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### Plus

- Big Data Flows Through NextGen
- Change is Tantalizingly Close for the FAA
- Coping with Adverse Winter Weather

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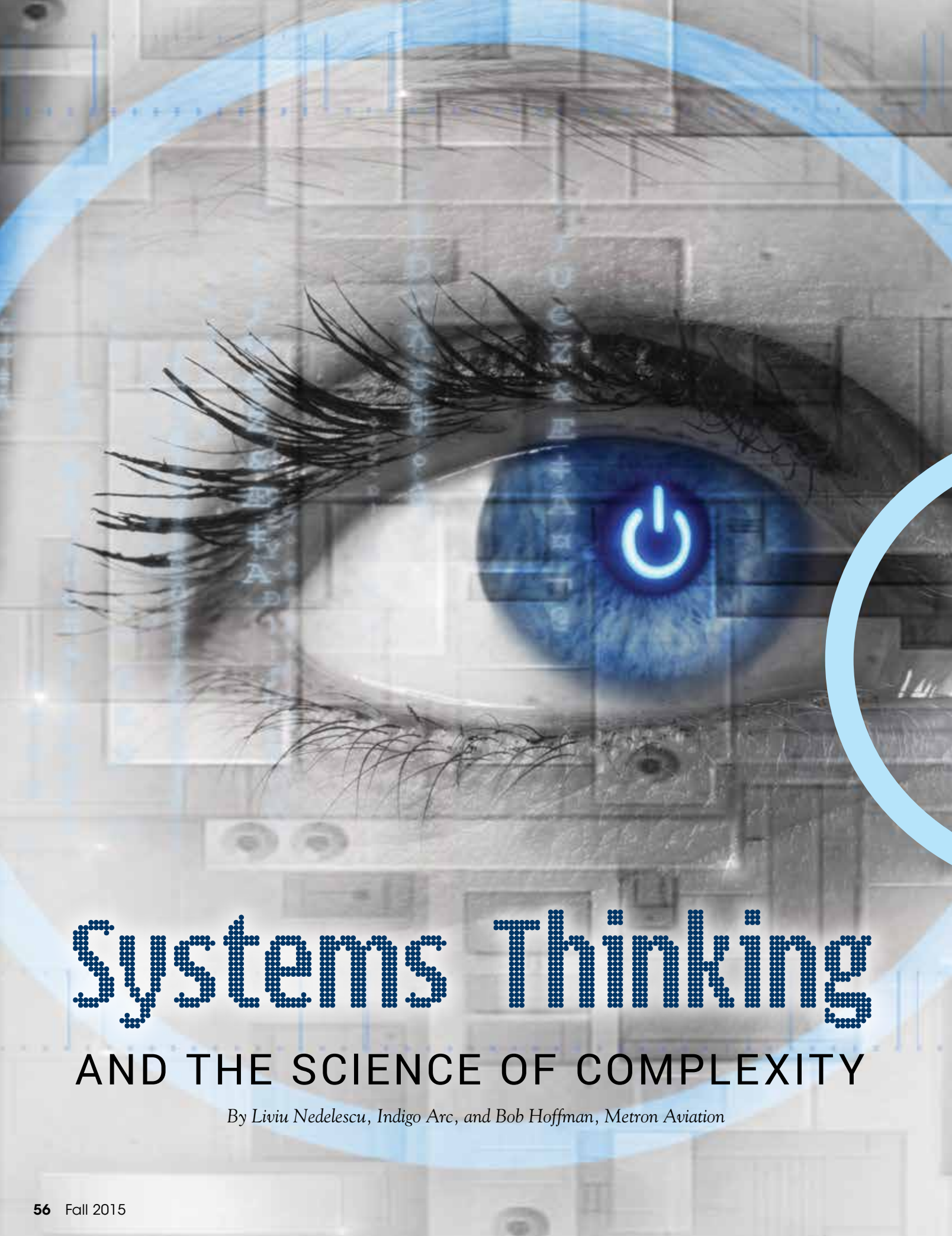


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# Systems Thinking

## AND THE SCIENCE OF COMPLEXITY

*By Liviu Nedelescu, Indigo Arc, and Bob Hoffman, Metron Aviation*

In this paper, we explore the extent to which systems thinking and complexity science can help evaluate progress and potential of advancements in the National Airspace System (NAS). We argue that, being a system of systems, the NAS has reached sufficient complexity that our current understanding must be augmented with examination from the perspective of systems thinking and complexity science. These perspectives allow interactions of component systems to be better understood. In addition, they admit holistic descriptions of the NAS that are difficult to capture by aggregating traditional performance metrics. We propose the customization of complexity and systems thinking principles into a suite of techniques for characterizing NAS evolution. We explore the ability of complexity principles to expose emergent phenomena and how this could be supported by groundbreaking modeling and simulation architectures.

