TECHNICAL REVIEWERS' RATING SUMMARY

R025-C

Solar Soaring Power Manager

Packet Digital, LLD
Principal Investigator: Andrew Paulsen
Request for $350,000; Total Project Costs $1,000,000

Rating Category	Weighting Factor	Technical Reviewer 1C Rating	2C Rating	3C Rating	Average Weighted Score
1. Objectives	9	4	4	3	33.00
2. Achievability	9	3	2	2	21.00
3. Methodology	7	2	2	3	16.33
4. Contribution	7	5	4	2	25.67
5. Awareness	5	2	3	3	13.33
6. Background	5	4	3	4	18.33
7. Project Management	2	3	1	3	4.67
8. Equipment Purchase	2	5	5	5	10.00
9. Facilities	2	5	5	4	9.33
10. Budget	2	5	5	3	8.67
Average Weighted Score		178	158	145	**160.33**
Maximum Weighted Score					**250.00**

OVERALL RECOMMENDATION

FUND	x		
FUNDING MAY BE CONSIDERED		x	x
DO NOT FUND			

R025-C
Solar Soaring Power Manager
Submitted by Packet Digital
Principal Investigator: Andrew Paulsen
Request for $350,000; Total Project Costs $1,000,000

1. The objectives or goals of the proposed project with respect to clarity and consistency with North Dakota Industrial Commission/Renewable Energy Council goals are: 1 – very unclear; 2 – unclear; 3 – clear; 4 – very clear; or 5 – exceptionally clear.

Reviewer 1C (Rating: 4)
The project clearly adds immediate jobs in solar technology, with a long term promise of use and sustainment of solar powered UAS that would complement other North Dakota industries such as agriculture and energy. Even if the renewable energy (solar conversion) doesn't work, other parts of the program could be a benefit to UAS products that complement North Dakota industries.

It is never made clear what baseline is "doubling" to achieve the object of doubling a commercial UAS flight endurance. The letter from the Northern Plains UAS Test Site claims their current systems being tested have a 19 minute duration, so doubling this would be 40 minutes, which is a very modest duration as many, many advertisers of commercial UAS's claim durations in excess of 40 minutes. While there is no deliverable in phase II (list is on page 8 of 15) associated with any specific duration, it remains a top- level aspect of their overall demonstration.

Reviewer 2C (Rating: 4)
- The primary objective of the Phase II project is to create a new solar soaring power management systems for unmanned aircraft systems (UAS) that can lead to considerable increases in fly times and pave the way towards self-sustained continuous flight. The team provides general expected impacts in many areas of direct value to ND landowners and producers, such as agricultural monitoring.
- The project directly aligns with the Council's goals of promoting renewable energy sources, creating positive economic impact from renewables in the region, and directly benefiting the landowners and agricultural producers in ND.
- One area of concern is that the team notes the project will support 20 to 25 persons for the duration of the project. This raises concern over the long-term value of the project. Will the effort not result in long-term job creation or retention? This should have been addressed in the proposal to highlight the direct and indirect impacts of the project on jobs in the region.

Reviewer 3C (Rating: 3)
The project goals are clear enough…what's somewhat lacking is the contemplated impact on ND specifically.

2. With the approach suggested and time and budget available, the objectives are: 1 – not achievable; 2 – possibly achievable; 3 – likely achievable; 4 – most likely achievable; or

5 – certainly achievable.

Reviewer 1C (Rating: 3)
I am surprised that the work scope can be executed in 9 months with the amount of man-hours they anticipate (page 15 of 15). However, this is phase II, and in phase I they were evidently successful, which supports their claim. Also, the work breakdown on page 15 of 15 isn't translatable to the timeline on page 14 of 15. The data provided is less useful than their experience in phase I.

