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NIAC: The NASA Innovative Advanced Concepts Program

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Abstract

The NASA Innovative Advanced Concepts (NIAC) Program nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs - radically better or entirely new aerospace concepts - while engaging America's innovators and entrepreneurs as partners in the journey. NIAC projects study innovative, technically credible, advanced concepts that could one day "Change the Possible" in aerospace. NIAC supports innovative research through three phases of study, each competitively awarded. Phase I studies are for nine-month efforts to explore the overall viability of visionary concepts. Phase II studies further develop the most promising Phase I concepts for up to two years, prepare a roadmap for further development, and explore potential transition options within NASA and beyond. Phase III studies are designed to strategically transition the most promising NIAC concepts to other NASA programs, other government agencies, or commercial partners. Since 2011, NIAC has funded 128 Phase I, 51 Phase II, and 2 Phase III studies. This paper provides an update on NIAC's history and current role in supporting NASA's sustained investments in advanced aerospace technology development.

Keywords: (NASA, aerospace, innovation, research)

Acronyms/Abbreviations

ESM = Equivalent System Mass

ICES = International Conference on Environmental Systems

IMLEO = Initial Mass to Low Earth Orbit

NASA = National Aeronautics and Space Administration

NIAC = NASA Innovative Advanced Concepts (starting in 2011)

NIAC = NASA Institute for Advanced Concepts (prior to 2011)

NSPIRES = NASA Solicitation and Proposal Integrated Review and Evaluation System

USRA = Universities Space Research Association

NEC = NIAC External Council

SSO = Source Selection Officer

STEM = Science, Technology, Engineering and Mathematics

STP = Space Technology Program

STMD = Space Technology Mission Directorate

1. Introduction

NIAC is unique! It is a program that values both technical acumen and imagination, inspired by curiosity and the quest for knowledge. We encourage innovators to be creative and attempt great leaps forward in aerospace endeavors. NIAC calls for visionary concepts that may be expansive in scope, may inspire new classes of enabling technologies, and may feature disciplines outside of the mainstream aerospace fields. A good NIAC concept seeks to

"Change the Possible" or offer revolutionary improvement. This paper provides an update to Turner, et al, 2017.¹

I. NIAC Goals and Objectives

NIAC supports innovative research through three phases of study. Phase I awards are nine-month efforts to explore the overall feasibility and viability of visionary concepts. The follow-on Phase II awards further develop the most promising Phase I concepts for up to two years, and explore potential infusion

options within NASA and beyond. Phase III studies are designed to strategically transition the most promising NIAC concepts to other NASA programs, other government agencies, or commercial partners.

A NIAC concept must be an aerospace architecture that is innovative, offers high potential impact, is credible and reasonable, and is examined in a mission context. Broadly, the term aerospace includes activities related to space and aeronautics. An architecture includes multiple systems, and a concept of how they are used together to achieve mission goals. A mission is a plan to achieve one or more clear objectives (e.g., advancing exploration, science, aerospace operations), to benefit NASA or the larger aerospace community.

NIAC concepts must break new ground, changing the conversation about future possibilities. They could enable an entirely new mission, greatly improve execution of current missions, or offer a great leap in capabilities. Conducting these early concept studies now greatly expands our view of what's possible, providing significant benefit even if the ultimate vision is far-term or high risk.

The underlying technologies or concepts and their implementation in a mission context must be technically sound, and based on solid scientific and engineering principles. Generally a NIAC concept is based on new technology, but it can also be based on existing technologies applied to a mission in substantially new and innovative ways, for example by adapting a technology typically applied in a non-aerospace domain into a NASA mission context.

As noted, a key feature of NIAC studies is they assess the concept in a space or aeronautics mission context; the main focus is determining feasibility and comparing properties and performance with those of currently conceived missions or concepts. This is just as important as a detailed analysis of the underlying phenomena or technology. Concepts that may support multiple missions must feature a detailed analysis of at least one candidate mission application. The mission context need not be a current or planned NASA mission. Rather, any aerospace mission (previously considered or hypothetical) may be selected, as long as it could reasonably fall within NASA's domain. The reason NIAC studies focus on missions, instead of just directly funding the development of a technology, is that NIAC studies are intended to show that it would be worth NASA's efforts to further develop an innovative idea. Investment in the underlying technology would come after the NIAC study demonstrates feasibility and mission benefit.

Mission context is often a challenge for technologists who traditionally focus on subsystems or narrow aspects of a larger mission. An

Environment Control and Life Support System (ECLSS) is a good example. For NIAC to choose a study of an improved ECLSS, the study must first compare the benefits of the new system to competitive concepts (state of the art, already under development, or systems previously considered for implementation). But it must also show, in a quantifiable way, that it would substantially reduce mission cost or complexity: perhaps by reduced total "initial mass in low Earth orbit" (IMLEO) compared to some reference mission or by estimating the Equivalent System Mass (ESM), which assigns a "mass budget" to subsystem power and volume. Such metrics would illustrate that while an approach may reduce the consumable mass required, it would also not demand so much power or thermal control (and the associated mass to provide them) as to swamp the consumable mass reduction.

NIAC Phase I studies receive funding of up to \$125k over nine months to perform preliminary concept investigations. Successful Phase I projects are eligible to compete for NIAC Phase II awards, which are funded for up to \$500k per award over a 2 year period. Phase II studies are designed to continue the exploration and development of revolutionary advanced concepts that have been initiated through the Phase I award. The primary goal of the Phase II effort is to study major feasibility issues associated with cost, performance, development time and key technologies. These results should provide a sound basis for NASA to consider the concept for further development and a future mission, substantiated with a description of applicable scientific and technical disciplines necessary for development. Typically, NIAC selects 12-16 Phase I awards and 6-8 Phase II awards to fund each year.