### The Need for Systems Thinking

The U.S. air transportation system is evolving from an arcane air traffic control system to a more modern one that fully capitalizes on recent and impending technology. Indeed, the Next Generation Air Transportation System (NextGen) promises an impressive array of operational improvements, such as higher positioning accuracy, increased capacity and quality of communications, and superior weather forecasting. But is the collective impact of these improvements sufficient to label NextGen as transformative? A truly transformative change comes about when the overall improvement is greater than the sum of the individual improvements. Can we confirm that the benefits derived from NextGen will be greater than the benefits of the operational improvements? Will the improvements converge to a qualitative shift in the system-level operation? Does this qualify as a new paradigm?

We believe these questions exceed the scope of traditional analysis of air transportation systems. While legacy analytic methods focus on detecting quantitative variations such as flight delays, what is needed are ways to broadly characterize the overall state of the system. Systems thinking, which is the process of understanding how systems influence one another within a whole, is ideally suited for this purpose. It can, for example, provide qualitative criteria for characterizing a system-level operation. We exemplify with the pertinent notion of “structure and agency.”

By “structure” we mean the set of operational constraints imposed by the service provider and others to make the system more predictable so that safety can be maintained. As rules, regulations, policies, and procedures are added, structure increases. “Agency,” on the other hand, is the desire for flight operators to achieve their own business and personal objectives, as free from intervention as possible. While operators recognize the collective need for structure, they would generally like to operate with as few constraints as possible. And so, structure and agency co-exist in a state of constant tension, shifting equilibria as substantial changes are introduced.

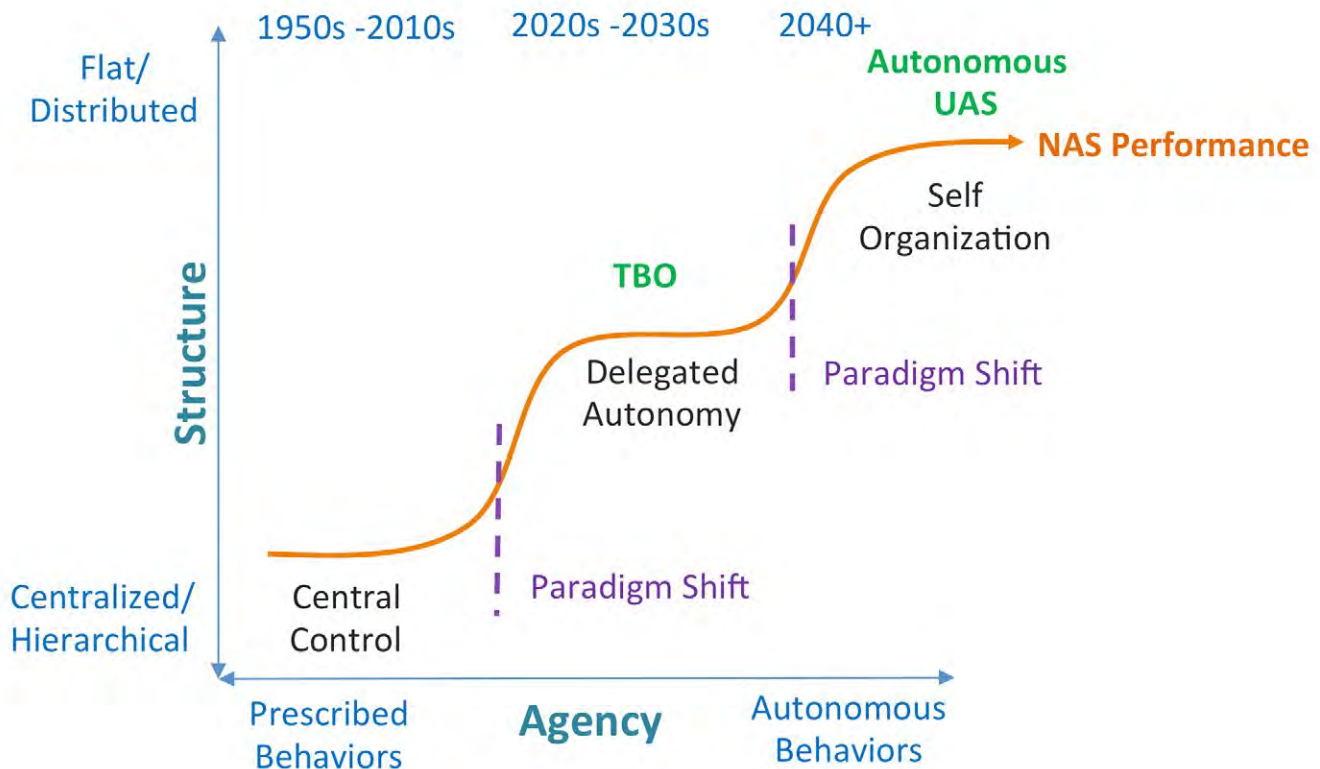
The question of where the airspace system now lies and where it is progressing on the structure-agency continuum is instrumental in qualifying the system-level operation. Figure 1 graphically depicts this question. The horizontal axis displays varying levels of agency, ranging from fewer degrees of freedom (left) to more autonomous behaviors (right). The vertical axis shows varying levels of structure – highly centralized structure (bottom), and more decentralized, distributed structure (top).

