# Collaborative Systems Thinking:
## Uncovering the rules of team-level systems thinking

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# Agenda

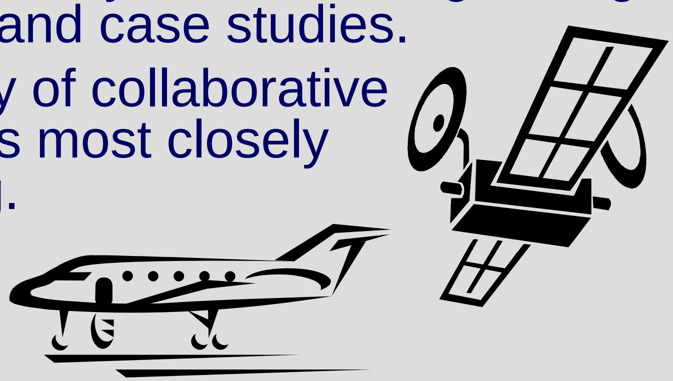
- Research Question
- Defining Systems Thinking
- Motivation
- Methodology
- Results
- Implications of Research
- Conclusions and Future Work

# Research Questions

1. What is collaborative systems thinking and how does it differ from individual systems thinking?
2. What are the empirically generalized traits of systems thinking teams within the context of the aerospace industry?
3. What observed mechanisms correlate with collaborative systems thinking?

Objectives:

- To describe team-based, or collaborative, systems thinking through an exploration of literature, interviews, and case studies.
- To propose an initial explanatory theory of collaborative systems thinking, identifying those traits most closely linked to collaborative systems thinking.






Massachusetts Institute of Technology

# What is Systems Thinking?

A framework for systems with four basic ideas: emergence, hierarchy, communication and control. Human activity concerns all four elements. Natural and designed systems are dominated by emergence. (Checkland 1999)

A method of placing the systems in its context and observing its role within the whole. (Gharajedaghi 1999)

A skill to see the world as a complex system and understanding its interconnectedness. (Sterman 2000)

A skill of thinking in terms of holism rather than reductionism. (Ackoff 2004)

A method and framework for describing and understanding the interrelationships and forces that shape system behavior. (Senge 2006)

Systems thinking is utilizing modal elements to consider the **componential**, **relational**, **contextual**, and **dynamic elements** of the **system** of interest. (Davidz 2006)

Component Complexity | Interrelationships | Context | Emergence | Wholes

*R. Ackoff. Transforming the Systems Movement. Opening Speech at 3rd International Conference on Systems Thinking in Management, May 2004. Philadelphia, PA.*
*P. Checkland. Systems Thinking, Systems Practice, Soft Systems Methodology: A 30-year retrospective. John Wiley and Sons, West Sussex, England, 1999.*
*J. Gharajedaghi. Systems Thinking: Managing chaos and complexity. Butterworth-Heinemann, Burlington, MA, 1999.*
*P. Senge. The Fifth Discipline. Doubleday, New York, NY, 2006.*
*J. Sterman. Business Dynamics: Systems thinking and modeling for a complex world. McGraw-Hill, New York, NY, 2000.*
*H. Davidz. Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers. PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 2006.*

# What is Systems Thinking?

**Systems thinking is considering the system, its components, interrelationships, context, and dynamic behavior during engineering design**