Beginning in FY19 the NIAC Program initiated a Phase III opportunity to strategically transition the most promising NIAC concepts to other NASA programs, other government agencies, or commercial partners. Phase III studies are funded for up to two years, at a total program cost of up to \$2M. Phase III proposals should demonstrate an advocacy, and preferably commitment, from a potential transition/infusion partner. While not required, external partnerships and resources to augment a potential Phase III award are encouraged. NIAC anticipates funding one Phase III award per year; however, in FY19, two inaugural Phase III awards were selected for funding by the Space Technology Mission Directorate in the areas of asteroid mining and lunar pit exploration.^{2,3}

As Phase II and Phase III studies are nominally two years long, midterm continuation reviews are held for these projects at the end of their first year. Continued funding for the second year is contingent

on successful demonstration of progress at the midterm review. To aid in the evaluation of the study results and the potential transition of the concept into future NASA missions, subject matter experts and technical representatives from possible target organizations (within and outside of NASA) are invited to participate in the reviews.

With the exception of federal agencies and NASA centers that will receive inter/intra-agency transfers or contracts, all Phase I and Phase II awardees can expect to receive grants. Phase III awards are firm-fixed-priced contracts with milestone payments.

A summary of the three NIAC study phases is provided in Figure 1 below.

PHASE I Establish the feasibility of your concept	PHASE II Address the most challenging aspects to solidify feasibility	PHASE III Implement strategy for technology transition and utilization
<ul style="list-style-type: none"> • Up to \$125K • 9 MONTHS for concept definition and initial analysis in a mission context • 12-16 awards/year 	<ul style="list-style-type: none"> • Up to \$500K total • 2 YEARS for further development of the most promising Phase I concepts, including comparative mission analysis, pathways forward, and spin off technologies • 6-8 awards/year 	<ul style="list-style-type: none"> • Up to \$2M total • 2 YEARS with the goal to strategically transition Phase II concepts with the highest potential impact for NASA, OGAs or commercial partners • 1 award/year

Figure 1. The NIAC Program funds innovative aerospace concept studies in 3 competitive phases.

2. NIAC History

NASA has always sought out innovative ways to push the boundaries of technology and exploration. Investment in futuristic, innovative research has historically benefitted the nation as a whole on a far-reaching basis, up to and including generating entire new industries. This section provides a brief history of the current NASA Innovative Advanced Concepts Program and its predecessor, the NASA Institute of Advanced Concepts. A more general background of NIAC, focused on the earlier NASA Institute of Advanced Concepts and its eventual transition to the current NIAC Program, is covered in Turner et al.⁴

2.1. 1998-2007: The NASA Institute of Advanced Concepts

The NASA Institute of Advanced Concepts (known widely as “NIAC” but referred to herein as “the Institute” to avoid confusion with the current program), was led by Dr. Robert Cassanova and started in 1998 under a contract to Universities Space Research Association. The Institute continued until its termination in August 2007. It was run as a virtual institute, which, befitting its name was an innovative operational construct at the time. During its nine years of operation, the Institute received 1309

proposals and awarded 126 Phase I studies and 42 Phase II studies⁵.

The Institute’s legacy may well be summed up by its signature quote, attributed to Dr. Robert Cassanova and Sharon Garrison, the NASA Contracting Officer’s Technical Representative: “Don’t let your preoccupation with reality stifle your imagination.”

The Institute’s 2007 termination occurred in a period when NASA was strongly focused on planning for a return to the Moon. In 2008, Congress directed NASA to commission a National Research Council (NRC) study to evaluate the Institute’s performance and to make recommendations concerning whether the Institute should be reinstated. If so, the NRC was also asked to suggest changes that could increase its effectiveness.

The NRC responded with a report in 2009, “Fostering Visions of the Future”⁶ that was highly supportive of the Institute, and recommended that NASA reinstate a NIAC-like entity, but suggested a few changes as well. The NRC endorsed the Institute’s vision, scope, and selection process. The most substantial change was to open the process to NASA researchers.

In 2010, the NASA Chief Technologist invited Dr. Jay Falker to NASA HQ to address the NRC recommendations about NIAC. Dr. Falker proceeded to establish the NASA Innovative Advanced Concepts (NIAC) program, hosted by the Space Technology Program in the Office of the Chief Technologist, in late 2010 and early 2011. The program name was modified slightly to reflect the fact that it would no longer be a purely external institute. But the acronym NIAC was preserved to send a clear signal that the new program would be true to the goals and ideals of the Institute.

2.2. 2011-Present: The NASA Innovative Advanced Concepts Program

In 2012, NASA more formally separated the Office of the Chief Technologist from the Space Technology Program, and in 2013 it elevated the Space Technology Program to Directorate level: The Space Technology Mission Directorate (STMD). Today, NIAC remains within STMD and continues its role as the entry point for innovative concepts that may someday “change the possible” in the words of its initial Program Executive, Dr. Jay Falker. Dr. Falker was promoted in 2015 to lead STMD’s Early Stage Innovation portfolio, and is currently the Deputy Director for STMD Strategic Planning and Integration. Mr. Jason Derleth (NASA Headquarters), the first Program Manager of the reconstituted NIAC Program, was subsequently promoted to the position of NIAC Program Executive. Dr. Alvin Yew was

detailed from the Goddard Space Flight Center to serve as the Program Manager from 2015 through 2017, with Dr. Michael LaPointe of the Marshall Space Flight Center subsequently filling this position. Dr. Ronald Turner (ANSER) and Ms. Kathy Reilly (Bryce Space and Technology) continued as Senior Science Advisor and Strategic Partnerships Manager, respectively, roles they've held since 2012. In 2018 Mr. John Nelson (Bryce Space and Technology) joined the team as Senior Technical Consultant, and Ms. Tara Halt (Bryce Space and Technology) as NIAC Program Analyst. Principal Investigators of funded NIAC studies are designated "NIAC Fellows" and are considered a part of the NIAC organization, even after their funded studies have concluded. Additional details regarding the NIAC Program Office may be found at the NIAC website.