We hypothesize the evolution of the NAS from a highly centralized operation with few degrees of freedom for operators (lower left) to a flatter, more distributed configuration with higher degrees of flight autonomy (upper right). Eventually, NextGen improvements such as point-to-point communications (Data Comm) and aircraft self-positioning (ADS-B) might be the stepping stones for extreme forms of agency, such as self-separating, autonomous operations.

We also posit the evolution is not linear, but may rather resemble recognizable leaps in performance, or epochs. Three such epochs are notionally suggested in Figure 1: highly centralized control (1950s to today), trajectory-based operations (near term) and autonomous unmanned operations (far future). This structure-agency plot is but one example of a system-theoretic tool for qualitatively assessing the state and evolution of the NAS.

### Complexity Science as a Means to Understanding NAS Behavior

From medicine<sup>1</sup> to counter-terrorism,<sup>2</sup> and from economics<sup>3</sup> to computing architectures,<sup>4</sup> complexity is entering mainstream awareness. While it can be difficult to describe formally, its observable effects are quite familiar: most of us have experienced



**Figure 1.** A complexity-inspired, performance leap view of NAS transformation

the “going viral” phenomenon and, before social media, there were runs on stocks. These occurrences share an element of surprise and unpredictability that embodies complexity. Disproportionate causation arises from simple first principles: in complex systems, feedback can amplify small effects until they manifest globally.

Safety management is perhaps the first area in aviation that should consider complexity. Outlier events or “black swans” in popular culture are more likely to occur as the complexity of the NAS rises. Because black swans are emergent from highly interdependent events, they have the potential to evade current hazard detection methods which presuppose the traditional normal distribution statistics assumption of event independence. Where normal (Gaussian) distributions may fall short, the new power law complexity statistics can pick up.

Figure 2 contrasts the familiar normal distribution with the so-called power law distribution (vertical axis represents probability of occurrence and horizontal axis frequency). Traditional Gaussian risk-based safety analysis is rather opaque to feedback effects where event interdependence generates cascading or avalanching outlier phenomena. Power law distribution, on the other hand, asserts a much higher probability for these. Indeed, recent developments in complexity research in ATM have demonstrated not only the existence of such power laws but also their relationship to outlier phenomena represented by cascading congestion and delays.<sup>5</sup> We are interested in the “fat tails” of the power law distribution as an opportunity area for extending the state of the art risk-based safety thinking in aviation.

### A Complexity View of Air Traffic Risk

The aviation community is currently advancing from a forensic, hindsight science toward predictive safety practices.<sup>6</sup> A representa-

tive initiative is precursor analysis, which uses data analysis to detect operational patterns with known risk signatures. As big data technologies advance, increasingly sophisticated patterns can be tackled. It is hoped that eventually all likely risk-embedded operational configurations will be exposed in near real time, thus rendering unsafe events all but obsolete.<sup>7</sup>

The notion of “likely patterns” needs to be considered in the context of complexity. Power law fat tails are characterized by a huge number of possible events with only a small number of actual occurrences. This many-to-few relationship skews the notion of likelihood while driving a huge computational tax. Even if we were to avoid the NP-hard problem, because complexity exhibits disproportionate causation, real-world variations that exceed modeling fidelity might in fact be the real world triggers for large scale emergent phenomena that elude simulated prediction – recall the popular “butterfly effect” notion.

