

Operationalizing “Wickedness” as Analytical and Creative Tools to Transform Aviation

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As the world grows increasingly networked and complex, so do challenges faced by aviation and technology professionals (e.g., fighting wildfires and increasing access to healthcare). There is a need to develop new methods to tackle complex socio-technical problems relevant to aviation. The concept of “wicked” problems offers new methods and perspectives for framing complex challenges. In this paper, we present two modes of operationalizing “wickedness” used by NASA’s Convergent Aeronautics Solutions (CAS) Project to develop transformative innovations in aviation: as an analytical, evaluative tool and a creative, generative tool. Through project examples, we demonstrate that using wickedness as a creative tool during the design process enables rich problem exploration with diverse stakeholders and reflection on how a problem is formulated, while usage as an analytical tool can provide criteria for project selection if internal agreement on the definitions of such criteria is established. Operationalizing wickedness as a creative tool may also enable organizational development of a generative mindset to better adapt to our rapidly changing future.

I. Introduction

The idea of “wickedness” or “wicked problems” was first introduced by urban planners, Rittel and Webber, in 1973 to challenge how policymakers approach complex societal challenges [1]. Since then, the idea has been applied across sectors—including business, design, and engineering—to describe problems that are exceedingly complex, resistant to solutions, and chronic in society. Literature offers several dimensions of “wickedness” as an attempt to capture Rittel and Webber’s ten criteria, but these are challenging to operationalize in practice. Organizations increasingly use terms like “wicked problems” or “Big Hairy Audacious Goals” [2] like the UN’s Sustainable Development Goals [3] to illustrate commitment to a particular vision and inspire innovation. NASA’s Convergent Aeronautics Solutions (CAS) Project aims to develop transformative innovations in aviation through tackling wicked problems across aviation and other domains. In this paper, we present two modes of operationalizing “wickedness” in the context of CAS by adapting a framework from Lönngren and Poeck [4]. We explore “wickedness” as (1) an analytical tool for evaluation and (2) as a creative tool for generation, and how these “tools” can be used to help transform aviation and society. Through project examples, we demonstrate that using wickedness as a creative tool during the design process enables rich problem exploration with diverse stakeholders and reflection on how a problem is formulated, while usage as an analytical tool can provide criteria for project selection if internal agreement on the definitions of such criteria is established.

II. Background

A. Wickedness and Aviation

In common engineering methods, problems are decomposed so that they can be addressed within specialized disciplinary or functional groups. Such approaches have worked for much of aviation’s history, but the future of aviation appears increasingly entangled with “wicked”, multi-domain problems of sustainability, digitization, accessibility, equity, and more. Such problems cannot be effectively decomposed and addressed by a single discipline but require engagement across disciplines and stakeholder groups (including non-technical experts).

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According to Pashkevich, changed relationships between humans, nature, and technology have resulted in more complex and wicked problems [5]. Dorst stresses that this new “open, dynamic, complex, and networked” type of problem emerging from our increasingly networked society requires transformation of organizations to tackle these challenges with a radically different approach [6]. This new approach requires thinking beyond technical constraints to produce holistic solutions to address wicked, socio-technical problems.

According to Ray [7], engineers typically receive technical specifications or design criteria, assess feasibility of technical solutions, and utilize a hierarchical system to delegate tasks from a decomposed problem. NASA Subject Matter Experts (SMEs) have extensive experience both developing and utilizing this approach to problem-solving, demonstrated by accomplishments such as the NASA Systems Engineering Handbook, which is now the industry standard for systems engineering methodology [8]. NASA engineers have used these methods to address complex problems structured by technical constraints, such as landing men on the moon [9]. Lönngren [10-11] suggests that while decomposition methods, like those commonly taught in engineering curricula, may be appropriate for engineering problems well-defined by technical requirements, ill-structured, wicked problems require approaches that deal with complexity, ambiguity, and dynamic social, political, and cultural dimensions. For example, NASA’s Advanced Capabilities for Emergency Response Operations project (ACERO) aims to manage complex responses to natural disasters, specifically demonstrating technology systems with wildfires in recent years. Many organizations coordinate to tackle wildfires, often with multiple aircraft operating in limited visibility and varying communication methods and organizational standards. NASA’s ACERO is developing drones to enhance situational awareness and inter-organizational communication to manage different types of aircraft in shared airspace, which requires both proven systems engineering approaches within NASA’s demonstrated expertise, in addition to new strategies for managing stakeholders and the dynamic nature of wildfires. Wicked, socio-technical problems in aviation, like wildfire-fighting, present valuable opportunities for the development of new competencies to generate positive impact from the industry.