The current NIAC retains a feature of the original Institute, an External Council, consisting of distinguished individuals whose role is to assess how well NIAC is meeting its vision and goals and to make recommendations to the NIAC Program Executive. The NIAC External Council (NEC) attends NIAC's public symposia and meets formally after each symposium to discuss any issues and to provide feedback. The position of Chair rotates among NEC members on a biannual basis; Dr. Louis Friedman currently serves in this position, with Ms. Ariel Waldman assuming these duties in FY20. More details on the NIAC External Council are located at: https://www.nasa.gov/directorates/spacetech/niac/nec_bios_all.html.

3. NIAC Study Selection Process

NIAC studies are selected by merit as determined by a thorough peer review process. Anyone is eligible to submit a NIAC Phase I proposal; however, NASA can only fund US organizations. Foreign entities may propose, but if selected the study will be conducted on a "no exchange of funds" basis.

3.1. Phase I Concept Requirements

NIAC Phase I selection begins with the release of a call for proposals through the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) (<http://nspires.nasaprs.com>). Scope is a tricky subject for NIAC, so the Program Office uses a two-step process to avoid wasting the proposers, and subsequently the reviewers, time. Step A proposals are brief 3-page descriptions of the concept. The NIAC Program Office reviews the Step A proposals and invites the most promising of the eligible concepts to submit a more thorough Step B proposal.

The full scope of NIAC Phase I concepts was described earlier. Other programs at NASA have the

responsibility to explore and develop new technologies, materials, or subsystems. A continuing challenge in the NIAC Program is to articulate to proposers the unique niche that NIAC fills: the opportunity to explore bold new ideas that may fundamentally change the way NASA embarks on future missions, by looking at concepts in mission context.

Concepts proposed in Phase I must satisfy the following criteria in order to qualify as candidates for a Phase I study. The proposed concept must be:

- *An Aerospace Architecture:* Aerospace includes activities related to space and aeronautics in terrestrial or extraterrestrial environments. An architecture includes multiple systems, and a concept of how they are used together to achieve mission goals.
- *Proposed in a Mission Context:* A mission context involves the architecture, science objectives, operations, logistics, system-level design, etc. that frames the particular innovation being proposed. Innovative technologies, such as an instrument or detector, should not be submitted as a standalone development in NIAC. Rather they should be incorporated within a mission context. A detailed discussion of mission context is provided in Section I above.
- *Innovative and Offer High Potential Impact:* Enables an entirely new mission or greatly improved execution, or offers a great leap in capabilities. There are benefits to conducting the study now, even if the ultimate vision is far term or high risk. Breaks new ground, changing the conversation about future possibilities or significantly contributing to science and understanding. Generally, a NIAC concept is based on new technology, but it could be based on existing technology applied to a mission in significantly new and innovative ways.
- *Credible and Reasonable:* Technically sound and based on solid scientific/engineering principles. Plausibly implementable; at least one reasonable path for further development and eventual implementation must be described.

To further clarify what NIAC is looking for in a study, NIAC solicitations also note what the program is *not* looking for. Table 1 is the list as published in the 2020 NIAC call for proposals.⁷ Out of scope examples, which are not considered for award, include narrowly focused technology studies, proposals for scientific studies, and broad literature reviews of advanced technology or approaches.

Table 1 NIAC Phase I Step A elimination criteria.

NIAC Phase I Elimination Criteria	
1.	Not an aerospace architecture. Fails to sufficiently address NASA goals or potential space or aeronautics benefits.
2.	Proposed concept is unclear or not adequately articulated. It fails to identify or propose to study a specific innovative concept. NIAC does not fund studies that identify a difficult challenge coupled with a plan for a thorough literature search or trade-off study of known alternative concepts.
3.	No mission context. The mission context is missing or insufficiently described.
4.	Previously explored. Does not identify a new factor that substantially differentiates the proposal from prior efforts.
5.	Incremental. Proposes typical next steps or aims at only modest improvement, rather than investigating far term or high risk "breakthrough" concepts.
6.	Not technically credible. Conflicts with established physics or engineering principles, without acknowledging this and offering a sufficiently plausible defense.
7.	Not programmatically credible. No reasonable path to implementation, without acknowledging the barriers (e.g., requiring unrealistic budgets or policy changes) and offering a sufficiently plausible approach.
8.	The proposal is too narrowly focused on technology or subsystems development of smaller scope (e.g., components, instruments, materials) without sufficient evidence of incorporation into a mission context. While some focused work may be appropriate to establish the credibility of the underlying technology, a NIAC study must also include a detailed mission analysis.
9.	The proposal is too narrowly focused on science experiments (e.g., laboratory characterization, field work) without sufficient evidence of incorporation into a mission context. While a NIAC study may involve such efforts, it must also include a detailed mission analysis.
10.	The proposal is too narrowly focused on the development of tools or processes (e.g., improve design, decision-making, algorithm development) without sufficient evidence of incorporation into a mission context. While these are often beneficial products of a study, a NIAC study must also include a detailed mission analysis.