Reviewer 2C (Rating: 2)
- The Phase II effort has five listed objectives:
Objective 1: Optimize the stack of two MJ solar cells to demonstrate 30-35% efficiency under 1 sun, with a target of 40% efficiency
Objective 2: Update the existing power system to be compatible with Altavian who is expected to be the manufacturer
Objective 3: Develop a hybrid smart battery system that would have high peak power and be chargeable in flight by the solar system
Objective 4: Optimize the torque motor control to assist in reducing wasted power
Objective 5: Implement solar soaring algorithms

- Objectives 2, 4, and 5 are all likely achievable within the time and budget allocations to the Phase II. This is supported by the prior work of the team and competencies of the associated collaborators.
- Objective 1 for Phase II identifies a goal of 30-35% efficiency that has already been met by the team – according to the Phase I achievements listed in the proposal, a 1 sun efficiency result of 32.4% from NRL has been demonstrated. It is thus not clear why the team would not provide a more challenging goal of 35% or higher efficiency if the ultimate goal of the project is to realize 40% efficiency under 1 sun.

- This reviewer remains skeptical that the team will manage to realize an efficiency close to 40% since it is well known that increases in efficiency of even 1% are hard to come by in such advanced MJ cells. As of the time of this review, the record 1 sun efficiencies for 4+ and 3 junction cells are 38.8% and 37.9%, respectively. These are lab-scale hero cells, far from form factors that are implementable on a UAS. Despite the technical competencies of the team, it is highly unlikely the group will realize efficiencies in the high 30's within the time and budget of the proposed project, particularly at a size and form factor that can conform to the UAS.

- Objective 3 is feasible, but it is a bit concerning that the battery/energy storage backbone of the system is dependent on external advancements outside of the team.

Reviewer 3C (Rating: 2)
The team does seem to have some core capabilities around power management and system design/integration that could go a long way towards improving UAS flying times. Where they don't have capabilities, and where they should be spending no time, is solar cell development. There are thousands of people and large, well-funded multi-national companies that are focused on improving solar cell efficiencies. This team should instead just be looking to integrate off-the-

shelf solar cells (albeit the highest efficiency ones, of course). No offense to the team here, but the types of efficiency improvements they contemplate takes away credibility from what could otherwise be a compelling effort to more realistically improve UAS performance.

3. The quality of the methodology displayed in the proposal is: 1 – well below average; 2 – below average; 3 – average; 4 – above average; or 5 – well above average.

Reviewer 1C (Rating: 2)
Modifications to the SBXC airframe (page 5 of 15) were listed as an achievement from Phase I. However, the methodology is changing to using a new airframe. The is certainly a benefit to using a UAS manufactured in North Dakota, but there is design and integration work that will need to be re-accomplished (page 6 of 15) because they are switching aircraft.

The techniques to be used for power management (page 9 of 15) are vague. Taking the best sentences from the proposal dealing directly with methodology, "The Packet Digital team will develop specialized power algorithms to optimize the solar energy. The techniques to be used for the power management portion will be well understood and familiar to Packet Digital." While this statement may be true, it hardly offers a reviewer any depth to assess whether the methodology is sound.

Reviewer 2C (Rating: 2)
- The proposal lack significant detail in its methodology. Words such as "optimized", "fine tuned", and "improved" are used throughout the narrative that provide no detail on the actual methodologies to be followed to accomplish the targeted goals.

- There are some confusing elements of the proposal. As an example, the team states that 40% efficient PV cells would enable eternal endurance flights, yet elsewhere it is noted that to achieve eternal flight a 50% airframe weight reduction is required along with 50% more area of the solar array. Neither of these is being addressed by the work in the project, and it is unclear how or when such developments will be undertaken. One wonders how 50% reduction in airframe weight might be realized, and if it is feasible. Furthermore, one must ask how much of the current body of the UAS is being covered by the MJ cells and if this leaves the requisite space for another 50% coverage.

- The reliance on finding a new storage technology outside of the project team is concerning. The team's method to overcome the low peak power density of the lithium ion battery solution they are currently using is to do a survey of emerging energy storage technologies – this seems rather plain and lacking as a mitigation strategy.