The classical notion of prediction based on an exact match to items in a look-up table also needs to be examined. Complex system dynamics can exhibit reoccurring patterns that bear resemblance but do not perfectly match. In the words of Mark Twain, “history will rhyme but never quite repeat.” Rhyme, an easy notion for humans, still baffles even the most sophisticated artificially intelligent technology. Bringing the human back in the loop, on the other hand, might compromise the near real-time safety risk identification approach.

### Emergent Behaviors and Operational Efficiency

One of the offerings of complexity science is the ability to expose emergent system behaviors. These are notable patterns that arise at a collective scale, due to the complex interactions that occur between

## Power Laws v. Bell Curves - Fat Tails Matter

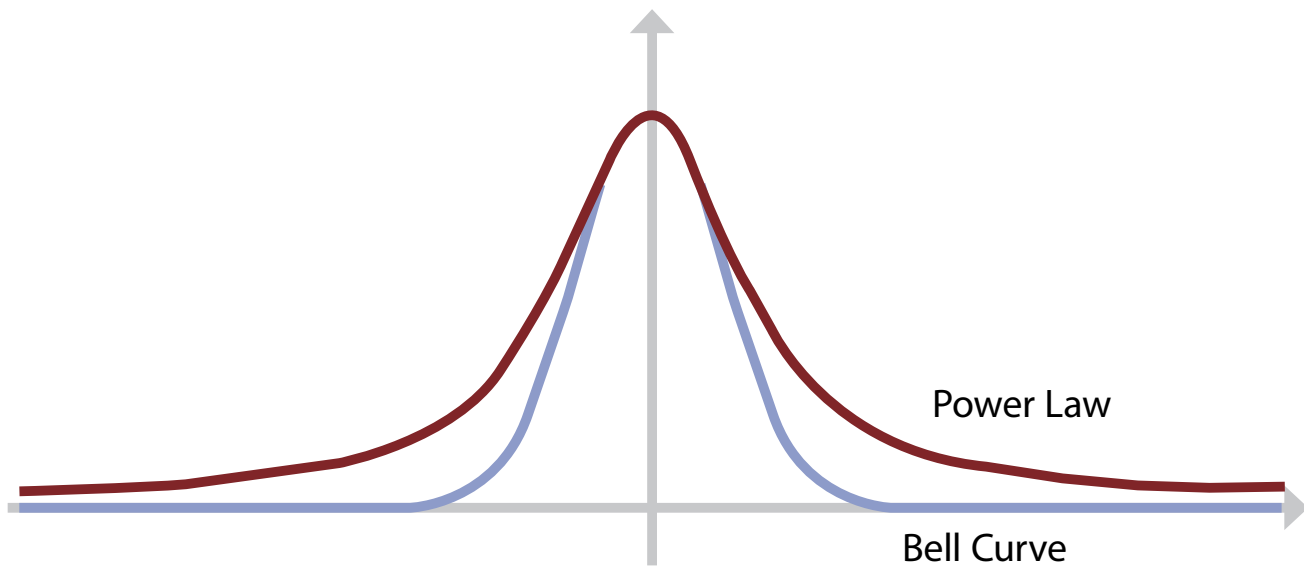


Figure 2. Power Law distributions more accurately capture likelihood of outlier events (Source: [www.intellivestor.org/](http://www.intellivestor.org/))

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## Being a system of systems, the NAS has reached sufficient complexity that our current understanding must be augmented with examination from the perspective of systems thinking and complexity science.

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more easily described processes. An example of emergence in road transportation is stop-and-go traffic on a major highway – a condition arising from a combination of overall congestion and over or under break compensation by drivers.

In air traffic, stop-and-go conditions do not occur because aircraft cannot stop in the air. Anticipated airborne delays are spread more gradually over upstream portions of the flight through path stretching, speed reductions, or in extreme cases, by holding aircraft on the ground. As a result of these actions, other forms of emergent behaviors manifest themselves in air traffic.