Component Complexity

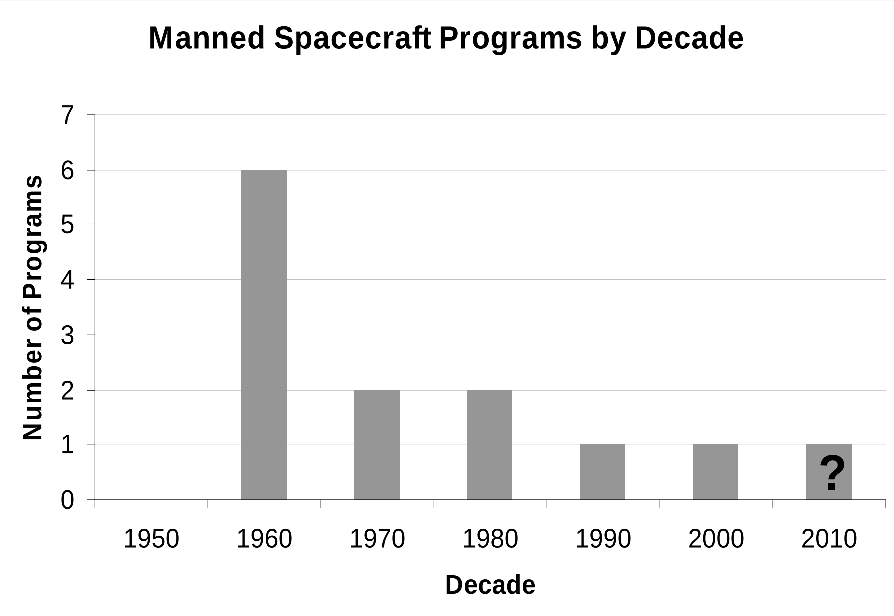
Interrelationships

Context

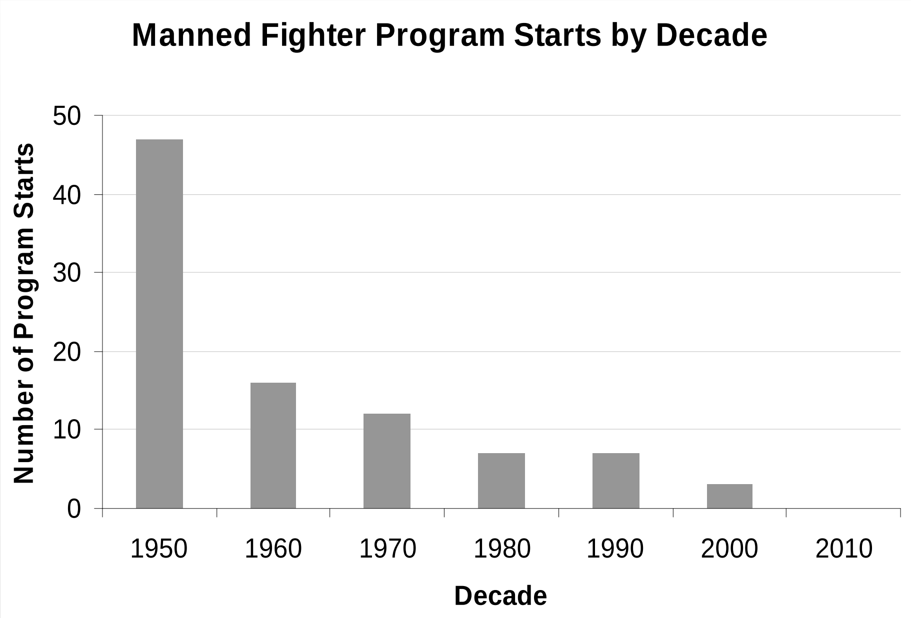
Emergence

Wholes

# Motivation: Fewer Systems Opportunities

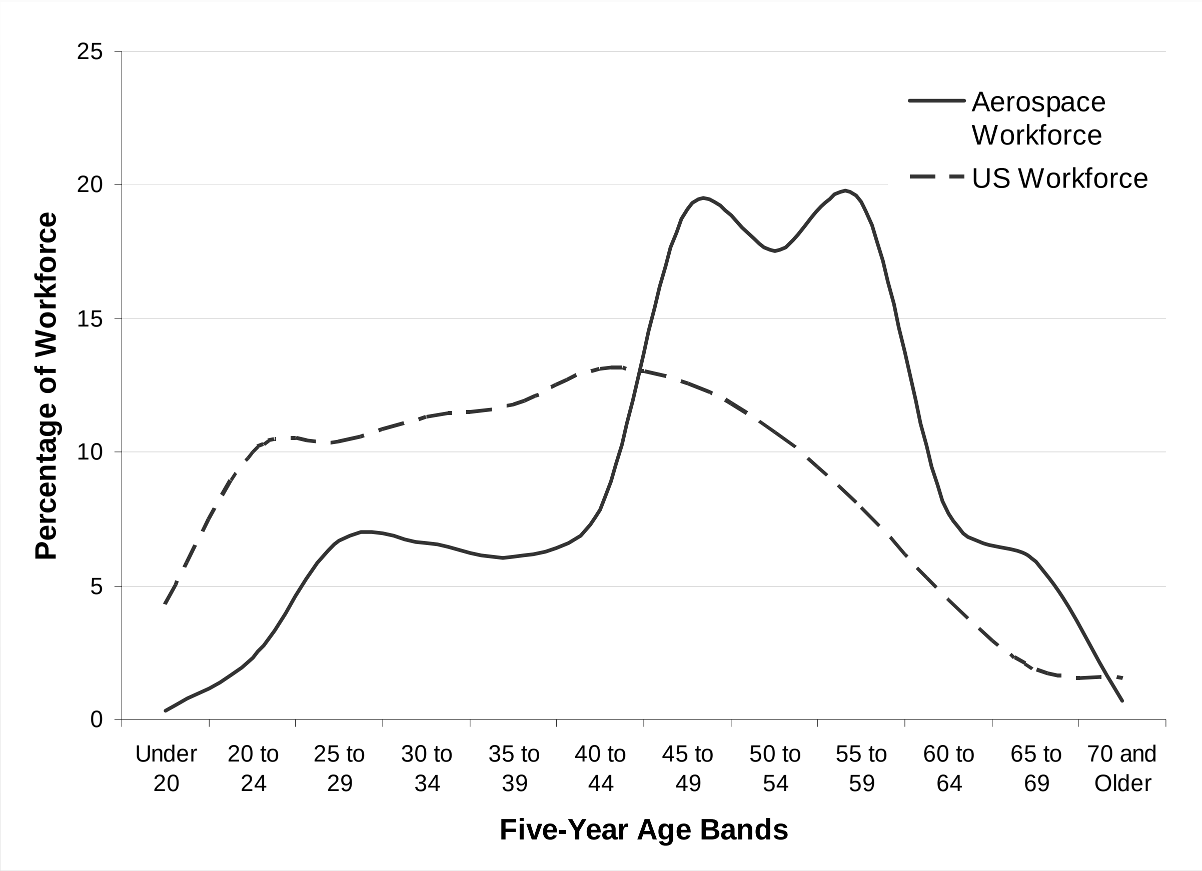



V. Neal, C. Lewis, and F. Winter, *Spaceflight.* Macmillan, New York, 1995.




E. Murman et al., *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*. Palgrave, New York, 2002.

# Motivation: A Workforce Nearing Retirement




D. Black, D. Hastings, and the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration. Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim report, 2006.

# Methodology: Research Structure

Using multiple types of data facilitates triangulation (Robson 2002)

Different types of data illuminate different aspects of a phenomenon.

Interviews, surveys, qualitative and quantitative data needed to describe collaborative systems thinking.