This paper describes two methods of operationalizing the concept of wicked problems to prototype new approaches to complex problems tied to aviation. We present examples of each method and comment on key learnings gained from experimenting with the concept of wicked problems to innovate in aviation.

B. Wickedness Framework

Lönngren and Poeck [4] propose three ways that wicked problems can be used in research, as (1) a descriptive/analytical tool, (2) a sensitizing/creative tool, and (3) a critical/emancipatory tool. Their framework stems from sociology studies of cross-disciplinary research [4] and provides a starting point for understanding how wicked problems can be used in an aviation context. In this paper, we adapt the first two tools of Lönngren and Poeck’s [4] framework for real-world design and engineering contexts. We refer to wickedness as an analytical tool when it helps to evaluate the type of complexity and multi-dimensionality of a problem. We refer to wickedness as a creative tool when it provides a “point of reflection” to inform an approach or generate new solution paths. These two types are described in more depth below.

C. Wicked Problems as an Analytical Tool

Several scholars present analytical tools for understanding wicked problems, primarily capturing complexity as it emerges from stakeholders and problem conditions. Alford and Head present two dimensions for capturing wickedness: problem complexity and complexity of stakeholder relationships [12]. For more tame problems, the problem is well-defined, possible solutions are known, and stakeholders generally agree on the problem and can collaborate to implement solutions. At the other extreme, in more wicked problems, it is difficult or impossible to know the root cause of a problem and possible solutions may be unknown. Stakeholder relationships can be difficult to manage when there are power differentials, hidden or fragmented information that is distributed across different stakeholders, or misaligned interests and values across different organizations and individuals that complicate collaborations [12]. Farrell and Hooker [13] present three dimensions that encapsulate the nature of wicked problems through finitude, complexity, and normativity. Finitude captures the limits of cognitive ability and resources for processing and developing problem and solution pairs. Complexity results from interactions between parts of systems, where wicked problems contain many. The third dimension of normativity describes the importance of human norms and values for problem understanding and resolution. An increase in any dimension increases the “wickedness” of the problem [13]. These dimensional breakdowns help us understand the types of complexity present in wicked problems, and what may be required for solution. For example, with high complexity in stakeholder relationships, a forum of many organizations and discussion to consensus may be required for resolution. This type of solution path may not be within the mission of all organizations. Recognizing types of complexity can help organizations identify whether

tackling a particular problem is within their mission and charter, and to down-select problems and opportunities in the design process to maximize transformation, impact, and success.

D. Wicked Problems as a Creative Tool

While many scholars decompose and refine the definition of wicked through dimensional breakdowns, others describe using wicked problems for exploration and creative generation in problem definition and solution identification. Framing problems is considered a creative, iterative process necessary for managing ambiguity and complexity [6]. Literature provides a variety of tools for exploring and incorporating diverse perspectives to generate problem frames and identify solution pathways in this creative process.

Engineering problems defined by technical constraints can be evaluated objectively, and as a result, decomposition and systems engineering methods need not consider or capture diverse viewpoints [6, 14]. However, literature emphasizes that the ability to understand and engage multiple perspectives is a necessary skill for dealing with wicked problems [6, 9, 15-19]. Wicked problems can be used as a creative tool for the generation of frames and visuals for considering diverse perspectives in problem formulation. Turnbull and Hoppe [20] explain how to use Douglassian culture theory frames to structure problems based on stakeholder perspectives as gaps between an “is” and an “ought”, or between the current state and the desired state. Maxwell [21] also describes the advantages of qualitative research methods (ethnography, observation, interviews, focus groups, etc) in understanding perspectives and causal relationships and for developing insights in exploratory studies, which could be beneficial for understanding and addressing wicked problems. In addition, Ireland et al. [22] analyzed the use of soft systems methodology to address wicked problems by developing and comparing multiple perspectives of the problem, concluding that it allowed for better problem definition and solution identification.

Scholars also suggest collaborating with different types of stakeholders to frame wicked problems and create paths for solution. [6, 17-18, 20, 23-24]. Horn and Weber [25] offer collaborative visualization tools for managing wicked problems: mess mapping, in which stakeholders collaborate to create a visual representation of the problem area—a “mess map”; and resolution mapping, which enables stakeholders to envision a desired future and generate steps needed to reach that future, integrating multiple perspectives into direct action items [25]. These tools assist in problem definition and solution identification in the design process, which are necessary for any organization tackling wicked problems.

