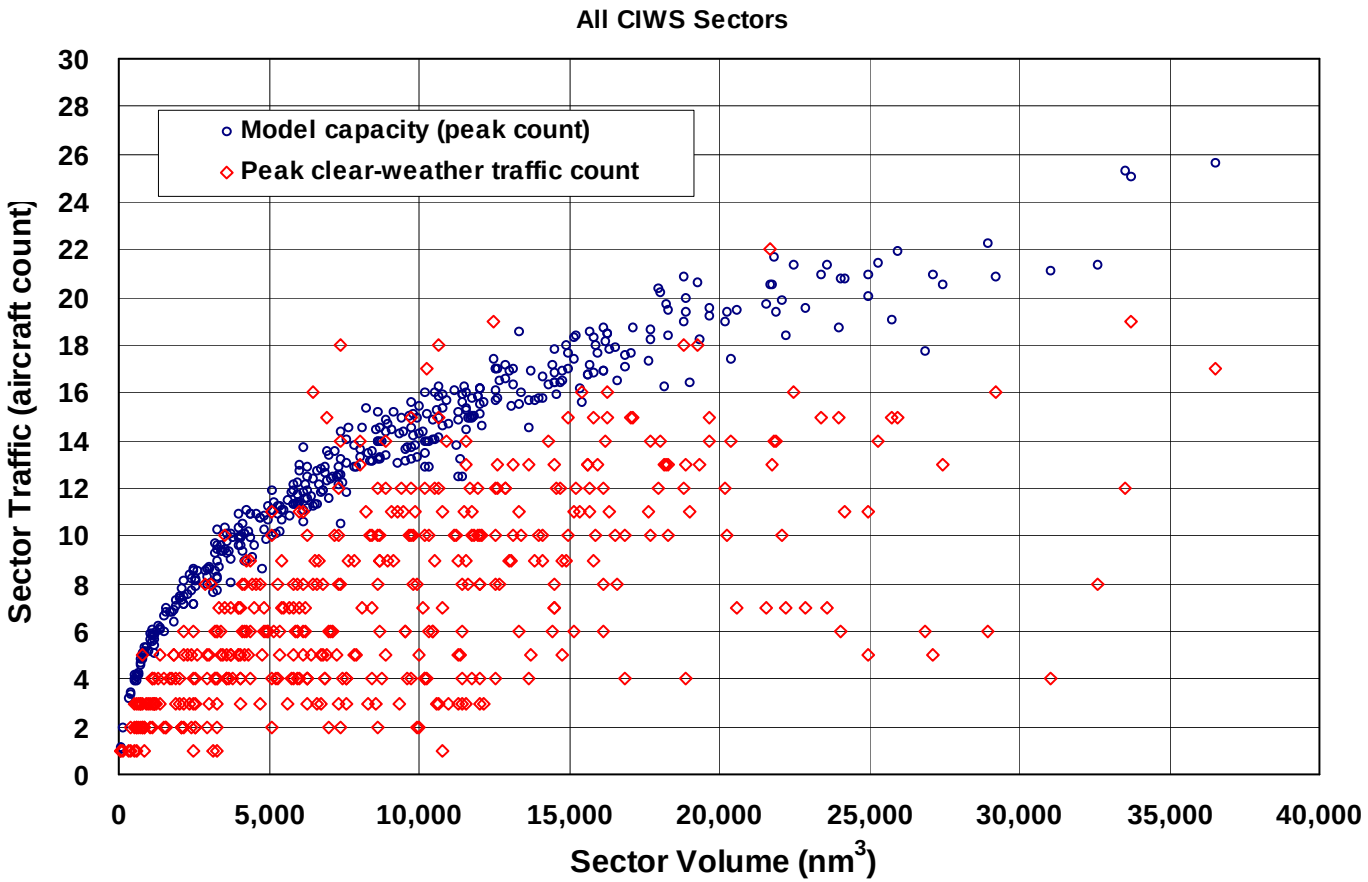
Model Capacities and Observed Counts
(Original Parameter Estimates)



Original parameter estimates

tt=	15	transit work time/aircraft (s)
tc=	50	conflict work time/aircraft (s)
tr=	10	recurring work time/aircraft (s)
Mh=	5	(miles)

