North Dakota Renewable Energy Council
Phase III Interim Report

Solar Soaring Power Manager

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Introduction

This document describes the accomplishments and current status of projects during phase III of the Solar Soaring Power Manager project. These activities took place at Packet Digital's facilities in Fargo, ND, as well as at the U.S. Naval Research Laboratory (NRL) facilities. Progress has been made on all phase III deliverables and the project is on track as per the original proposal. A status update of each deliverable is listed below.

Objective:

This research and development project will create a solar soaring power management system for Unmanned Aircraft Systems (UAS) to initially double fly times and ultimately provide unlimited endurance powered by solar energy. This will be achieved by harnessing solar energy with high-efficiency, flexible photovoltaics and auto-soaring technology to enable the UAS to autonomously gain lift from rising hot air along with advanced power management algorithms. Packet Digital will create an advanced solar power management and distribution system (PMAD) combining flexible, high-efficiency power conversion circuitry to dramatically extend flight times in unmanned aircraft.

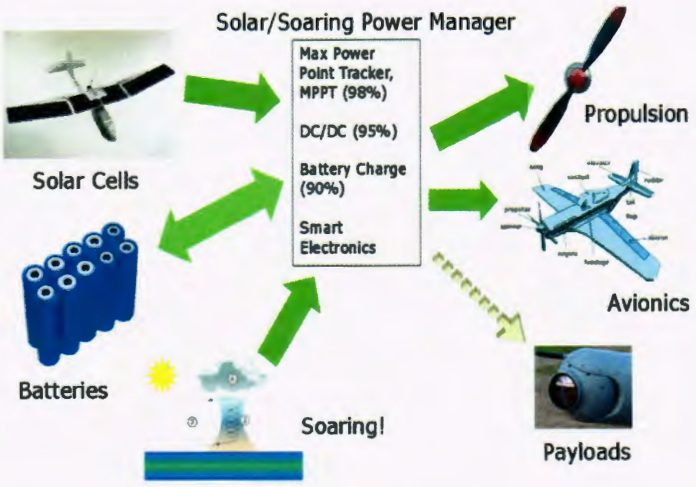

Figure 1: System Overview

This product will optimize the power conversion from the solar array to the batteries, from the batteries to the electronics, and from the batteries to the propulsion motor. The power conversion circuitry will provide state-of-the-art, high-efficiency power while the microprocessor will run advanced algorithms for Maximum Power Point Tracking (MPPT) and auto-soaring.

Schedule

This project is divided into three phases, of which phases I and II are 9-month duration and phase III is 12 months. This interim report covers the progress made during months 4-6 of phase III.

Deliverables

Phase III Deliverables:

- Produce a solar cell covering the desired spectrum with 30-35% efficiency, with a target of 40%
- Perform multiple flight tests utilizing a solar-enabled, extended-endurance UAS
- Achieve power management system with greater than 90% efficiency for typical loads, with a target of 95%, to extend battery life sufficiently to survive nighttime flight
- Innovate Maximum Power Point Tracker (MPPT) algorithm for extracting maximum charging capacity from the solar cells
- Develop a manufacturing plan for a commercial, extended-endurance, solar UAS

Status Updates

Objective 1: Solar Cell Development

The NRL team has been continuing the development and fielding of solar cells and arrays for the UAV wings. The last report included results from the solar arrays that the NRL team made using Si solar cells. These arrays have been integrated in the wings of the airframe and flight testing has been reported. NRL is currently building the prototype of Si array-powered UAVs, and flight-testing will commence during the next quarter. Once these wings have been flight-tested, one of these wing sets will be delivered to Packet Digital for further testing.

Within the reporting period, the NRL team has initiated efforts with the high-efficiency, multijunction (MJ) solar cells. These MJ solar cells are capable of achieving upwards of 33% efficiency. NRL has built initial test panels and performed outdoor ground testing (Figure 2).

There was ideal sun on the testing day (1/6/2016), and while the team is still analyzing the measured data, the performance numbers from the 4 MJ wing sections produced 53-60W, which translates to 22-25% array efficiency.

Considering the insolation was slightly higher than nominal (e.g. slightly higher than 1000W) and that the temperature of the panels are slightly higher than room temperature (~48°C compared to standard AM1.5G of 25°C), the ongoing analysis is expected to show peak performance at 62W (26% efficiency). It should be noted that the measured panel performance includes the blocking diode and coversheet accounting for slightly lower performance (~5% from coversheet and 0.6W (~2 amps) from the diode).