E. NASA Convergent Aeronautics Solutions (CAS)

The NASA Convergent Aeronautics Solutions (CAS) project works to transform how airplanes fly and the aviation industry along with it. It invests in seemingly improbable ideas to address the problems that plague aviation and impact safety, air traffic, and community and planetary health. Participation in the CAS process enables greater organizational and individual transformation to increase capacity for innovation and the ability to tackle more complex societal problems across NASA. One of the strategies that CAS uses to enable such transformations is by operationalizing the concept of wicked problems. CAS uses wicked problems as both (1) an analytical tool to identify compelling societal problems tied to aviation, and (2) as a creative tool to transform aviation professionals to be increasingly innovative in the face of a rapidly changing technological landscape, environment, and society. This paper describes how CAS uses wicked problems for transformation in aviation and lessons learned from these methods. The authors describe recommendations for operationalizing wickedness as a tool for transformative innovation in aviation and intersecting domains.

III. Wicked Problems in Practice to Achieve Transformation

A. Wicked Problems as an Analytical Tool for Evaluation

This section will describe specific examples of how CAS is exploring the use of wickedness as an analytical tool. The first example is a prototype strategic framework to guide project selection at various stages of development in CAS at the organizational level. The second and third examples demonstrate the use of wicked problem characteristics at the project-level to assist in selecting and scoping topics for exploration. The second example is the use of a Pugh chart based on a specific set of wicked problem characteristics to down-select problem areas for further exploration. The third example is a prototype of operationalizing the Rittel and Webber dimensions of wickedness [1] as criteria for problem scoping.

Organizations such as CAS must operate within their mission with the resources available to them. Because of these constraints, the organization must choose carefully which projects to pursue. CAS developed a first prototype for using dimensions of wicked problems as criteria for project selection. In this initial attempt, the CAS team chose three dimensions to capture the aspects of wicked problems relevant to the organization:

- 1) Irreducible interdependencies amongst social, economic, technical, and other factors,
- 2) Substantial effort needed to understand the problem, and
- 3) Uniqueness and scale of impact for NASA, the USA, and humanity.

The first dimension refers to the types of complexity that emerge in wicked problems due to the cross-boundary nature of wicked problems, indicating that CAS is looking to tackle problems with more than just technical complexity. The second dimension explicitly states the need for problem framing and formulation for understanding the problem, ensuring a problem-focus in project selection, rather than a solution-focus. The final dimension is only implicitly present in the wicked problems concept—theoretically, if a problem is extremely complex in various ways and requires a multi-stakeholder approach, then the problem likely affects many people. This is illustrated by the numerous examples of wicked problems in literature, including climate change, healthcare, poverty, pandemics, water resource management, and terrorism [9], which affect people around the globe. The impact and uniqueness in criteria 3 refer to the mission of NASA to innovate, “for the benefit of humanity” [26] and helps us reflect on the extent that CAS as part of a federal agency can positively affect the problem. We have attempted to use these “wicked” dimensions at the organizational level to guide projects in ways that allow us to expand the capabilities of NASA beyond technically complex problems and transform aviation utilizing the excellence and expertise of the agency.

At the individual project level, CAS has also tried using dimensions of wickedness in Pugh charts when selecting problem areas to continue exploring (Table 1). The Zero-Impact Aviation - Human Health (ZIA-HH) project initially explored opportunities for aviation to positively impact human health. To choose a topic area for deeper investigation, the team generated a list of criteria based on their shared understanding of “wickedness” and other relevant selection criteria. The criteria generated for the problem area selection meeting were:

- 1) Reach,
- 2) Impact,
- 3) Multi-stakeholder/multi-domain conflict and convergence,
- 4) Is there a gap in this whitespace area?
- 5) NASA resources and role as a federal agency—should NASA fill this gap?
- 6) Fit with expertise of NASA Subject Matter Experts (SMEs)

The team used the criteria in a Pugh chart to down-select from five to two problem areas to pursue in more depth. The subsequent design team of interns and SMEs made the final choice based on passion and interest in the subject. The first two criteria similarly echo the reach and impact implicitly present in wicked problems. The third criterion requires a specific type of complexity: the explicit presence of multi-stakeholder conflict and convergence, or complexity in the organizations, groups or individuals connected to the problem and the relationships between them [27]. The problem area must have this type of complexity as well as potential for NASA to play a key role in the co-evolution of solutions among stakeholders with potentially competing priorities. One capacity CAS aims to build in the organization is transdisciplinary collaboration to address complex societal challenges, so this third dimension ensures that topic areas provide the opportunity to develop this capacity further. The fourth dimension ensures that there is real need for effort in the problem space, that there is a gap in the innovation ecosystem needed to address the problem, so that CAS may have the opportunity to transform aviation through innovation. The final two dimensions describe fit for CAS in tackling the challenge by NASA’s position as a federal agency and technical competencies. Key questions associated with these dimensions include: What would happen if NASA does nothing on this problem? Does the problem align with NASA’s mission? To what extent are others working on this problem? Are there existing NASA SMEs that have relevant expertise? These questions enabled the selection team to reflect on the level of match between problem areas and CAS’s strengths and resources.