For instance, consider the ground delay program (GDP) conducted at San Francisco International Airport (SFO) on December 31, 2014. Figure 3 shows flight counts per time period over the life of the GDP. The colors decompose the flight counts by flight status. A long-standing operational problem for traffic flow managers is that near the end of the GDP time window, the canceled flights (blue) tend to accumulate in the later hours of the program, thereby displacing the uncontrolled flights (light green) that would like to arrive at or just after the end of the program time window (Canceled slots are ‘owned’ by the airlines until they decide how to use them).<sup>8</sup> Traffic managers are still experimenting with various exit strategies for how to shut down a GDP in a way that avoids this buildup. It is

the interaction of the airlines with traffic flow management practices and GDP slot substitution rules/opportunities that creates this emergent behavior, with the associated operational efficiency tax.

Ideally, we would like to be able to project emergent operational patterns associated with new concepts and procedures in the design phase. We would like to know which operational patterns might be spawned by concepts such as Trajectory-Based Operations and autonomous unmanned aircraft systems (UAS). Since this is a new way of looking at the system, we will need new techniques, which is the topic of our next section.

### The Advancement of Modeling and Simulation

The current suite of air transportation modeling and simulation (M&S) tools mirrors the fragmented nature of the current NAS operations. Efforts are underway to upgrade the airspace simulation infrastructure – notably NASA’s Shadow Mode Assessment using Realistic Technologies for the NAS (SMART NAS).

A problem with traditional M&S design remains. The design of most current or foreseen air traffic simulators is axiomatic. That is, a set of assumptions about how agents or objects act are formulated and become enshrined in the computer logic. This certainly has its place. However, as the scientific philosopher Francis Bacon pointed out,

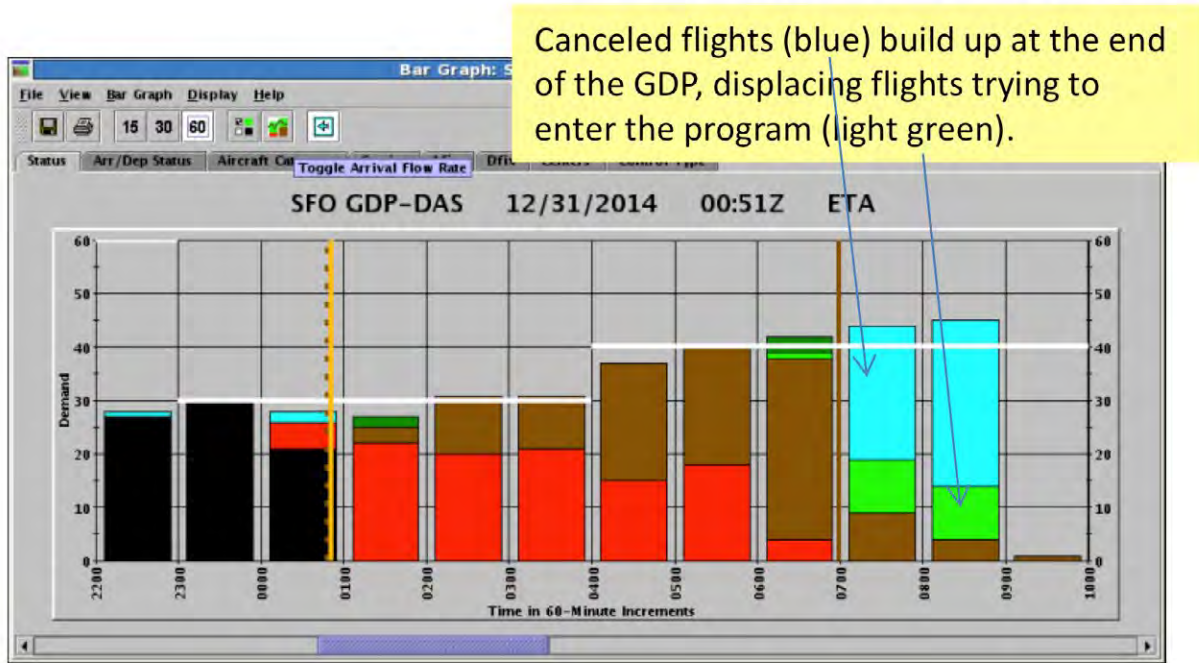


Figure 3. Example of emergent behavior in a ground delay program – canceled flights build up at the end of the GDP due to airline cancellation policies