Based on the preliminary results, a full PV airplane of MJ cells would deliver ~118 W. For comparison, the Si panel is estimated to produce 107 W (21.8% array efficiency), which

includes a cover film, but no blocking diode. Since these panels deliver ~7.3 Amps at the max power point, the blocking diode losses are 2.2 W resulting in ~105 W (21.4% array efficiency) of power under the same test conditions. In summary, the preliminary results suggest that the MJ panels can deliver ~13W more power than the Si arrays.

Figure 2: Members of the NRL team performing outdoor ground testing of the MJ arrays.

With the initial ground testing completed, the NRL team had commenced on building the MJ solar cell wing sets. Photos of the build are shown in Figure 3. The assembly will result in two wing sets. The team has built one wing set and is building the second wing set currently. Flight-testing is expected during the next quarter.

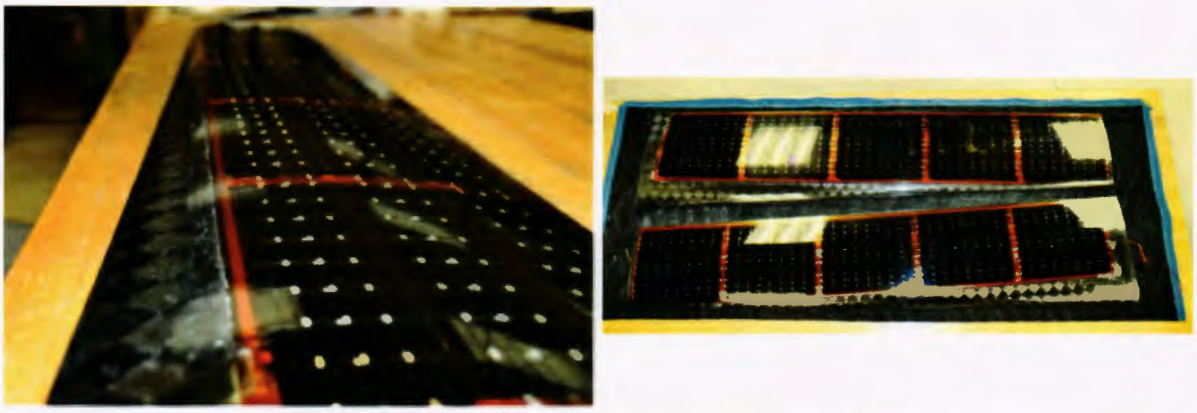

Figure 3: Photos of the MJ solar arrays being build in the NRL laboratory.

Objective 2: Test Flights

No test flights were performed during this interim. Test flights with the C2Renew wings will begin in interim 3.

Objective 3: Power Management Update

Electronic Speed Control

Data was collected with the new alternate version of the optimized electronic speed controller (ESC) to compare to the previous ESC options. The new platform was selected for it's ability to overcome the shortcomings of the previous version. It allows support of smaller shunt resistors which in turn allows the ESC to support motor currents up to 48A. It also implements an overmodulation scheme which overcomes the issue of the previous version not allowing maximum power output to the motor. Automated bench tests were performed with the same Neu 1110 motor and 13x11 graupner combination to compare the amount of thrust produced per watt of power supplied to the motor. This thrust efficiency was then compared to the previous ESC to determine an optimal solution.