3.2. Phase I Selection Process

There is great enthusiasm within the aerospace community for exploring revolutionary ideas. As a result, there is a tremendous response to NIAC’s calls for studies. Since NIAC can only fund a fraction of the hundreds of proposed concepts, the first step in the evaluation process is a determination by the Program Office whether each proposal meets NIAC’s scope, as explained in the solicitations. Proposals that fail are assigned a primary, and in some cases also a secondary, reason why it was determined to be out of scope based on the elimination criteria defined in Table 1. The frequency with which a Step A proposal failed to be deemed in scope for FY 13 through FY 19 is shown in Table 2. For the past few years, the chief reasons have been that the concept was either seen as incremental; the proposed study did not adequately put the innovative idea in a mission context; or the proposal was too narrowly focused on an underlying technology or research.

Table 2 Percentage of out of scope criteria invoked as a Primary or Secondary reason for eliminating a Phase I Step A proposal from further consideration.

A subsequent screening of the remaining Step A proposals looks at the potential competitiveness of the concept, which is based on (i) the proposed concept’s potential impact if fully successful, and (ii) the clarity with which the proposal describes the essential elements of the concept and addresses the concept’s plausibility and feasibility. Following this additional screening, Principal Investigators of the highest rated eligible proposals are invited to submit a more complete Step B proposal.

NIAC Phase I Step B proposals are assigned to Technical Panels for review. The number of panels is determined by the number and technical mix of the proposals: in FY 12, there were five technical panels, from FY 13 on, there have been three technical panels and one follow-on Integration panel. The technical panels are charged to evaluate the proposals against set review criteria; Table 3 shows the FY19 criteria, as published in the NIAC solicitation:

Table 3. Phase I Step B evaluation criteria.

	Step B Evaluation Criteria	Weight
#1	Innovation	30%
a.	The concept is unexplored or provides sufficiently new approaches to successfully execute the proposed mission.	
b.	Preliminary justification and “back of the envelope” approximations are included and show credibility. However, identified unknowns remain whose parameters are not readily determined, thereby warranting further study.	
#2	Technical Approach/Merit	30%
a.	The work plan demonstrates an understanding of major issues, and proposes a logical, strategic, and judicious course of study to address significant unknowns, barriers, and necessary technology development.	
b.	There is a plan to evaluate alternative approaches to the concept and how new factors substantially differentiate it from prior efforts.	

c.	Team members are sufficiently well qualified, and adequate resources are identified to complete the study as proposed.	
d.	The study timeline is commensurate with the scope of the proposed budget. There is sufficient budget for labor, materials and supplies, mandatory travel, etc. to complete the study.	
#3	Mission Context	20%
a.	The concept must describe a mission and its architecture in sufficient detail to enable assessment by a cognizant reviewer. Novel capabilities should be included and must be contextualized by a mission to show where and how it can be implemented.	
b.	The work plan includes analysis of one specific mission that involves the development of its architecture and system trade considerations.	
c.	The underlying architecture is technically sound, with at least one plausible implementation path.	
#4	Potential Impact	20%
a.	If successful, the concept will enable wholly new missions, offer a significant advantage to previously studied work, or provide a great leap in capabilities for NASA or the greater aerospace community.	
b.	The concept has the potential to generate enthusiasm for a mission and potential to build advocacy to support it within NASA or in the greater aerospace community.	
c.	As a result of performing the study, there are notable scientific, engineering, or creative benefits that contribute to its specific field, even if the concept is shown infeasible.	
d.	There are wider benefits of the study. For example, but not limited to, engaging the public, making a contribution to the national economy, or producing potential non-aerospace spinoffs.	

The fourth criterion deserves some elaboration, as it is unique to the NIAC process. In keeping with NIAC’s goal to “change the possible” it is important that the outcome of the study itself have value, before the concept would have time to be implemented. This has both positive and negative aspects. Positive influences would include significantly changing the dialogue about a proposed concept...would the study focus attention on the idea, would it lead others to consider the approach more critically? Other positive impacts may include the possibility of leading to the start of immediate spinoffs, perhaps outside of the aerospace community. However, a proposal could be downgraded if it were judged that the study would not contribute substantially to a body of existing studies of closely related concepts. If an idea is innovative in the sense that it has promise yet has not been implemented, but a large body of work has previously been done to explore the same or a similar concept, then further study would have less benefit.

The technical panels review the proposals and submit a technical evaluation against the criteria resulting in an overall technical score. They then submit a final overall recommendation to NASA: how strongly would they recommend funding the proposed study? This advice is guided by the technical scores, but need not be constrained by them. While rare, a panel may issue a recommendation that is higher or lower than the technical scores would suggest, provided with an accompanying justification.

The final Technical Panel evaluation forms the basis of all further deliberation and discussion, and also provides the formal evaluation feedback to the proposers (in most cases exactly as received; in rare cases subsequent discussion adds a further notable comment). No subsequent step ever changes any technical review. However, there are additional steps in the selection process, to include:

- *An Integration Panel.* NIAC holds multiple Technical Review Panels in Phase I. The Integration Panel looks across the evaluations from each technical panel, and may recommend shifts in the final recommendations if some proposals appear to be out of family in terms of merit or quality from the Technical Review, compared to the others that received similar ratings. The Integration Panel also takes the first look at the final list within the context of a NIAC portfolio, and votes to recommend the funding order of the highest rated proposals.
- *HQ Discussion/Selection.* NIAC reviews the recommendations with other NASA programs for potential duplication or synergy. This process is to seek comments only, not further technical review. These inputs may or may not affect the final recommendation order sent to the Source Selection Officer (for NIAC this is the STMD Associate Administrator, or his Deputy if designated), but all Technical Panel scores are presented, unchanged. The Selection Officer also considers political factors and overall STMD portfolio balance, and makes the final selection.