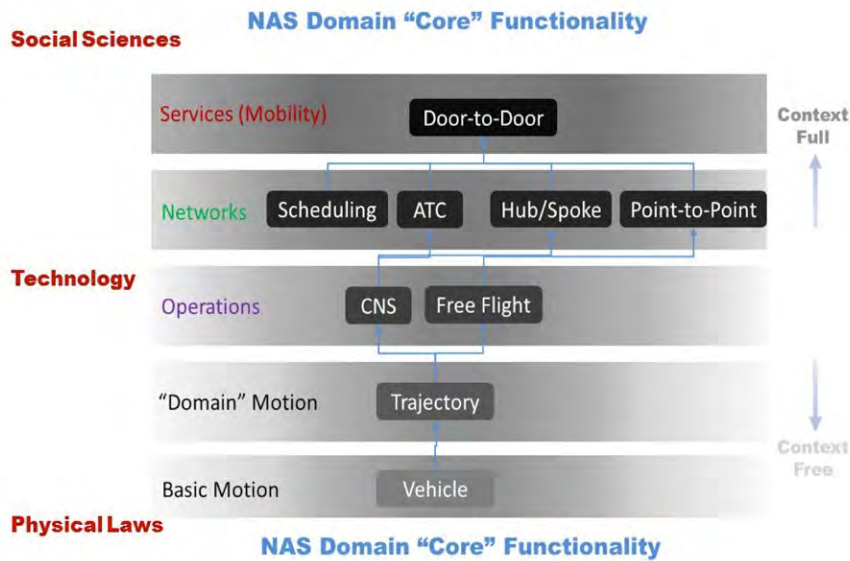


Figure 4. Possible instantiation of layered ontologies; specificity and ATM domain context are added as the layers move toward the top

you won't learn much that was not already embedded in the axioms.

Domain-specific operational context, as obtained from axiomatic assumptions, is a necessity for effective modeling. But the more operational context is pre-programmed into a simulation environment, the lesser the modeling robustness. It appears we need a way to build domain realism on demand, to suit the particular purpose of a certain simulation scenario.

New system-theoretic architectural concepts for NAS modeling and simulation

Jointly drawing from systems thinking and information science may provide a solution. In information science, ontology is a formal naming and definition of the types, properties, and interrelationships of the entities that fundamentally exist for a particular domain of

discourse. Common ontological items in air traffic include flights, aircraft, jet routes, and departure queues. It is precisely this ontology that yields context that is meaningful to the operational domain.

Systems thinking suggests that robustly instantiating operational context requires the ability to manipulate ontological levels or strata. The notion of stratified ontology proposes that successive ontological levels or strata are used to build up to the highest level domain context, anecdotally referred to as the big picture. Figure 4 illustrates a notional view.

Because this approach builds domain realism from context-free building blocks that are based in immutable physical laws, it can exhibit extreme operational context robustness.

To leverage the full advantages of a stratified ontology approach to NAS simulation architecture, it is important that the ontology