Table 1: Pugh Chart from Zero Impact Aviation – Human Health (ZIA-HH) CAS Project

PROJECT TOPICS <i>Criteria</i>	PAND-EMICS Aviation as a vector of pathogens (datum)	AMR Aviation as a contributor of pathogen growth / antimicrobial resistance	HEALTH CARE ACCESS Access to healthcare as distance to advanced care increases	AAM STIMULI Negative mental & physical health impacts of future AAM noise or visual stimuli	DRUG EFFICACY Drug efficacy due to lack of clinical trial representation for which aviation could be a catalyst for change
<i>Reach</i>	0	0/-	-	-	0
<i>Impact</i>	0	+	+	0	+
<i>Multi-stakeholder/domain conflict & convergence</i>	0	+	0	0	0
<i>Gap in whitespace</i>	0	+	0/+	-	+
<i>Fit with NASA's resources & role as a federal agency</i>	0	0	-	+	-
<i>Fit with NASA SME expertise</i>	0	-	0	+	--
<i>Sum</i>	0	1.5	-0.5	0	-1

The Pugh chart shown in Table 1 displays the results of the ZIA-HH selection team's reflection on the different dimensions of wickedness and relevance to the organization. These results were used to help the team understand the various aspects of the five problems areas. Subsequent to the analysis, the team combined Pandemics (Aviation as a vector of pathogens) and AMR (Aviation as a contributor of pathogen growth/microbial resistance) for presentation to the project team along with the Access to Health Care (Access to healthcare as distance to advanced care increases). The project team then considered these two topics in terms of initial excitement, what we want to learn more about, and who we might consult. This discussion led the team to eventually select Access to Health Care as the final problem area to explore during Fall 2022 and Spring 2023 phases of the ZIA-HH project because of the interest of the team and the more open-ended opportunities for aviation to impact the problem. As a result of the subsequent investigation into access to advanced healthcare, we successfully identified several dozen opportunities for aviation to positively impact the problem space.

Another CAS project effort, Capabilities, Communities, and Connectivity (3C), used eight of Rittel and Webber's ten characteristics as criteria for problem scoping to analyze the problem of rural revitalization. As the team conducted its initial problem scoping work, the eight Wicked criteria helped the team to ensure that the problems considered were adequately "wicked." For each criteria used, the team identified specific goals that would allow for the exploration of a wicked problem within the project schedule and cost boundaries. Table 2 shows the criteria used and the operationalization of those criteria for the specific project.

Table 2: Wicked Criteria, Made Actionable for CAS 3C Project

Characteristic	We Can't Answer:	But We Will:
There is no definitive formulation of a wicked problem. It's not possible to write a well-defined statement of the problem, as can be done with an ordinary problem.	<i>In a concise statement, what is the problem?</i>	- Define 'edges' or boundaries (what is it NOT; what is it more/less of?) - Have specific research questions - Let the problem statement evolve - Act vs. over-analyze
Wicked problems have no stopping rule. With a wicked problem, the search for solutions never stops.	<i>When will it be solved?</i>	- Predict and share good future paths - Define time/geographic rationale - Take only a 'slice' to work on - Time box our work - Press ahead with a solution area - Identify first- and second-order interdependencies
Solutions are not right or wrong. They're "Better" or "Worse," "Good Enough" or "Not Good Enough"	<i>What is the right thing to do?</i>	- Document lab notes and aggregate across the team - Weighted argumentation, pros, cons, counters to increase confidence in micro-decisions
There is no immediate and no ultimate test of a solution to a wicked problem. Scale of solutions to wicked problems make it difficult to measure their effectiveness.	<i>Did we do the right thing?</i>	- Acknowledge improvements expected and the potential unintended consequences - First-degree stakeholder network feedback as litmus test - Continuous iteration/prototyping to sense impact - Light / agile prototypes that we can easily pivot - Set progress based criteria for measuring impact
There are no throwaway rounds, every implemented solution has consequences that cannot be undone.	<i>What will do if it doesn't work?</i>	- Acknowledge error is inherent and embrace as learning - Iterate / get feedback from stakeholders to determine some consequences - Practice knowing our own bias and listening for it - Continue to learn about possible consequences - Ensure good intention
Every wicked problem can be considered to be a symptom of another problem.	<i>What is the primary problem?</i>	- Intentional about problem slice, may move but keep the same size - Know there are many problems; scope to a pain point - Set norms about what is relevant vs. not to our slice - Iteratively make decisions about our slice and update - Use network to describe vs. hierarchy - Clearly track steps to debrief others yet to come on how did we change the system.
Stakeholders will have different explanations of what the problem is and what its causes are.	<i>What is the root cause?</i>	- Illuminate latent needs through data collection - Identify causes, evaluate, integrate, map - Proactively identify and document other domains involved but note what we'll be focused on
No right to be wrong. Problem solvers dealing with a wicked issue face consequences of any actions they take.	-	- Ongoing stakeholder engagements - Identify ecosystem and prioritize the desirability, viability, and feasibility interdependencies - Use tools and outside expertise to understand first-order ecosystem impacts