Technically, all of NIAC’s review inputs are merely advisory to the STMD Source Selection Official, but to date NASA has demonstrated confidence in and respect for the NIAC review process, and implemented very few changes in final awards.

3.3. Phase II Selection Process

NIAC Phase II selection also begins with the release of a call for proposals through NSPIRES. However, the eligibility is substantially different. Only Fellows who have completed a Phase I study may submit a Phase II proposal, and the study must

be substantially based on the Phase I study results. Because of its termination, Fellows of the Institute may also submit Phase II proposals if the concept was not selected for Phase II or if it was selected but the Phase II study was cancelled before it could be completed. Again, the concept must be substantially based on the prior Phase I study.

The proposed studies are submitted to one or more technical panels for review. Since these concepts have already been selected against the NIAC scope criteria, and since the studies are aimed at providing a sound basis for NASA to consider the concept for further development and a future mission, the evaluation criteria are different from that of the Phase I studies. Table 4 shows the NIAC Phase II evaluation criteria as posted in the FY19 Phase II NIAC solicitation.⁸ The evaluation criteria are similar to the Phase I criteria, but adjusted to reflect the lessons that should have been learned in Phase I:

Table 4. Phase II evaluation criteria

	<i>Evaluation Criteria</i>	<i>Weight</i>
#1	Innovation	20%
a.	The concept continues to demonstrate unexplored and exciting aspects of value to investigate over the Phase I study.	
b.	Analysis completed in Phase I is credible. However, unknowns remain that are not readily determined, thereby warranting further study.	
c.	The concept is thoroughly described in a mission and its architecture. Novel capabilities are included and contextualized by a mission to show where and how it can be implemented.	
#2	Potential Impact of the Concept	30%
a.	If successful, the concept will enable wholly new missions, offer a significant advantage to previously studied work, or provide a great leap in capabilities for NASA or the greater aerospace community.	
b.	Based on results from the Phase I study, the concept continues to generate enthusiasm for a mission and potential to build advocacy to support it within NASA or in the greater aerospace community.	
#3	Technical Approach	30%
a.	Work plan demonstrates understanding of major issues, proposing a logical, strategic, and judicious course of study to address significant unknowns, barriers, and necessary technology development.	
b.	Proposed research objectives build on Phase I findings.	

c.	Team members are sufficiently qualified and adequate resources are identified to complete the study as proposed.
d.	The study timeline is commensurate with the scope of the proposed budget. There is sufficient budget for labor, materials and supplies, mandatory travel, etc. to complete the study.

The Phase II Technical Panel products are similar to those of Phase I Technical Panels: detailed evaluations and advice on funding priority. There has only been one Technical Panel each year, so there has been no need for an Integration Panel. The Phase II Technical Panel is followed by steps similar to the Phase I process, with final award selections made by the STMD Source Selection Official.

3.4. Phase III Selection Process

As noted, NIAC Phase III studies are designed to strategically transition Phase II concepts with the highest potential impact to other NASA programs, other government agencies, or commercial partners. Phase III awards again utilize a two-step proposal and evaluation process, where Step 1 is a brief Mandatory Preliminary Proposal (MPP) based on the Fellow's Phase II research. The Phase III competition is open to all categories of U.S organizations with current or successfully completed NIAC Phase II studies; for FY19 and FY20, the opportunity was also open to prior Phase II studies completed under the predecessor NASA Institute for Advanced Concepts. The MPPs are evaluated by NIAC Program Office personnel and external subject matter experts using four equally weighted criteria:

- 1) **Innovation and Benefits:** Describes a well-defined aerospace concept, proposed in a mission context, and identifies key innovative features, benefits, and potential major impacts for a future NASA mission(s). Includes potential opportunities for commercialization or technology transition to NASA, other government agencies or industry partners.
- 2) **Prior Performance:** Adequately describe the key results obtained in the NIAC Phase II study, including the beginning and ending TRL of the proposed concept and justification for the current TRL. Identifies the critical gaps that must be addressed in the Phase III study to advance the technology and enable a successful transition to other projects or programs.
- 3) **Proposed Milestones:** Provides suitable Phase III milestones to address the critical technology development gaps identified in the prior work, and a high-level schedule of estimated

completion date of each key milestone. Milestones should demonstrate that the technology has reached a development level appropriate for transition into other NASA funded projects or missions, or other funding opportunities through non-NASA entities.

- 4) **Transition Strategy:** Outlines a realistic strategy to transition the results of the Phase III research into a future NASA mission or project, and demonstrates why NIAC funding is uniquely required to support a successful transition. Identifies additional opportunities, such as the development of a commercial product or potential transition into other non-NASA government or industry programs. Transition strategy includes potential partners identified during or since the Phase II study that have expressed an interest in further funding or transitioning the Phase III technology into a NASA mission or other future project.

Once the technical evaluation of the MPP is complete, NIAC will consider programmatic considerations such as portfolio balancing, costs, and other programmatic considerations, in order to determine the most competitive MPPs to be invited to submit a Final Proposal. The Phase III solicitation, feedback regarding MPPs, and invitations to submit Final Proposals are all provided to proposers via the NSPIRES system.

Phase III Final Proposals are significantly more detailed, and define the promise of the concept, the technical and management approach, a proposed statement of work with technical milestones, price and budget justifications, and letters of commitment and resource support. The concept described in the Final Proposal must be the same as the concept submitted in the MPP, and involve the same technological approach described in the MPP. The Final Proposals are evaluated by the NIAC Program Office and an independent team of subject matter experts, with major and minor strengths and weaknesses defined against the criteria shown in Table 5.