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Phase 1: Literature Review
- Identify relevant constructs
- Establish framework for further inquiry

Phase 2: Pilot Interviews
- Validation of framework
- Formulate a definition for collaborative systems thinking

Phase 3: Case Studies
- Empirical data collection
- Basis for theory development

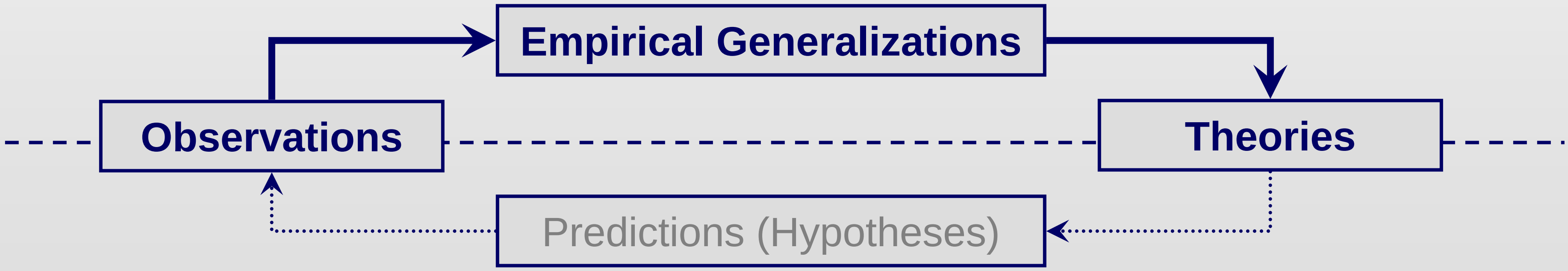
Phase 4: Validation Activity
- Test explanatory power of theory on new cases
- Ensure results are generalizable beyond initial cases

*C. Robson, "Real World Research", Blackwell Publishing, Malden, MA, 2002.*

# Methodology: Grounded Theory

Grounded Theory is the 'top half' of the scientific process (Glaser and Strauss 1967)

- Method is exploratory in nature
- Starts with a question
- Execution is based in observation
- Ends with an explanatory theory and set of hypotheses




B. Glaser and A. Strauss. *The Discovery of Grounded Theory: Strategies for qualitative research.* Aldine Publishing Company, Chicago, IL, 1967.

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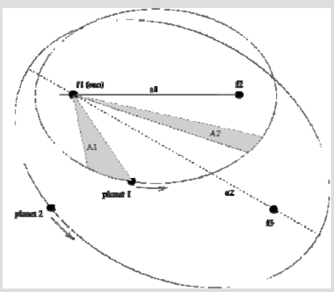
Copernicus’s Heliocentric Cosmology (c1500)



Kepler’s Laws of Planetary Motion (c1600)

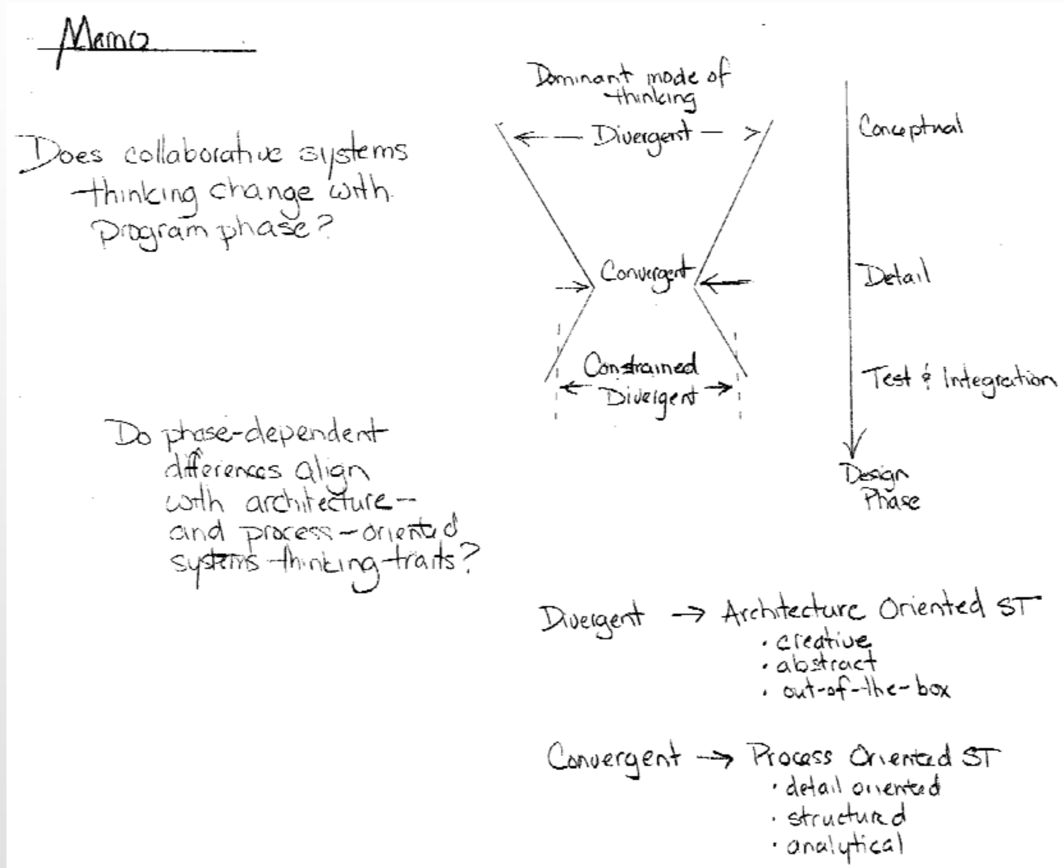
Newton’s Laws of Gravity (c1680)

Genetics and Modern Medicine

# Methodology: Qualitative Analysis

Descriptive Analysis

- Memo writing
  - Definition: record of researcher thoughts, data interpretations and questions
  - Code, theoretical, operation, diagrams
- Coding
  - Definition: breakdown of textual data into central ideas with goal of creating relational structure for interpreting data and explaining observations
  - Open, axial, and selective coding
- Tools
  - MaxQDA




K. Eisenhardt. Building Theories from Case Study Research. *The Academy of Management Review*, 14(4):532{550, 1989.
D. Krathwohl, editor. *Methods of Educational and Social Science Research*. Waveland Press, Inc., Long Grove, IL, 1998.
C. Robson. *Real World Research*. Blackwell Publishing, Malden, MA, 2002.
R. Stebbins. *Exploratory Research in the Social Sciences*, volume 48 of *Sage University Papers Series on Qualitative Research Methods*. Sage Publications, Thousand Oaks, CA, 2003.