This prototype for using wickedness as an analytical tool informed the approach of the design team, helping them to scope a “slice” of the problem for CAS to tackle. The team went from the broad problem space of ‘rural revitalization’ to the more narrow problem statement ‘How might we illuminate ways for rural production communities to thrive and become resilient outside of single industry infrastructure?’ using the wicked criteria along with consideration of how actionable and appropriate the problem “slices” were for CAS. The wicked criteria as an analytical tool evolved into a creative tool for reflection, allowing team members to set their expectations and design the methods for exploration to address the various complexities of the problem. CAS prototypes for creative tools are discussed more in the next section.

B. Wicked Problems as a Creative Tool for Generation

This section describes specific examples of how CAS has used wickedness as a creative tool. The first example is the use of stakeholder mapping and causal loop diagrams to explore the wicked problem of healthcare access in the United States, specifically analyzing access to healthcare as distance to care increases. The second example is the use of engaging outside stakeholders in many different fields and with different experiences to scope a “slice” of a problem in the broad rural community resilience problem space.

CAS has prototyped using wicked problems as a creative tool in exploration to encourage reflection on the approach and to help team members explore and understand diverse perspectives on the problem and generate novel solution paths. In the 3C project, reflection on the complexities of the wicked problem of rural revitalization helped the CAS team engage a variety of stakeholders, especially non-technical experts in social sciences, and scope a “slice” of the challenge for CAS to tackle. The attempt to use wicked problems encouraged reflection not only within the team on the methods used in 3C, but also across the organization on the approach to achieving transformation.

Both 3C and Zero-Impact Aviation – Human Health (ZIA-HH) utilized qualitative research methods to engage stakeholders in the design process. In the initial research phase of 3C, the team conducted 22 one-hour-long interviews with rural community members recruited from across the United States. Community members were recruited from four prioritized stakeholder groups: ‘foundational’ community members, ‘fresh eyes’ community members, essential service providers, and local decision makers. Subsequent rounds of research stemming from the initial 3C work included additional interviews and multiple site visits to rural communities. ZIA-HH team members engaged over 150 healthcare and aviation stakeholders by conducting 96 interviews, facilitating nine collaborative round table design sessions, and two site visits. These helped to co-evolve problems related to access to healthcare and co-develop opportunities for aviation to address these.

In addition, the ZIA-HH design exploration in CAS utilized stakeholder mapping and causal loop diagrams to explore the wicked problem of healthcare access in the United States, specifically analyzing access to healthcare as distance increases. These two methods have been used in practice to understand stakeholder relationships and problem complexities, which are especially relevant for wicked problem exploration. As part of the problem exploration, the team of interns and SMEs collaborated to create stakeholder maps in order to understand who might be impacted by solutions and who CAS may want to engage in the design process. This consisted of mapping out various patient journeys interacting with the healthcare system, as well as tracking funding and value streams to better understand power dynamics and which stakeholder may have undue influence. As a result of this exercise, the team was able to engage a diverse set of stakeholders from the healthcare sector in exploring the problem space in a series of interviews and co-design workshops to learn more about the problem and identify several opportunities for aviation to transform this sector.