- Generally, the methodology is not well outlined in the proposal. This is perhaps a result of the limited space available in the application. The team spent more time outlining their Phase I accomplishments than detailing their methods going forward to realize the project goals. A more direct discussion of the methods to be used and relation to milestones and deliverables in the timeline would have been beneficial.

Reviewer 3C (Rating: 3)
The major lacking component is any reference to cost. If a UAS that can fly twice as long costs more than 2x as much, is it really worth it? There is benefit to extending UAS flight times, and it would appear that the team has some real core capabilities around how to do that through better power electronics and other means, but the goal of continuous flight is a long way off and would require technological breakthroughs (the substantial increase in solar cell efficiency, for one) that go well beyond the scope of this project.

4. The scientific and/or technical contribution of the proposed work to specifically address North Dakota Industrial Commission/Renewable Energy Council goals will likely be: 1 – extremely small; 2 – small; 3 – significant; 4 – very significant; or 5 – extremely significant.

Reviewer 1C (Rating: 5)
A near-perpetually flying UAS is an incredible product. To do it with a renewable resource (the sun) is a great leap forward.

Reviewer 2C (Rating: 4)
- It is clear that the project, if successful in its goal of eternal endurance flight capability for UASs, would have a direct impact across many sectors in ND. In particular, agriculture would benefit greatly, as outlined in the proposal.

- The planned goal of manufacturing in ND by Altavian is also of direct value to ND and aligns well with the goals of the REC.

- The project aligns with the REC interest in promoting renewable sources given that the UAS is being designed for solar energy operation without the need for conventional fuel sources.

Reviewer 3C (Rating: 2)
Increased UAS flight times is a valuable pursuit, but relative to other grants in more of a stretch vis-à-vis direct impact on North Dakota.

5. The principal investigator's awareness of current research activity and published literature as evidenced by literature referenced and its interpretation and by the reference to unpublished research related to the proposal is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.

Reviewer 1C (Rating: 2)
The proposal did not reference published research. There was no synopsis of competing or complementary activities outside the proposal's own team-mates. A quick google search of topics such as percent efficiency for solar cells and soaring algorithms suggests there are other doing work in area. The efficacy of this proposal's way ahead as compared to others is a challenge to determine.

Reviewer 2C (Rating: 3)
- The PI provided no references to external work, so it is difficult to assess his awareness of published literature in the technology areas of the Phase II.

- The NRL group clearly has past experience and current demonstrated knowledge of MJ solar cells, thought there really is no discussion in the narrative about the challenging task of increasing their current 32.4% efficient cell to 40%. This reviewer highly doubts the team lacks an understanding of the significant challenges in reaching 40%, but it is puzzling why it feels 40% is obtainable in the near future through the proposed program.

Reviewer 3C (Rating: 3)
The full team (including partners) would appear to be well-positioned with regards to current UAS industry capabilities and advancements.

6. The background of the investigator(s) as related to the proposed work is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.

Reviewer 1C (Rating: 4)
The people listed had strong credentials and track records to do work in this area.

Reviewer 2C (Rating: 3)
- Review of the qualifications and background of the involved researchers indicates that the team has sufficient background knowledge in the various aspects of the project, particular advanced power management/MPPT electronics, and understands critical technological barriers that must be overcome in order to realize a UAS with unlimited flight time.

- NRL brings significant prior experience in MJ solar cells and has a demonstrated accomplishment track record in the field.

- This is further benefited from the involvement of various supporting entities with measurable UAS background, as evidenced from the support letters.

- It is concerning that the team will carry out a survey of available energy storage technologies since this indicates the project is highly reliant on storage capabilities that are not within the control or expertise of the team.

Reviewer 3C (Rating: 4)
Excluding the forays into solar research, the team is very well positioned around power management, which should have positive implications for increasing efficiency of UAS systems overall.