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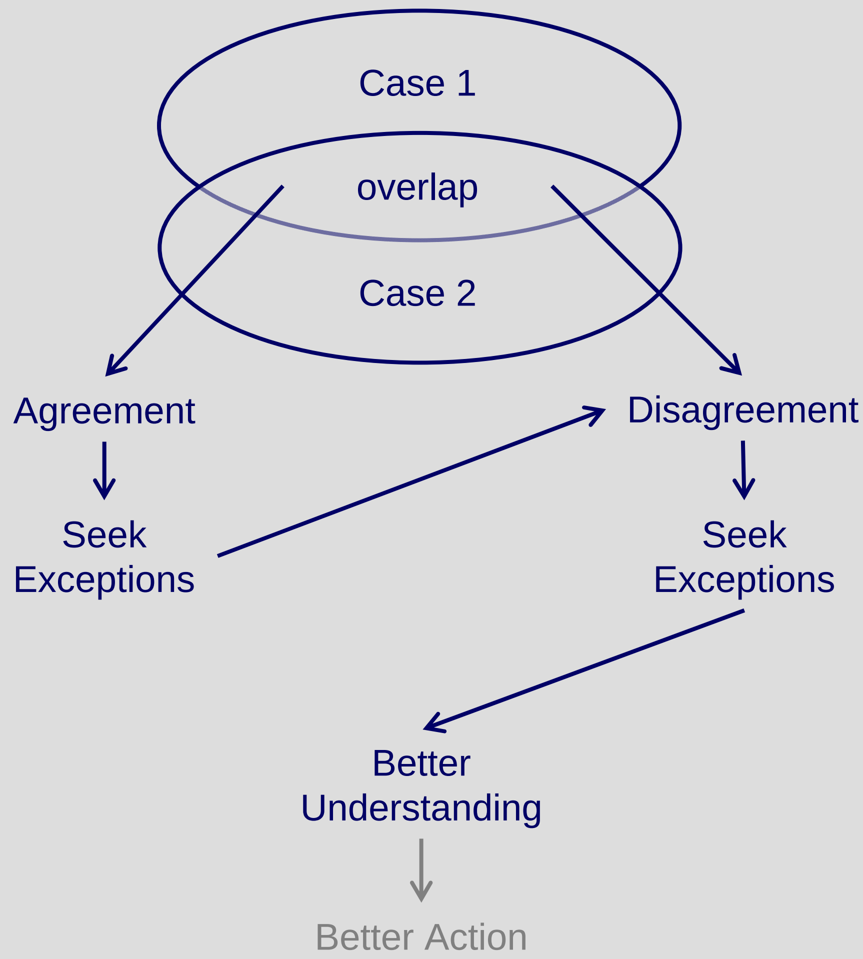


# Methodology: Quantitative Analysis

**Descriptive Analysis**

- Survey statistics
- 'Distance' between case studies
  - Based on grouping teams based on distance between vectors describing the teams
  - Used complete linkage method

**Inferential Analysis**

- Multivariate Regression Analysis
  - Identify regressor variables that best explain team-reported CST: A model explaining CST observations
  - Use new case studies and model to validate chosen variables are generalizable

Equation governing 'distance' matrix

$$\begin{pmatrix} - & \delta_{12} & \delta_{13} & \cdots & \delta_{1j} \\ \delta_{21} & - & \delta_{23} & \cdots & \delta_{2j} \\ \delta_{31} & \delta_{32} & - & \cdots & \delta_{3j} \\ \vdots & \vdots & \vdots & - & \vdots \\ \delta_{j1} & \delta_{j2} & \delta_{j3} & \cdots & - \end{pmatrix}$$