Based on the identified strengths and weaknesses, the Phase III reviewers assign a consensus score for each criterion and compile a prioritized ranking of proposals. The program prioritized recommendations are then presented and discussed with an STMD Recommendation Panel to ensure coordination and mitigation of potential organizational conflicts of interest across STMD, and to gather final comments and recommendations for the STMD Source Selection Official. The Recommendation Panel does not modify scores or evaluations from the review team, but it may shift proposals between rating

categories or adjust the prioritization of proposals within a rating category relative to those developed by the review team. The results of the review team and Recommendation Panel are presented to the Source Selection Official to make the final selection of proposal(s) to be negotiated for award, based on the review panel findings and other considerations such as budgetary restrictions or portfolio balancing. With the exception of federal agencies and NASA Centers that will receive inter/intra-agency transfers or contracts, Phase III awards are firm-fixed-priced contracts with milestone payments.

Table 5. Phase III Final Proposal evaluation criteria.

	Phase III Final Proposal Evaluation Criteria	Weight
#1	Introduction/Promise of the Concept	25%
a.	The concept continues to demonstrate unexplored and exciting aspects of value that address strategic need(s) defined by NASA, another government agency, or a commercial partner.	
b.	Based on the results of the Phase II study, the concept has generated advocacy, and preferably commitment, from a potential transition/infusion partner.	
c.	If successful, the concept will enable wholly new missions, offer a significant advantage to previously studied work, provide a great leap in capabilities for NASA or other transition/infusion partner, or greatly advance national aerospace capabilities and U.S. economic competitiveness.	
#2	Technical Approach	35%
a.	Proposed specific goals and objectives build on Phase I and II study findings.	
b.	The extent to which the proposed technology development work plan, including a detailed schedule with milestones, represents a feasible, sound technology development plan that accomplishes the objectives of the effort within the proposed time period and that advances the technology readiness level to enable transition or commercialization.	
c.	The extent to which the proposed technology development plan identifies one or more specific, clearly defined transition opportunities to be initiated during or after Phase III development.	
d.	The extent to which major technical challenges and risks are clearly identified and feasible mitigation strategies are proposed.	

e.	The suitability and capability of proposed facilities, laboratory space, fabrication methods, equipment, and test techniques to accomplish the work.	
#3	Management Approach	25%
a.	The merit of the overall management approach for the proposed effort	
b.	The merit of the proposed organizational structure and teaming arrangement.	
c.	The extent to which the SOW clearly reflects the work plan outlined in the Technical Approach, as well as the Management Approach of the offeror.	
#4.	Price	15%
a.	The reasonableness of the proposed price of the overall proposed technology development effort.	
b.	The reasonableness of the payment distribution in the Milestone Payment Schedule and the extent to which the milestone payments are tied to technical achievement, and the proposed funding profile	
c.	Funding commitments (if any) from a potential transition/infusion partner.	

4. Overview of NIAC Funded Projects

As noted, NIAC funds early stage feasibility studies of visionary concepts that address government and commercial aerospace goals. Concepts are solicited from any field of study that offers a radically different approach or disruptive innovation that may significantly enhance or enable new human or robotic science and exploration missions. Concepts are framed in terms of a mission context that clearly identifies scientific or technical advancements and associated benefits compared to current approaches. NIAC typically receives over 200 Phase I Step A proposals each year, from which a smaller, highly competitive subset are invited to submit Step B proposals based on the criteria outlined in Section 3.1; of that number, NIAC typically funds 12-16 Phase I proposals each year. Upon completion of a successful Phase I study, proposers are eligible to submit for a Phase II award; NIAC typically receives around 25 Phase II proposals each year, of which 6-8 are competitively selected for award. In the first year of the Phase III opportunity, NIAC received 25 Mandatory Preliminary Proposal submissions, from which 5 were invited to submit Final Proposals, resulting in 2 awards. All Phase I – III proposals not selected for award receive a summary of technical review panel comments related to proposal strengths and weaknesses, and are eligible to reapply to subsequent NIAC solicitations.

A full list of NIAC funded studies, along with links to final reports and associated symposium presentations, is available on the NIAC website: www.nasa.gov/niac.

4.1. General Statistics

Since 2011, NIAC has funded 179 studies (128 Phase I and 51 Phase II, with an additional 2 Phase III awards currently selected for funding). The distribution of awards by organization type is shown in Table 3. It is anticipated that 12-16 new Phase I studies, 6-8 new Phase II studies, and 1 Phase III study will be selected in the March 2020 timeframe. Figure 2 shows the approximate dollar total (in U.S. \$M) awarded to date by the type of organization for Phase I and Phase II. Prior to 2017 the Phase I awards were a maximum of \$100k, after which they were increased to \$125k; Phase II awards are each funded at a maximum of \$500k. The amounts are grouped by the Principal Investigator’s (the NIAC Fellow’s) organization, so the dollar distribution does not reflect funds that may have been subcontracted or otherwise allocated to other organizations. The category “NASA” includes all NASA Centers, including the Jet Propulsion Laboratory. The category “Industry/Other” includes a variety of organization types, including large and small businesses, not-for-profit and research institutes, etc. Of interest, the funding allocation between NASA researchers, academia, and other institutions is approximately evenly split at 1/3 each. This is not a requirement of the program, nor is the type of organization considered in the review process; rather, it concisely illustrates that innovative ideas can arise from a variety of sources, and that the program is effectively tapping that broad pool of national talent.

Figure 2. A breakdown of total NIAC awards by dollar amount (see text for additional details).