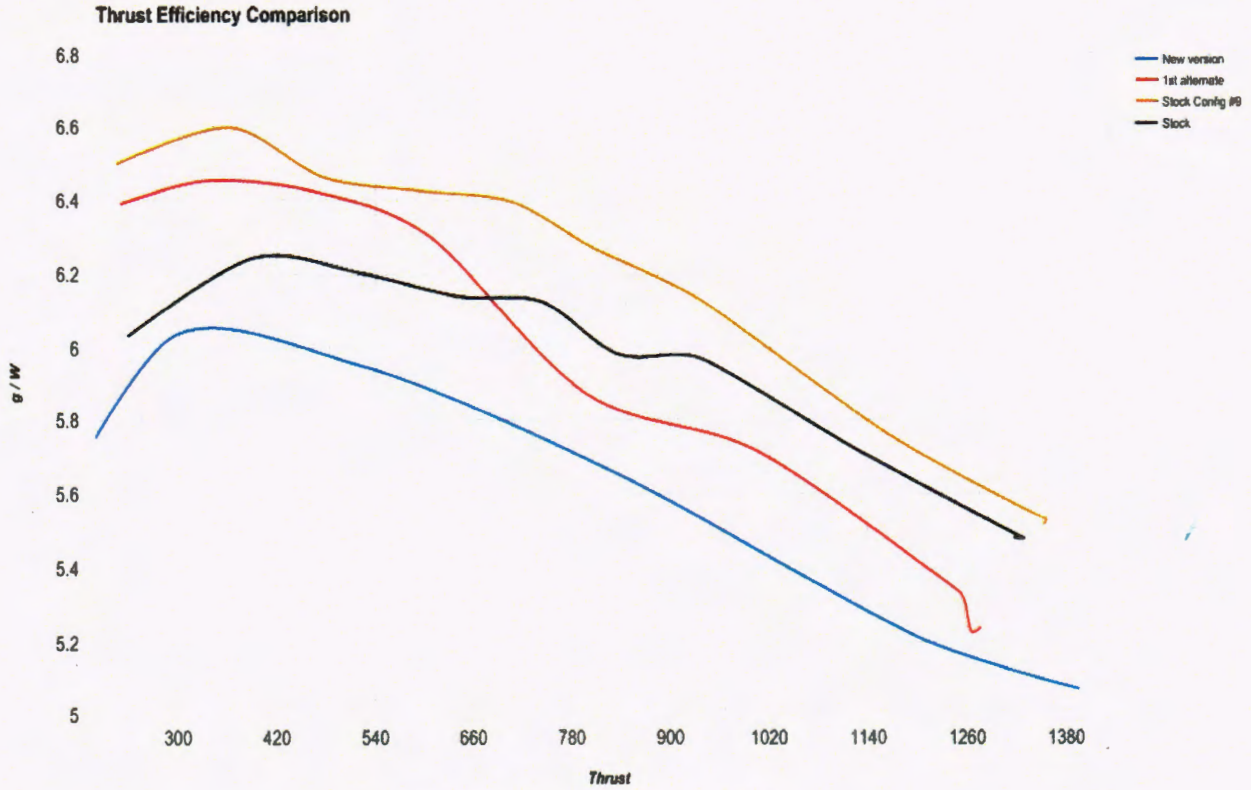

Figure 4: Thrust efficiency data.

Smart Battery

Proprietary Information

Objective 4: Maximum Power Point Tracker Update

The new MPPT will be designed with both buck and boost mode capabilities. A different gate driver will be used in order to make the input and output 50V tolerant. Simulations were performed to help determine part selection and efficiency estimates. The following efficiency graphs are calculated efficiency measurements that do not account for losses in the PCB, temperature rise, or power consumed by the microcontroller and its subcircuit.