$$\delta_{ji} = \sqrt{\sum_{k=1}^{P} (x_{ik} - x_{jk})^2}$$

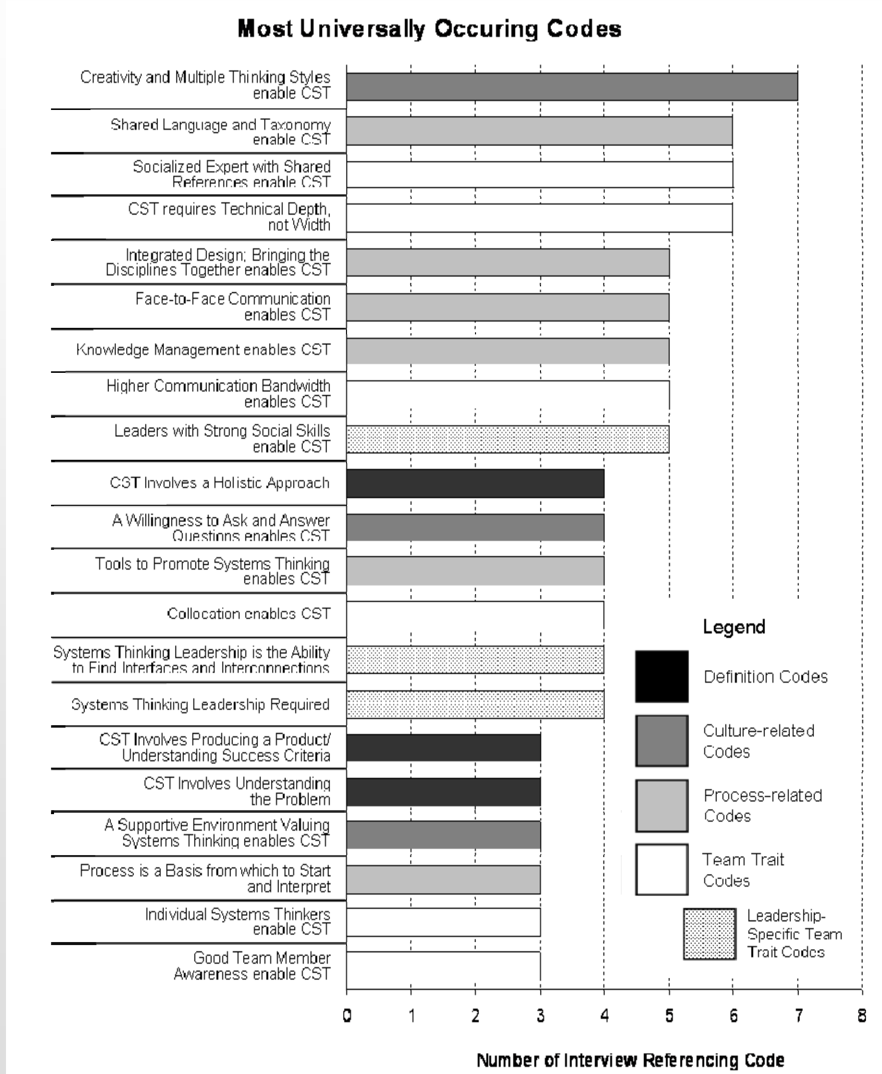
Equations describing multivariate regression

$$y_i = \alpha + \beta_1 x_{i1} + \beta 2 x_{i2} + \ldots + \beta k x_{ik} + e_i$$

$$\hat{y} = a + b_1 x_1 + \ldots + b_k x_k$$

# Defining Collaborative Systems Thinking: Pilot Interview Results

- 8 Pilot Interviews
- Most universally cited concepts
  - Definition
    - Requires a holistic approach
    - Involves producing a product
  - Culture
    - Creativity is an enabler
    - A willingness to ask and answer questions
  - Process
    - Provides a shared language and taxonomy
    - Bringing disciplines together early is an enabler
  - Team Traits
    - Well-socialized experts enable CST
    - High communication bandwidth



# Defining Collaborative Systems Thinking: Basis in Literature

| Literature Concepts | PI Concepts | Central Concept |
|---|---|---|
| Team thinking is valid concept based on shared processing of information. (Salas and Fiore 2004) | "A willingness to ask and answer questions" | **Team Interaction** |
| Team thinking is supported by interactions that create pointers to knowledge held within team. (Wegner 1986) | | |
| Creative environments/multiple perspective support systems thinking. (Thompson and Lordan 1999) | "Creativity is an enabler" | **Multiple Thinking Styles / Design Process** |
| Normative design processes that utilize divergent and convergent thinking are superior for handling complexity. (Stempfle and Badke-Schaub 2002) | "Process provides a shared language and taxonomy" | |
| Multiple design languages (e.g. sketching, modeling, etc) are required to communicate design knowledge. (Dym et al. 2005) | "High communication bandwidth enables CST" | **Multiple Communication Media** |
| Emphasis on end product a differentiator between successful and failed product development teams. (Dougherty 1990) | "Involves producing a product" | **Importance of an End Product** |

# Collaborative Systems Thinking Defined

Collaborative systems thinking is an emergent behavior of teams resulting from the **interactions of team members** and utilizing a variety of **thinking styles, design processes**, tools and **communication media** to consider the system, its components, interrelationships, context, and dynamics toward **executing systems design**.

(Lamb, 2008)

C. Lamb Systems Thinking as an Emergent Team Property. IEEE Systems Conference, Toronto, Canada, April 2008

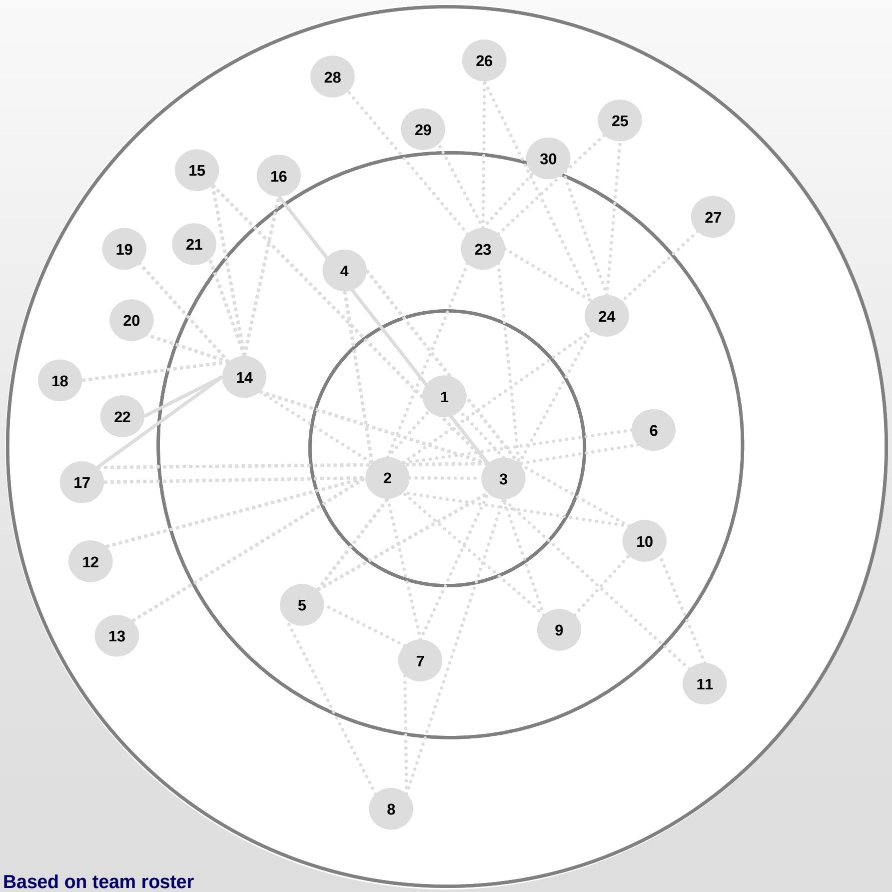
# Empirically Generalized Traits: Team Structure