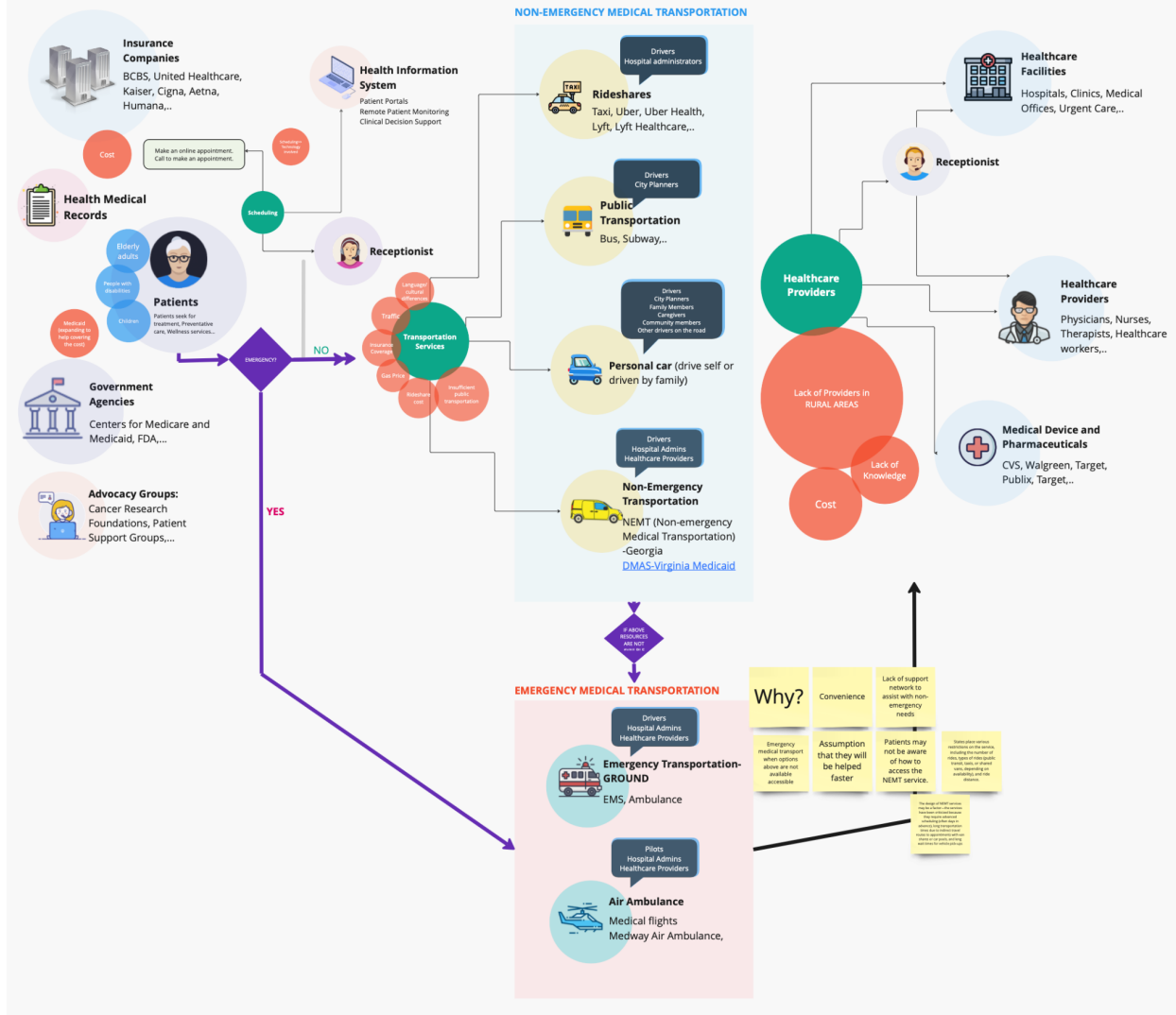


Figure 1: Stakeholder Map of Non-Emergency Medical Transportation

Figure 1 shows a stakeholder map created by the ZIA-HH team to identify gaps in knowledge and key stakeholders in non-emergency medical transport situations. Red circles indicate barriers while green circles indicate enablers related to accessing healthcare. Other circle colors indicate different types of stakeholders, including patients, doctors, and transportation providers, that may be involved in non-emergency healthcare access. Creating this map allowed the team to identify specific patient groups that may experience additional barriers to accessing transportation for non-emergency medical care, such as elderly patients and people with disabilities, with whom to consult and co-create to further investigate related challenges. It also enabled the team to visualize the complex web of stakeholder relationships and technologies engaged in the process of accessing and providing medical care, an important step in framing this problem as an opportunity for aviation.

The ZIA-HH team also created causal loop diagrams (see Figure 2), a structured type of mess mapping or system mapping, to understand factors that positively and negatively influence various challenges in the broader problem space. Identifying these “feedback loops” allowed team members to identify leverage points [28], or opportunities to impact the problem, in the system and mitigate the feedback loops exacerbating the problem.