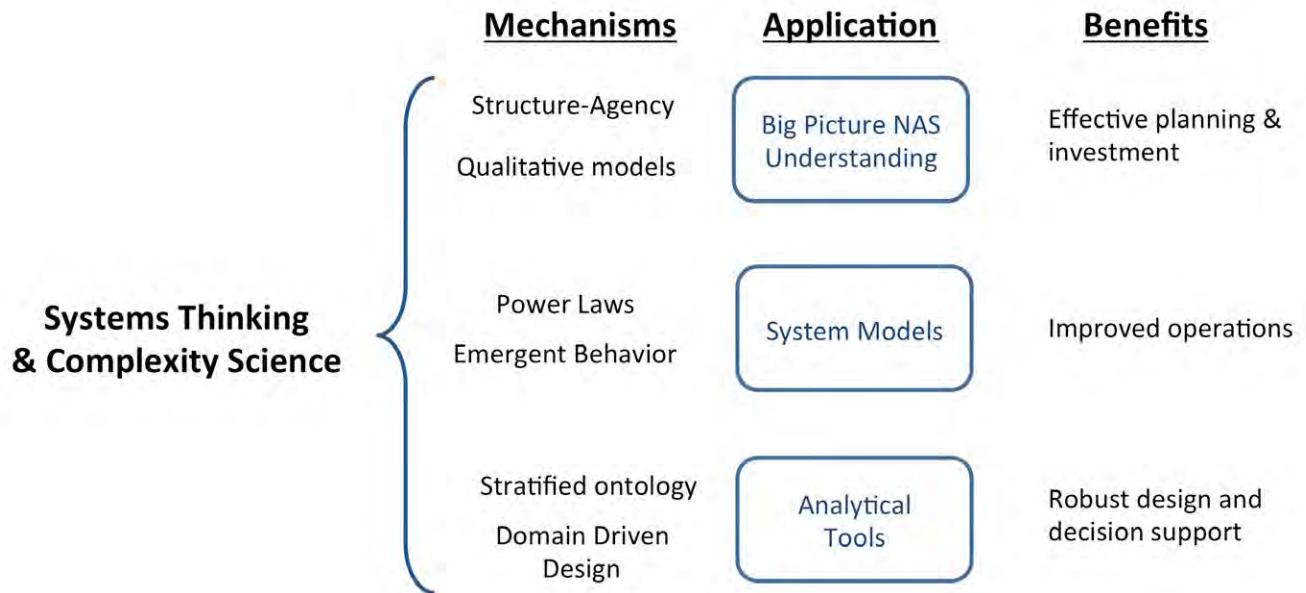


Figure 5. Summary of key concepts, their applications, and benefits

extend to the lowest level of “immutable” laws for a certain domain. In our example the basic logic strata refer strictly to physical laws of motion, while domain motion refers to the operational laws that restrict aircraft trajectory movement.

The software industry has latched onto this notion of stratified ontology through such practices as Domain Driven Design (DDD). Tested software tools that reinforce system-theoretic principles are available for enhancing airspace simulation infrastructure.

### Summary and Conclusions

In this paper, we have proposed the customization of complexity and systems thinking principles into a suite of techniques that can be used to describe conditions associated with complex interactions within the NAS.

We have introduced several thoughts along these lines as summarized in Figure 5, and explained below:

- Big picture NAS understanding: Qualitative evolutionary modeling, such as structure-agency mapping, enables big picture understanding of the NAS. This is the best way to assess transformational claims and so inform effective planning and investment decisions. An added advantage of this approach is that it facilitates an intuitive understanding that speaks to the original visionary perspective of NextGen goals.
- System models: Detection of complexity conditions – black swans and emergence – is a requirement for a complex NAS. We need to evolve beyond traditional analytic practices based on implicit assumptions of independence of constituent elements. Safety programs and risk analysis in particular could well benefit from this line of thinking.
- Analytic tools: A complex NAS with unpredictable future business models requires robust simulation capabilities. To this end, we are proposing the overhauling of design practices for air transportation simulation infrastructure.

Our approach seamlessly unifies into a single thread research areas of key interest at this time: development of truly revolutionary features for the next generation suite of simulation capabilities, development of system-wide safety methods, and the enabling of advanced operational concepts, such as Trajectory Based Operations (TBO).

Our argument supports the NAS evolution toward system-wide, networked operations that are both implicit in concepts such as TBO and explicit in NASA’s newly stated prognostics safety research agenda. Through the lens of complexity and systems thinking, we can support the quest for a truly transformative NAS operation. Indeed, by aiming to qualify the very meaning of the phrase “transformative NAS,” we hope to elevate the future airspace design and development efforts to a new qualitative level. ✈️

### Footnotes

- [1.] A. Barabasi et al., *Network medicine: a network-based approach to human disease*, *Nature Reviews – Genetics*, Volume 12, January 2011
- [2.] K. M. Carley et al., *Destabilizing Terrorist Networks*, *Carnegie Mellon University CASOS working paper*, 2003
- [3.] W. Brian Arthur, *Complexity Economics: A Different Framework for Economic Thought*, *Santa Fe Institute Working Paper 2013-04-012*, 2013
- [4.] S. Anthony, *IBM creates learning, brain-like, synaptic CPU*, *ExtremeTech*, 2011
- [5.] See *Single European Sky ATM Research (SESAR) Work Package-E ComplexWorld Position Paper* at <http://www.complexworld.eu/wp-content/uploads/2012/06/E-01.01-D23.2-COMPLEXWORLD-00.00.03.pdf>
- [6.] F. Fiorino, *Safety Column: FAA Safety Analysis*, *Aviation Today*, January 1 2012
- [7.] K. Martin and R. Fraga, *Near Real-Time Predictive Safety Evaluation*, *ICNS 2013*
- [8.] Ball, M., R. Hoffman, D. Lovell, and A. Mukherjee, “Analysis of Demand Uncertainty Effects in Ground Delay Programs”, *4th USA/Europe Air Traffic Management R&D Seminar*, Santa Fe, New Mexico, 2001.