Collaborative Systems Thinking (CST) Teams have 3 Membership Categories

- Strong systems leadership
  - 2-3 individuals acting in coordinated manner
  - Strong individual systems thinkers with complementary social and technical skills
- Developing systems professionals
  - Functional background
  - Demonstrated ability to ask questions outside their functional background
  - Convey functional information to team at correct level of detail (translators of technical information)
- Functional specialists
  - Have concurrent membership in several teams
  - Participation driven by when expertise is required
  - Role on team changes with design stage

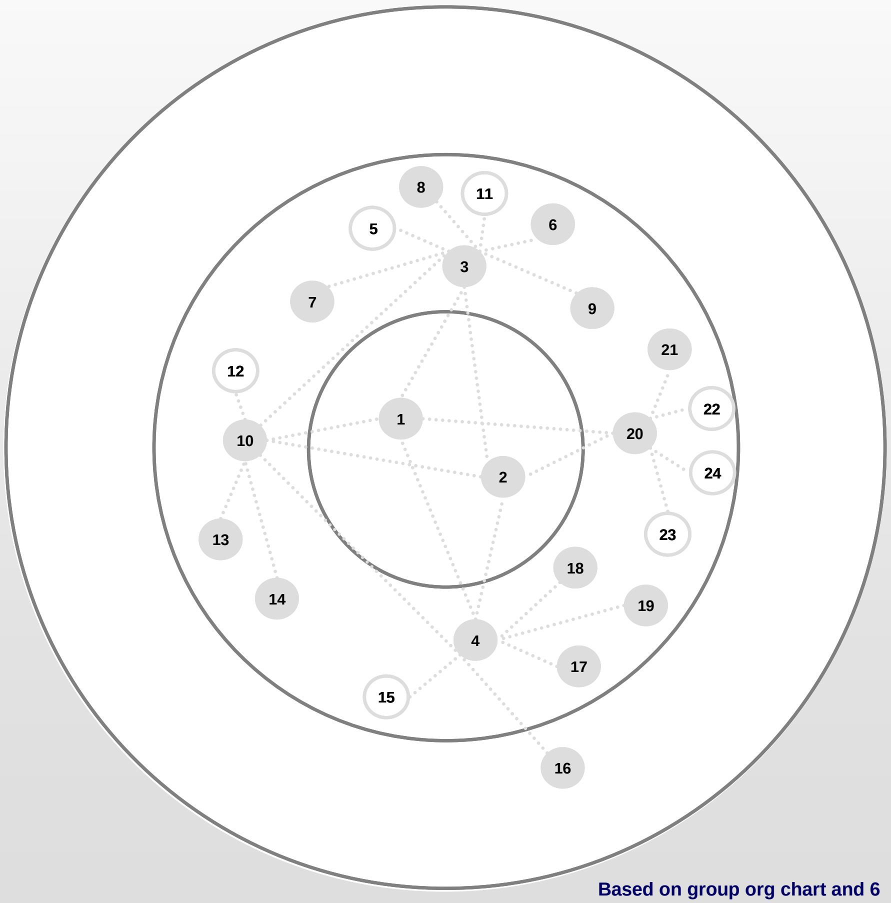
# Empirically Generalized Traits: Team Structure (2)

CST Rated 7.9/10
(Std 0.9)