Figure 3 shows how NIAC awards have been distributed throughout the United States as of March 2019: 24 states and the District of Columbia are home to one or more NIAC Fellows.

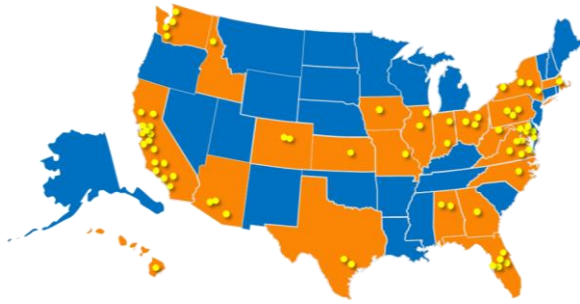


Figure 3. Locations of NIAC Fellows at time of award.

4.2. Technical Areas represented by NIAC Studies

NIAC is open to any technical area that is relevant to NASA, and NIAC has funded concepts that cover almost all of the areas defined in the NASA Technology Roadmaps.⁹

NIAC studies are often multidisciplinary, and it can be difficult to associate a concept with a specific area if it includes multiple disciplines and objectives. Nevertheless, NIAC concepts can generally be categorized into the following overarching areas, which helps facilitate their grouping for review panel evaluations:

- Transportation, including Earth to Orbit, In-Space, Entry/Descent/Landing, Infrastructure, and Aeronautics;
- Human Exploration, including Environment Control, Radiation Mitigation, Habitats, and Infrastructure;
- Robotics, including Mobility and Sample Collection;
- Science, including innovative technologies to enable or significantly enhance Astronomy, Astrophysics, Planetary Science, Heliophysics, and Earth Science missions; and
- Other, including such areas as Navigation, Power, Communications, Structures, and Asteroid/Orbital Debris Mitigation, if they don't directly map to one of the areas defined above.

While the above categories are useful for binning general proposal areas, it should be emphasized that concepts are solicited from any field of study that offers a radically different approach or disruptive innovation that may significantly enhance or enable new human or robotic science and exploration missions.

5. Strategic Partnerships, Communications, and Outreach

NIAC aims to capture and inspire the ingenuity of visionaries to build the future of tomorrow. This exciting work allows NIAC to successfully engage a wide ranging, diverse global audience. NIAC's audience includes members of technical and scientific communities, independent researcher groups, government institutions, industry, academia, and the general public. NIAC has developed unique partnerships and collaborations with institutions around the U.S. that help the program expand its reach. NIAC engages educators and students with educational outreach that encourages a young audience to consider Science, Technology, Engineering, and Mathematics (STEM) careers through NIAC Fellows' innovative research. NIAC innovations have the potential to fuel economic growth, the creation of new industries, companies, jobs, products and services, and the global competitiveness of the U.S. NIAC's strategic partnerships, communications and outreach serves as a critical element of NASA's public and educational value to the nation. Below is a brief summary of each of NIAC's communications efforts.

5.1. Community

NIAC inspires an atmosphere of innovation with its Fellows that stretches the imagination and encourages creativity. The program actively cultivates a sense of community with its Fellows. Many continue to follow up with the program alerting the team years later, of awards or notable achievements that grew from their original NIAC studies. This community has prospered and continues to grow.

5.2. NIAC Website

NIAC's website (www.nasa.gov/niac) is the central hub of communicating program information to the public. NIAC's online followers use this site to stay current on NIAC upcoming events, funded studies, solicitations, presentations, press releases, external media, videos, and podcasts. Each NIAC Fellow is given a web-based research page devoted to their study. Each page includes a brief abstract, graphics and related visual media and the final report. Past NIAC Symposia have also been archived to the site via LiveStream. NIAC staff and External Council biographies are available, as well as links to other NASA Space Technology programs.

5.3. Annual NIAC Symposium

NIAC holds annual public Symposia at different locations around the United States. The primary purpose of this event is for the Phase I, II and III

Fellows to report on current research findings, progress, and discuss their future plans. Additional time is built into the event to allow the Fellows to collaborate and nurture the interdisciplinary community. Unique technologies have developed through this cross-pollination between Fellows from different scientific backgrounds and many have developed into unique ‘hybrid’ research. The meeting receives approximately 150 in-person attendees, plus approximately 5,000+ virtual participants who watch live via LiveStream. Links to prior NIAC Symposia can be found at: <https://www.nasa.gov/content/niac-symposium>.

5.4. NIAC in the News

NIAC and its Fellows are privileged to receive extensive press coverage. Hundreds of media articles have appeared detailing NIAC Fellows’ concepts, and NIAC’s media footprint continues to grow each year. A small sampling of publications that routinely report on NIAC studies are: NBC News, Popular Science, The New York Times, The Washington Post, Space.com, AIAA Daily Launch, Aviation Week, MSNBC, Discovery News, Smithsonian Magazine, Universe Today and hundreds more at major universities, newspapers and other media outlets throughout the U.S. and abroad. For examples of news articles about NIAC projects, see: <https://www.nasa.gov/content/niac-in-the-news-archive>.

5.5. NIAC Videos

The NIAC program produces NASA 360 videos that are released via YouTube each spring. Video content is captured from the Symposia to create short, 3 minute videos with animations in collaboration with the National Institute of Aerospace (<https://www.youtube.com/user/FollowNASA360>). Many television production teams have developed extensive programming of NIAC research based on their introduction from the NASA 360 videos. For examples of NASA 360 videos that have been produced, see: <https://www.nasa.gov/directorates/stmd/niac/videos>.