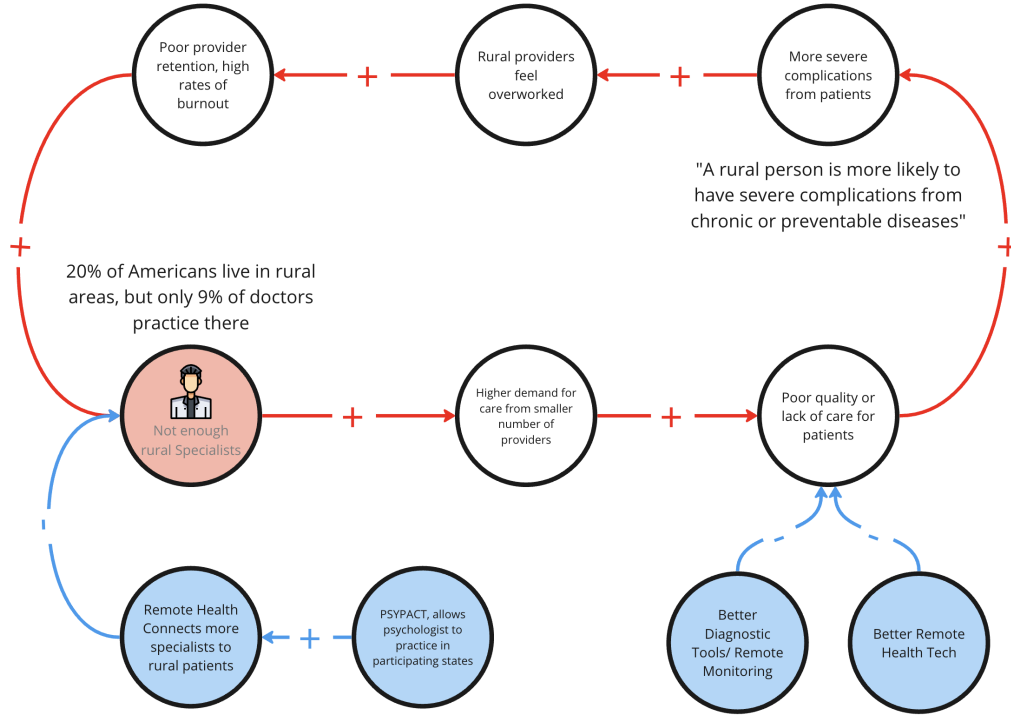


Figure 2: Causal Loop Diagram of Delivery of Medical Diagnostics to Expand the Applicability of Telemedicine and Access to Specialists

In the causal loop diagram in Figure 2, the red connections indicate relationships which create problems in the system, while the blue connections indicate relationships where opportunities exist to mitigate challenges in the system. Positive and negative labels on these connections signal the originating bubble adds to (+) or reduces (-) the receiving bubble. For example, in the bottom left-hand corner, the organization “PSYPACT” adds to the ability of remote health to connect more specialists to rural patients, which reduces the problem of “not enough rural specialists”. Blue bubbles indicate leverage points, while white bubbles show trends. The red bubble is the primary trend identified for the problem area. Diagramming the problem in this way allowed the team to understand how different aspects of the problem relate to each other and visualize the resulting “feedback loops” that demonstrate the persistence of healthcare access problems, in rural areas in particular for this diagram. By understanding how problems relate to each other, team members were able to identify existing leverage points that organizations are already making progress on as well as find remaining gaps that aviation may be able to tackle. Both stakeholder mapping and causal loop diagramming allowed the team to understand healthcare access at the system-level, which is necessary for addressing complex societal problems in which root causes and possible solutions are non-obvious. More information on the exploration and problem identification strategies used in ZIA-HH, 3C, and other CAS projects can be found in other related publications, e.g., [29].

IV. Discussion

This section will reflect on the use of wickedness as both a creative and analytical tool to generate and evaluate ideas for transforming the aviation industry and thereby transforming the world. We will describe our lessons learned from the case study projects and recommendations for operationalizing wickedness as a tool for transformative innovation in aviation and intersecting domains.