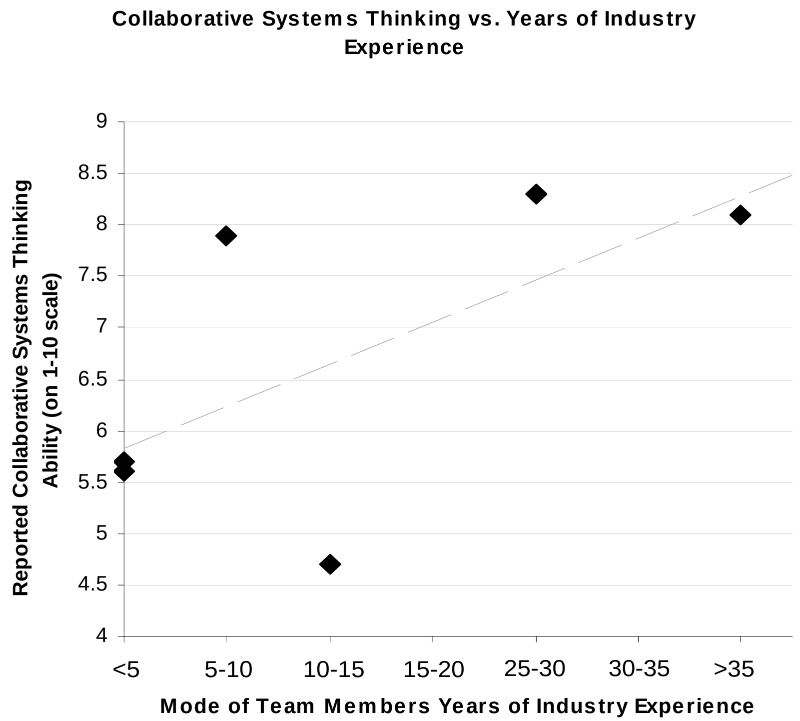

Based on team roster

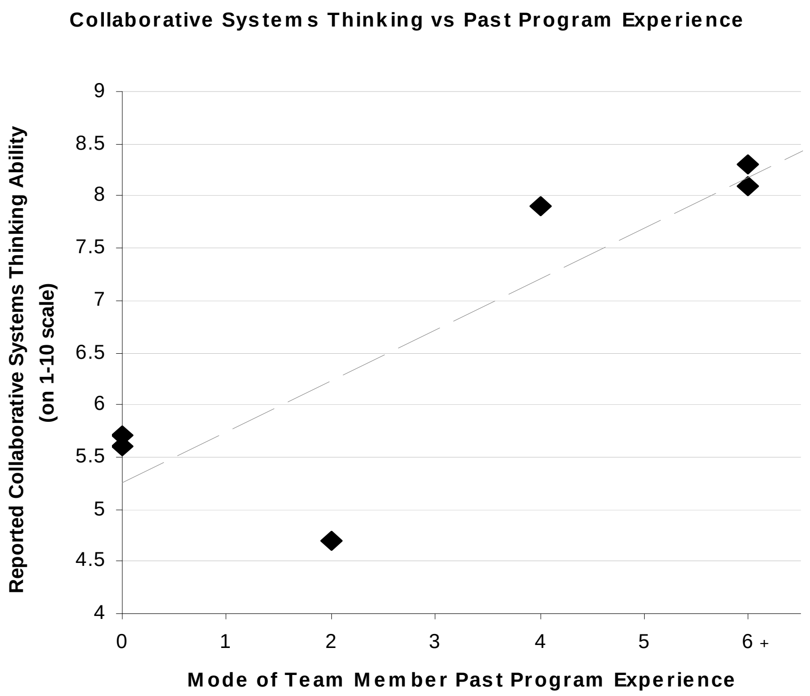
CST Rated 5.6/10
(Std 2.1)




Based on group org chart and 6 interviews

# Empirically Generalized Traits: Experience



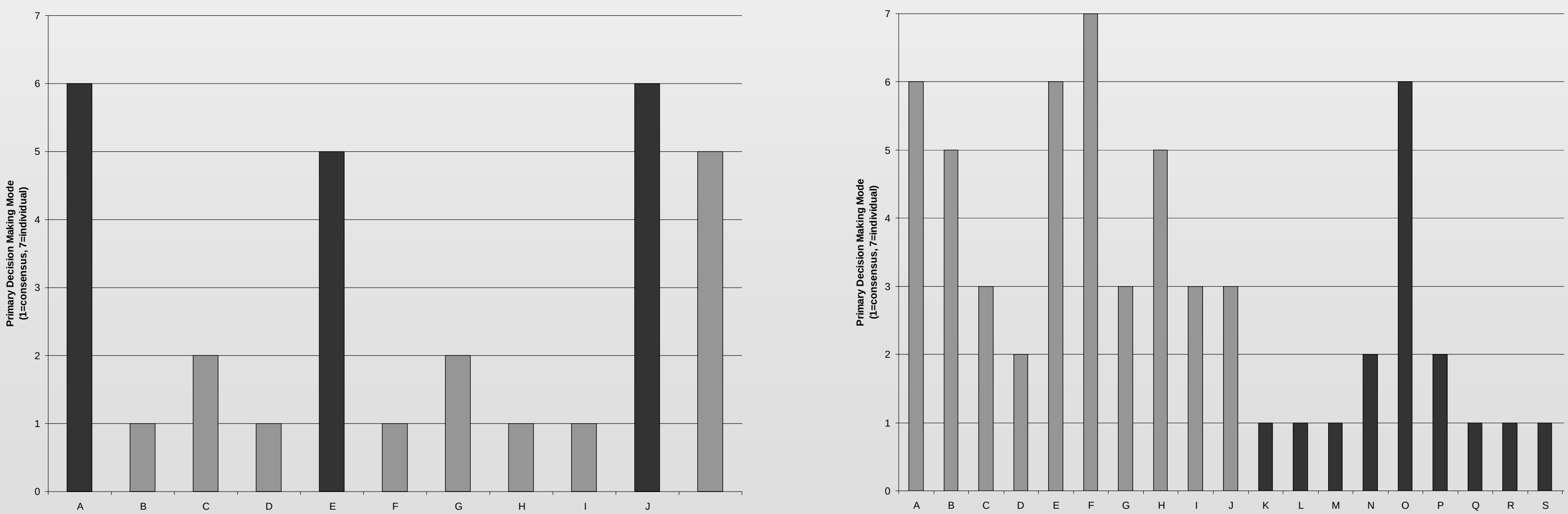




- Years of experience is an important indicator of collaborative systems thinking
- Past program experience is a better indicator of collaborative systems thinking