5.6. Radio Programming

Additional content from Symposia are used to create radio broadcasts and podcasts for Innovation Now radio (<https://www.innovationnow.us/>) through the National Institute of Aerospace. Innovation Now provides listeners with compelling stories of revolutionary ideas, emerging technologies and the people behind the concepts that are shaping our future. Reaching several million listeners each day, Innovation Now broadcasts air each weekday, with new 90-second episodes exploring how these

innovations benefit our lives and impact our world. In addition, numerous NIAC Fellows have also been interviewed on Planetary Radio, supported by The Planetary Society. Each week, Planetary Radio visits with a scientist, engineer, project manager, astronaut, or writer who provides a unique and exciting perspective on the exploration of our solar system and beyond. For more information visit: <http://www.planetary.org/multimedia/planetary-radio/>

5.7. NIAC Social Media

Further extending NIAC’s visibility to the public, NIAC concepts are routinely placed on NASA’s social media sites, which have a large audience of followers and subscribers. Several of these social media platforms, and their current number of followers, are shown in Table 6:

Table 6. NIAC Social Media Participation

Site	URL	Followers
Facebook	https://www.facebook.com/NASA/	22,243,593
Twitter	https://twitter.com/nasa	32.9M
YouTube	www.youtube.com/NASATelevision	4.6M
Instagram	www.instagram.com/nasa/	49.1M
Pinterest	www.pinterest.com/nasa	223,341

5.8. NASA Technology Day on the Hill

Each year, hundreds of researchers across NASA are nominated to attend NASA’s Technology Day on the Hill, to introduce examples of NASA space technology development to members of Congress and staffers. In addition to the public, attendees typically include U.S. Senators, Representatives, their staff members, the NASA Administrator and Deputy Administrator.

5.9. Science & Technology Museums

A unique partnership has developed between NIAC and many science and technology museums around the U.S. NIAC researchers are invited to share their research with large public audiences through an educational lecture series called, From Science Fiction to Science Fact (SFSF) Participants have included the Museum of Flight, in Seattle, WA, the Museum of Natural History in Raleigh, NC and the Chicago Museum of Science and Industry (MSI) in Chicago, IL.

At MSI, the event is hosted in the OMNIMAX Theater where NIAC Fellows introduce their STEM related innovations to a general public audience of ~ 300-500 youth, underrepresented students, and the general public. NIAC Fellows also speak with MSI’s Science Minors and Science Achievers Youth Program. This youth development program provides

out of school STEM learning experiences for high school aged youth from across the Chicago area. The program is designed to nurture participants in science and engineering content, to prepare them for college and to consider STEM careers. These interactions have included discussions with the Fellows about their individual career paths. NIAC looks forward to continuing this partnership to inspire the next generation of explorers and innovators.

5.10. *World Book, Inc.*

In collaboration with NIAC, World Book, Inc. has published a series of children's books (in print and e-book form) about applications of basic science principles in advanced aerospace sciences.¹⁰ A theme in each book is the link between commonly understood science principles and the uncommon NIAC technologies to which they contribute. A feature of each title is a capsule biography of the scientist(s) associated with each research project. The purpose of the biographies is to show that today's working adult scientist was once a school child, like the reader, who became attracted to the sciences, perhaps through books he or she read or because of an inspiring teacher, and from there, fulfilled an aspiration to become a scientist. The first book series, published in 2017, has reached over 250,000 students and was named one of Booklist's Top 10 Best New Nonfiction Series for Youth. A second series is currently in work, along with a new spin-off activity in association with WorldBook called NIAC Jr., with the goal of further enhancing STEM involvement at the elementary through high school levels.

5.11. *Mentoring*

NIAC staff mentors interns on an annual basis, both through NASA intern programs as well as mentoring programs at ANSER and Bryce Space Technology. NIAC is also engaged with multiple school and community outreach activities, including the FIRST Robotics competition, the NASA Girls/NASA Boys program, and several other venues where we can inspire the next generation of NIAC Fellows to "Change the Possible" in aerospace.

6. **Leading to Success**

Several technology concepts initially developed under the NIAC Program have gone on to achieve significant success through the acquisition of additional external funds, the submission of patents, and standing up new entrepreneurial companies dedicated to enabling new aerospace capabilities. A partial list of examples includes the development of a new, highly reflective coating material to enable extreme thermal protection and deep space cryogenics;¹¹ the award of over \$1M in ARPA-E

funding to further develop the physics of a novel fusion concept;¹² the upcoming 2021 launch of the ultra-long duration GUSTO (Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory) balloon mission incorporating technology derived from a NIAC Large Balloon Reflector study;^{13,14} the interstellar Breakthrough StarShot project¹⁵ based on a prior NIAC directed energy concept study;¹⁶ and the formation of several new businesses such as Trans Astronautica¹⁷ and Contour Crafting,¹⁸ which are leading the industry in the development of asteroid mining architectures and exoplanetary construction techniques using *in situ* resources, respectively. With the advent of the new Phase III opportunity directly focused on technology infusion, the successful transition from NIAC concept to mission reality is only anticipated to accelerate.

7. **Conclusion**

There have been many aerospace research and technology programs, inside NASA and around the nation, but NIAC truly is unique. While scientists and engineers are usually constrained to careful, incremental steps, this program invites researchers to be bold and imaginative. NIAC successfully communicates its cutting edge technology research with the public, educators, and students as well as developing unique strategic partnerships and collaborations. These efforts provide opportunities to change aerospace conversations, expand NASA's vision, inspire STEM, participate in NASA's Mission, foster innovation and contribute to a strong national economy. NIAC is helping to excite the general public, and inspire the next generation to dream and dare ever further.

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