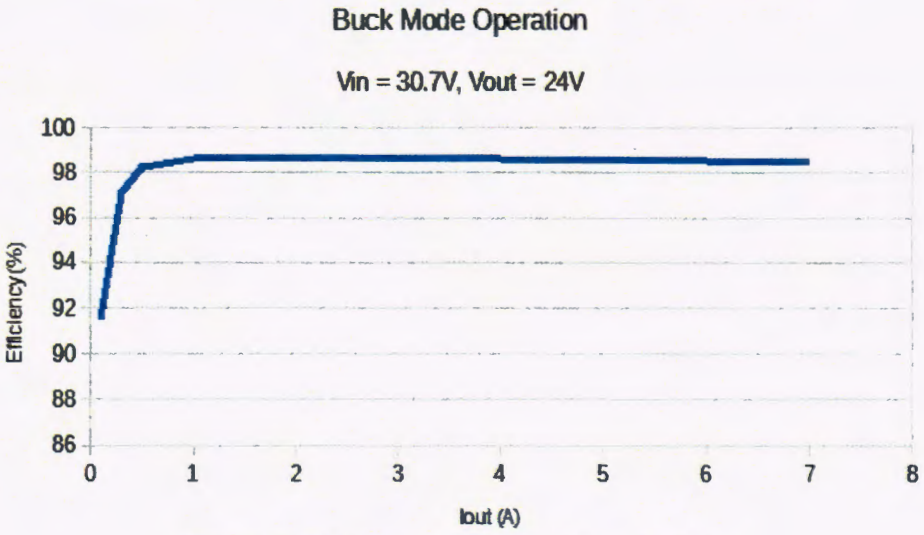

Figure 6: Efficiency in buck mode operation

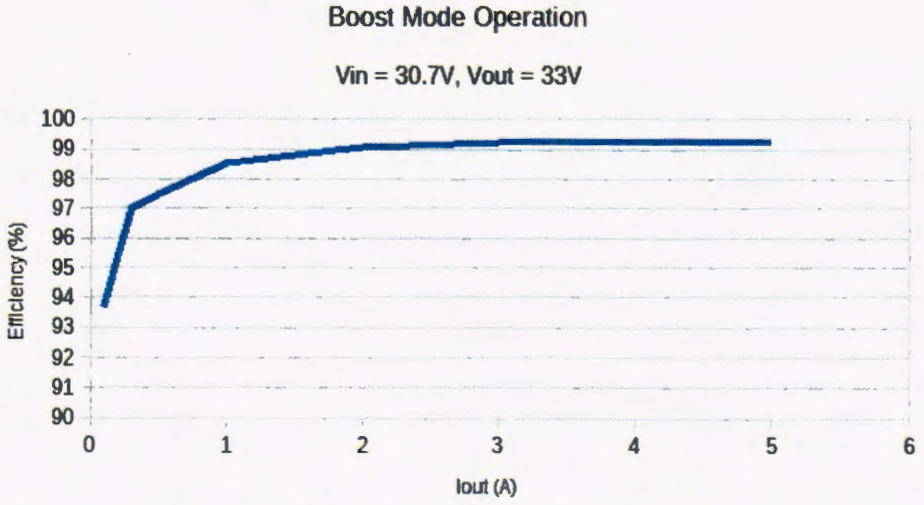

Figure 7: Efficiency in boost mode operation

Objective 5: Manufacturing Plan

This part of the report along with Pages 8 and 9 contain proprietary information.

Other activities:

Packet Digital was contracted by the US Navy Naval Air Systems Command (NAVAIR) to optimise the power system of a commercially available sUAS that is currently used by the military. A detailed analysis was completed and the entire power system was replaced to optimise efficiency, enhancing both endurance and performance. An initial test flight was performed at Yuma Proving Grounds indicating over 100% endurance improvement. Further test flights will be performed to fully characterize and prove performance.

Budget

Total project cost for phase III is expected to be $1,000,000, of which $375,000 is provided by NDIC, and $625,000 is provided by the Naval Research Lab as matching funds. Table 2 lists the budget estimate for Phase III and Table 3 lists the budget status as of February 28, 2017.

Project Associated Expense	NDIC's Share	Naval Research Lab Share	Total
Total Personnel Costs	$265,000	$505,000	$770,000
Software Costs/Materials	$110,000	$120,000	$230,000
Total	$375,000	$625,000	$1,000,000

Table 2: Phase III Budget Estimate

Project Associated Expense	NDIC's Share	Naval Research Lab Share	Total
Total Personnel Costs	$340,159.95	$407,226.44	$747,386.39
Software Costs/Materials	$72,373.46	$26,406.15	$98,779.61
Total	$412,533.40	$433,632.59	$846,165.99

Table 3: Interim Budget Status as of February 28, 2017

Summary

Phase III Deliverables:

- Solar cell development
  - MJ solar array testing complete and ~26% efficiency was demonstrated.
  - First set of wings with integrated MJ solar arrays were built up and ready for flight testing.
- Test flights
  - No test flights were conducted during this period.
- Power Management System
  - New, improved ESC has been designed and tested.
  - Commercial smart battery prototypes built and currently being tested.
- Maximum Power Point Tracker
  - Designing buck/boost MPPT. Simulations show very high efficiency.
  - Commercial MPPTs built
- Manufacturing Plan
  - Initial prototype wing was molded by c2renew. Several modifications to the process were made to improve the production of the second wing.

Significant progress has been made in phase III of this project and Packet Digital is on track to complete the objectives as per the original project timeline. NRL is also on track in terms of the solar cell development.