# Empirically Generalized Traits: Culture

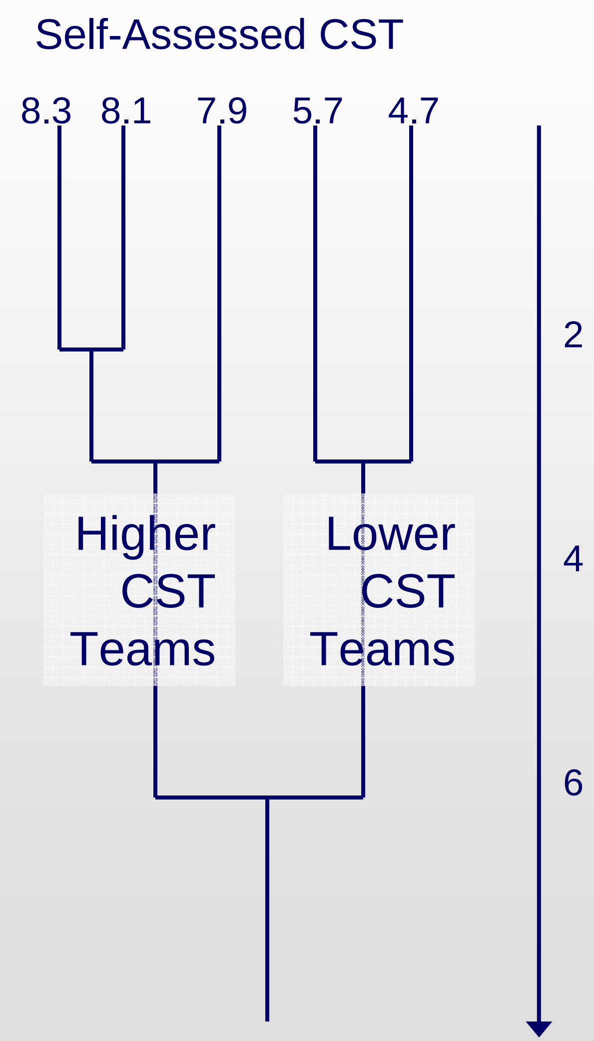
- CST teams have more creative environments
  - –E.g. Challenging work, collaborative work environment, decision freedom, access to resources. (Thompson and Lordan 1999)
- Technical and social leadership are important on CST teams
- Consensus decision making is more common on CST teams
  - –Collocation affects perceptions of how decisions are made within team

Perceptions of Team Decision Making (1—Consensus; 7—Individual)



# Mechanisms Explaining CST Observations

| Concept | Correlation to CST |
|---|---|
| Relative Frequency of Consensus Decision Making | 0.89 |
| Creativity: Realistic Schedule | 0.79 |
| Past Similar Program Experience | 0.79 |
| Team Environment: Trust in Team Member Abilities | 0.78 |
| Creativity: Collaborative Environment | 0.65 |
| Perceived Relevance of Standard Process | 0.60 |
| Relative Frequency of Face-to-Face Interactions | 0.53 |



# Recap: Research Questions

1. **What is collaborative systems thinking and how does it differ from individual systems thinking?**
2. **What are the empirically generalized traits of systems thinking teams within the context of the aerospace industry?**
3. What observed mechanisms correlate with collaborative systems thinking?

Objectives:

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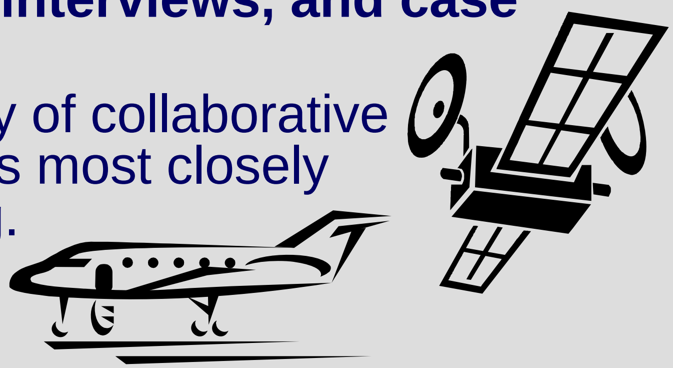

# Implications for Industry and Academia

1. Program experiences are essential
   – Industry should provide more opportunities to see and participate in the entire system lifecycle
   – Example: Phaeton early career hire rotation program (Reiber et al. 2008)
   – Secondary Benefits: Shorter program cycles improve workforce retention (Pieronek and Pieronek 2004)
2. The social and technical components of engineering need to be balanced
   – Engineering coursework and promotion decisions overemphasize the technical aspects of engineering
   – Teams should be formed on the basis of both technical contributions and social roles
   – The best systems engineers and leaders balance the social and technical needs and interactions within their programs (Griffin 2007; Derro 2008)

R.R. Reiber, et al., "Bridging the Generation Gap: A Rapid Early Career Hire Training Program," *AIAA Space 2008 Conference*, AIAA, Washington D.C., 2008.
C. Pieronek and T. Pieronek. Attracting Women to Careers in Aerospace Using Lessons Learned in Higher Education. In *Proc. AIAA Space 2004*, San Diego, CA, September 2004.
M. Griffin. System Engineering and the "Two Cultures" of Engineering. Purdue University Boeing Lecture, March 2007.
M.E. Derro, "NASA Systems Engineering Behavior Study," URL:www.nasa.gov/pdf/291039main_NASA_SE_Behavior_Study_Final_11122008.pdf [cited November 20 2008].

# Conclusions and Future Work

- Collaborative systems thinking (CST) is distinct from individual systems thinking
- CST teams have characteristics that differentiate them from non-CST teams
  - Strong systems leadership is present (social and technical)
  - Teams have 3 consistent categories of team membership
  - Team membership have relatively more past program experience
  - Teams are using sketches, models and prototypes more frequently
  - Teams utilize more consensus decision making

- Future Work
  - Validation Case Studies

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  - Develop Simulation Activity to measure and/or foster CST
  - Longitudinal Study
    - Track relative performance of teams; quantify value of CST
    - Role of CST in individual systems thinking development