Fitted Model Capacities and Observed Counts

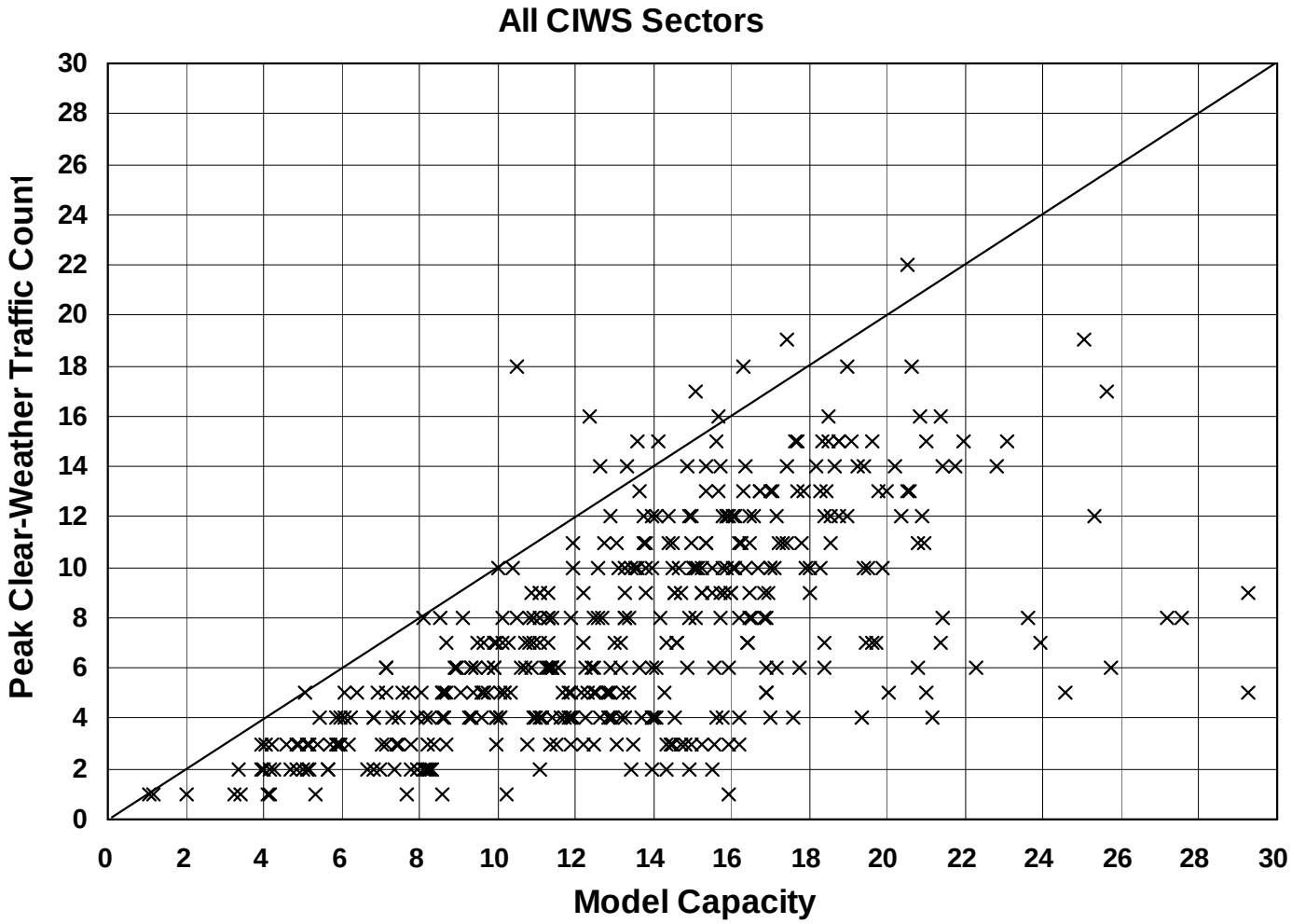


Maximum observed count at each volume fits model bound.
Most sectors operate below capacity.