CAS experimented with the concept of wickedness in different levels of the organization and as different kinds of tools. As an analytical tool at the organizational level, we found it difficult to specify and agree on the definition and dimensions of wickedness. Because of the variety of project efforts in CAS and the range of tailored approaches to each, it was difficult to standardize an analytical tool for repeatable use in many different contexts. This resulted in vague understanding of the concept of wickedness and confusion on the usefulness of the concept for evaluating projects. As an analytical tool for isolated evaluation activities, there was strong agreement among participants because of the collective process of defining the dimensions of wickedness. This enabled the selection committee to

operationalize the concept with a shared meaning of the term. This aligns with Lönngren and Poeck's recommendations for using wicked problems as an analytical tool, citing that the concept should be "carefully and narrowly defined" with a clear explanation for how to operationalize the term [4].

As described previously, the definition and application of wicked problems varies greatly across literature and in practice, even within one organization. Some scholars criticize broad application of the term "wicked", citing that it loses its meaning when stretched to accommodate additional applications [27]. However, Lönngren and Poeck [4] cite the usefulness of wickedness as creative tools in exploration, where ill-definition enables researchers to remain open to surprises while being given a starting point for reflection to guide the exploration process [4]. This sentiment is reflected in the experience of CAS researchers utilizing the wicked problems concept to explore opportunities to transform aviation and society. The concept of exploring wicked problems encouraged reflection on the design process traditionally practiced by NASA. This reflection, along with CAS's goals for transformation beyond aviation, enabled new methods of exploring the problem space and engaging diverse stakeholders to collaboratively identify opportunities. Using wicked problems as a tool for reflection, creativity, and generativity enables problem exploration through iterative framing and reframing from different perspectives, and identification of multiple opportunities to impact the problem. This type of usage does not require agreement on the definition of wicked problems, as a detailed, concise description of the dimensions is not necessary to use wicked problems for exploration and may actually prohibit problem framing and opportunity identification [4]. As a result, using wicked problems as a creative tool may be easier to operationalize than as an analytical tool because it does not require organizational alignment and precise definition for productive use of the concept.

While the prototype of utilizing wickedness as an analytical tool in isolated team activities proved initially useful for down selection, it may be more useful as a creative tool to develop generative, flexible mindsets in the technical workforce. The practice of using analytical tools for evaluation is common to engineering methods and technically structured projects. In state-of-the-art engineering practices, engineers use an evaluative mindset and analytical tools to define technical requirements. We found that in using wicked problems as an analytical tool, there was a tendency to expect the analysis to similarly result in a fully defined problem and clear direction. While we recognize that analysis provides useful information, there is a risk in using wicked problems as an analytical tool in that users may neglect the ambiguous and dynamic nature of wicked problems, expecting the same level of definition resulting from standard engineering methods. In the case of wicked problems, analytical tools result in enhanced understanding of the problem, but it is far from fully defined [12-13]. Problem structuring and formulation remains a rigorous, collaborative, iterative part of the process of tackling these problems, and requires creativity to generate different framings and associated solutions [6]. To more effectively develop a new competency in tackling modern challenges in aviation, it may be useful to embrace wickedness as a creative tool to encourage reflection on common processes and develop a generative mindset for tackling wickedly ambiguous, dynamic problems.

V. Conclusion and Future Work

This paper describes two approaches to operationalizing the concept of wicked problems to address complex socio-technical challenges tied to aviation like fighting wildfires and improving access to healthcare. For over fifty years, the concept of wicked problems [1] has been used by scholars and design practitioners with varied levels of definition and success. In this paper, we build upon research from Lönngren and Poeck [4] to operationalize wicked problems as (1) an analytical/evaluative tool and (2) a creative/generative tool. As an evaluative tool, dimensions of wicked problems can be used to help unpack complex socio-technical problems for further analysis. In practice, NASA CAS used dimensions of wicked problems as criteria for down selecting challenges for further investigation. Doing so required a shared definition of wicked problems across the teams. As a creative tool, the wicked problems literature suggests a variety of methods to frame problems and generate solutions, including qualitative methods, stakeholder mapping, and casual loop diagramming. In practice, CAS teams engaged in such methods while consulting and co-creating with stakeholders within and beyond NASA.

The case studies we present recommend a set of future work to further operationalize the concept of wicked problems as an analytical/evaluative tool and a creative/generative tool and putting these into conversation with other related approaches and methods like strategic foresight, speculative design, liberatory, participatory, and systemic design. Additionally, these approaches may be carefully combined with AI agents to support human-AI collaboration that improves the speed and quality of these evaluative and generative methods. Lastly, we suspect that using wicked problems as a creative tool may assist in the development of flexible, generative mindsets in aeronautics professionals. Future research may explore the development of such mindsets and capabilities. This may be increasingly important for technical experts as technical challenges become increasingly interconnected with social, political, economic and ethical dimensions.

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