7. The project management plan, including a well-defined milestone chart, schedule, financial plan, and plan for communications among the investigators and subcontractors, if any, is: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – very good; or 5 – exceptionally good.

Reviewer 1C (Rating: 3)
Team coordination will be a key to success, and the weekly telecoms and quarterly face- to-face meetings are a sound plan for collaboration.

The milestone chart, schedule, how it relates to the funding and man-hour projections is hard to understand.

Reviewer 2C (Rating: 1)
- The Phase II timeline on page 14 of the proposal is not legible and seems inadequate. It lacks indications of major milestones and deliverables for the project.

- The Phase II Completion statement on page 7 of the proposal indicates integration into a prototype airframe with be done and tested, yet there is no mention or tasks item listed in the Gantt timeline chart of the proposal.

- No communication plan is indicated, but it seems the group has been collaborating in the past and under the Phase I effort, so this is likely not an issue.

- A goal of the Phase II project is to demonstrate a 30-35% efficient solar cell (see page 8 that lists phase II deliverables). This seems to be a useless goal given that the team states it already has demonstrated 32.4% efficiency as of the Phase I. If the team expects to realize 40% efficiency, a much higher target should be listed, particularly given that this 30-35% is already satisfied before the Phase II start.

- It is highly unlikely that the team will realize a solar cell efficiency near their 40% goal, and this should be better addressed by the team. If it agrees, a discussion of what is likely feasible should be made along with an assessment of what is required in order for the project to be considered successful. This reviewer does not feel the team is being realistic given the lack of deeper discussion in the proposal, and thus there are still major concerns over the feasibility within the listed timeline of meeting the solar cell goals of the project.

Reviewer 3C (Rating: 3)
Some aspects make sense – developing the power system and designing control algorithms, for instance, but others like developing hybrid batteries and solar cell improvements would go significantly beyond the scope of this project.

8. The proposed purchase of equipment is: 1 – extremely poorly justified; 2 – poorly justified; 3 – justified; 4 – well justified; or 5 – extremely well justified. (Circle 5 if no equipment is to be purchased.)

Reviewer 1C (Rating: 5)
NO equipment being purchased.

Reviewer 2C (Rating: 5)
- No equipment is to be purchased under the Phase II effort.

Reviewer 3C (Rating: 5)
No equipment

9. The facilities and equipment available and to be purchased for the proposed research are: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – notably good; or 5 – exceptionally good.

Reviewer 1C (Rating: 5)
The NDSU nano center has $25M worth of special equipment, and the UAS test range is only one of 6 in the country. Navy facilities for experimenting with solar cells, and Packet's own ability to make electronic devices are leading edge. The strengths of so many contributors are combined to make facilities and equipment exceptionally good.

Reviewer 2C (Rating: 5)
- The team has all necessary equipment and infrastructure to carry out the Phase II tasks.

- Perhaps the costliest facilities required relate to the high efficiency MJ cell development, and these assets are in place and available to the team at NRL, as evidenced by NRL's prior MJ cell demonstrations.

Reviewer 3C (Rating: 4)
Partnerships with NRL and the UAS test site should prove to be extremely valuable.

10. The proposed budget "value"[1] relative to the outlined work and the financial commitment from other sources is of: 1 – very low value; 2 – low value; 3 – average value; 4 – high value; or 5 – very high value. (See below)

Reviewer 1C (Rating: 5)
The U.S. Navy provides the bulk of the funding for the activity, and makes a substantial contribution 'in-kind' in the form of in-house research to get the higher efficiency solar cells. There is some private investment. My own organization would have to spend five to ten times the money to meet the tasks and objects outlined for phase two. There has to be another funding source or extremely low overhead for all parties involved.