Fitted Model parameters

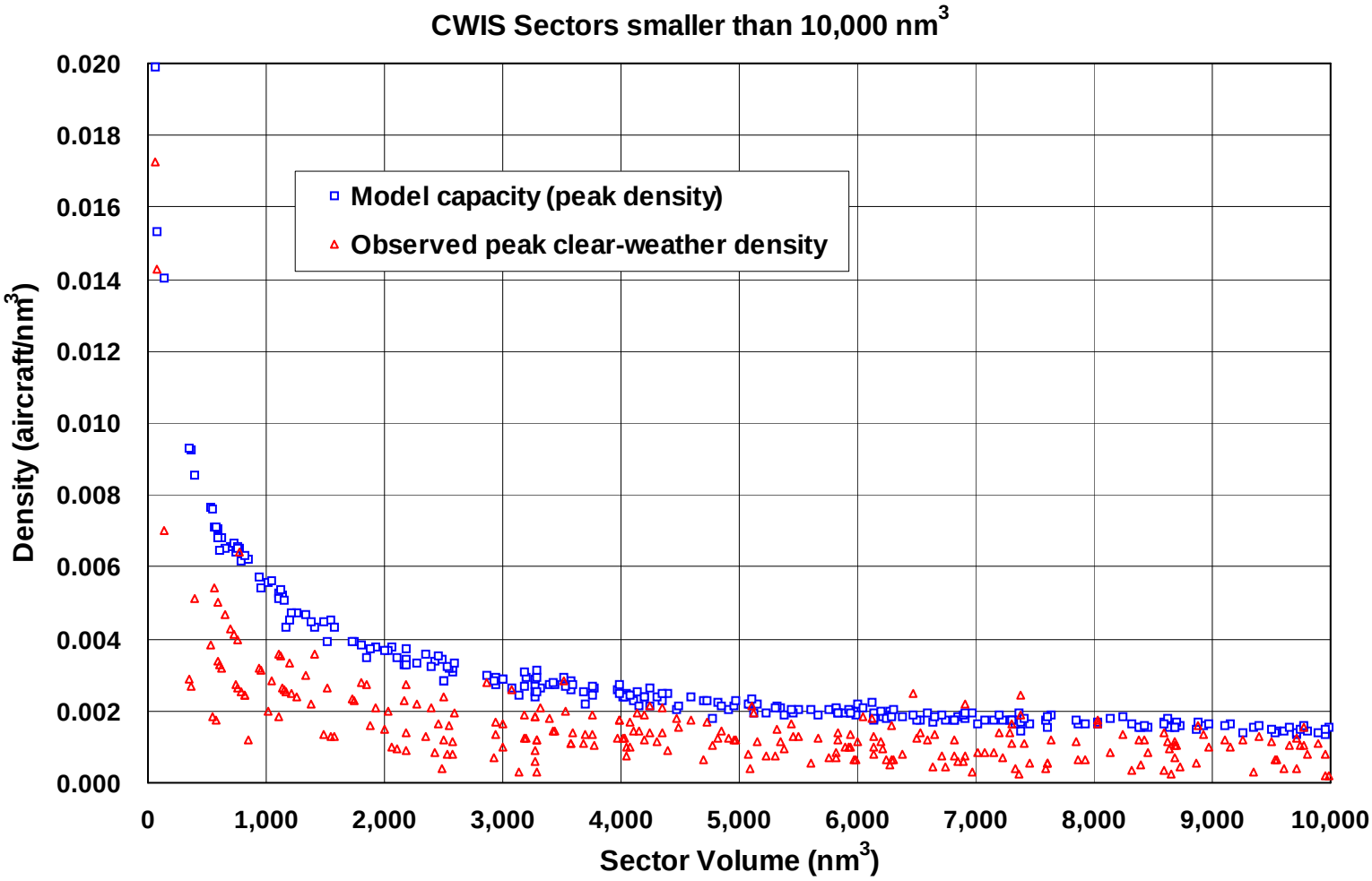
tt=	15	transit work time/aircraft (s)
tc=	50	conflict work time/aircraft (s)
tr=	~~10~~ 2	recurring work time/aircraft (s)
Mh=	~~5~~ 7	(miles)

Observed Counts vs Model Capacities



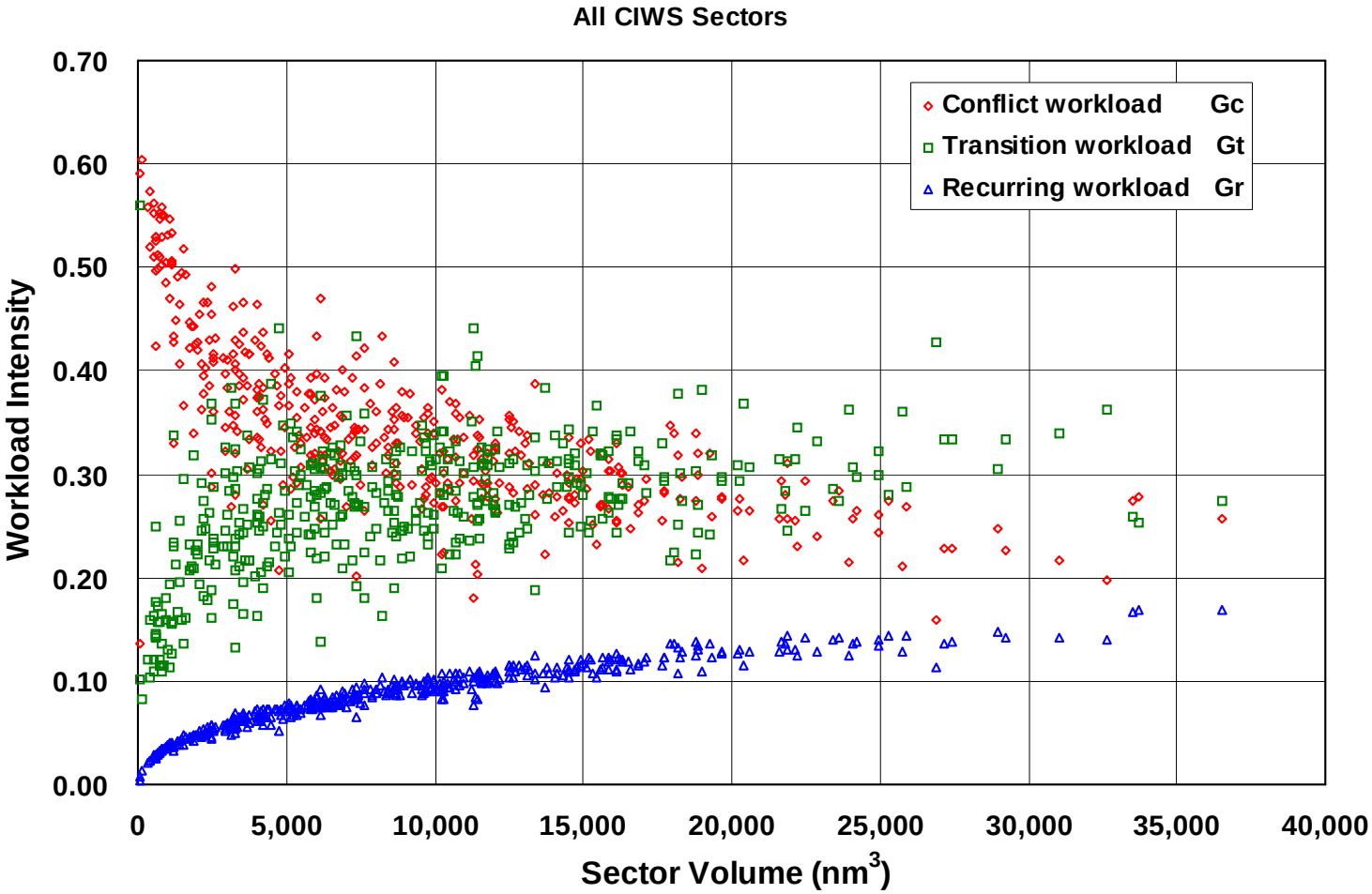
Few sectors operate above the model bound

Traffic Densities



Small sectors handle denser traffic (but with more controllers per aircraft)

Model Workload Components



At capacity, conflict workload dominates in smaller sectors

Observations from Model

- **Most en route sectors operate below model capacity**
  - **lack of demand**
    - **little-used routes**
    - **system flow constraints**
  - **local deviations from model parameters**
    - **higher airspeeds (closing, transit)**
    - **non-longitudinal flow**
    - **increased separation standards (horizontal, vertical)**
- **Large sectors improve workplace efficiency (aircraft/controller)**
- **Small sectors handle higher traffic densities**

Conclusions

- **Macroscopic workload model fits observed peak traffic data**
  - **operationally reasonable service times**
  - **all sector shapes and volumes**

- **Explains observed relationships**
  - **utility of small sectors in dense airspace**
  - **non-linear sector capacity growth with volume**

- **Applications**
  - **replacement for “declared” capacity**
  - **real-time sector capacity estimation**
  - **tool for airspace design**
  - **guidance for ATM research**

Next Steps

- **Include traffic information**
  - **Vertical motion**
    - **Will increase conflict frequency**
  - **Mean transit time**
    - **Will increase transit frequency (usually)**
- **Examine more sectors**
  - **U.S.**
  - **Europe**

END