Reviewer 2C (Rating: 5)
- **Note**: *My responses to this question are based on the assumption that the team would realize the targeted Phase II objectives and goals despite my concerns over the likelihood they will be realized within the 9-month phase II*

- The Phase II cost is reasonable and aligned with what would be expected

- The proposed Phase II effort leverages $650k in matching funds, offering cost share to the project of nearly 2:1, greatly exceeding the 50% minimum required.

- A letter of commitment is included from NRL, validating the $600k of cost share being offered to the Phase II effort.

Reviewer 3C (Rating: 3)
No comment provided.

[1] *"Value" – The value of the projected work and technical outcome for the budgeted amount of the project, based on your estimate of what the work might cost in research settings with which you are familiar.*

[2]*Financial commitment from other sources – A minimum of 50% of the total project must come from other sources to meet the program guidelines. Higher priority is to be given if the application has private industry investment equal to or at least 50% or more of total cost.*

Section C. Overall Comments and Recommendations:

Please comment in a general way about the merits and flaws of the proposed project and make a recommendation whether or not to fund.

Reviewer 1C ***(Fund)***
Reliability: The obstacles associated with the end product (a UAS with unlimited duration) have been narrowly defined. Certainly a UAS needs a renewable energy source if it is to stay aloft for extremely long durations, but a "low battery" or "empty gas tank" is not the only reason a UAS lands. If it has a problem in a critical component (sensor, communications, engine, etc…) it may have to land for maintenance. That said, reliability is a key concept in the proposal's components. For example, if a solar cell achieves the 40% efficiency, but breaks after hours of use, this negates the benefit of high energy conversion (ie. the plane still has to land because it can't renew it energy source). The proposer may understand this concept but did not include it in the proposal, but designing in reliability from the very start (and not trying to engineer it in after all the other obstacles are solved) should be high on the project's priority list, and not just for the solar cell but the other components as well.

Intellectual Property: Although State and Federal funds provide a very high percentage of the project's budget, it appears that no intellectual property (IP) rights are transferred to these entities, and all IP is held by the proposer. This seems out of balance, and I would suggest the State of North Dakota's legal counsel consider what IP (eg. general purpose rights, governmental use rights) it warrants if the proposer applies for patents as an outcome of this work.

Reviewer 2C ***(Funding May Be Considered)***
My general thought is that the team is quite competent in many of the aspects of the targeted system, though I believe some unrealistic goals have been targeted within the time line of the proposed program. My most significant concern is the expectation put forth by the team to realize a 40% efficient MJ cell. Despite the considerable prior experience NRL has in MJ cells, there is not sufficient evidence in the proposal to validate such an expectation. This is further compounded by the need of the resultant cell to conform and be compatible with a UAS, creating greater challenge and risk.

I also have some reservation over the battery development, where the team will rely on advancements outside of the proposed project in order to overcome the low peak power density of the currently employed lithium ion batteries.

I do feel the Phase II is fundable if:

(1) A satisfactory timeline with defined milestones and deliverables can be created prior to award to enable tracking of progress.
(2) The team identifies a *realistic* maximum 1 sun efficiency it believes it can hit with its MJ cell concept *at manufacturing scale*, providing evidence it is achievable based on the current status, and validates that the system will still function effectively if this realistic maximum is demonstrated.
(3) A more pro-active approach is taken on the energy storage system to validate that a feasible solution exists. It must be quickly determined what solutions exist that will meet the requirements of the application so that the team can begin to develop the charging and power delivery system.

Reviewer 3C ***(Funding May Be Considered)***
Increasing UAS efficiency and yielding improved flight times can be very valuable, and the ultimate goal of continuous flight would be a game changer, but it's still very much pie in the sky as evidenced by the need for significant technical breakthroughs. I'd be interested to see a proposal in which the company focused on their core strengths and only purchased off-the-shelf components like solar and batteries. How much improvement would there be with just the smarter power management approaches and soaring algorithms. Is that worthwhile? Also, there's no discussion of cost, which is really the most important factor for the various applications discussed.