Development of a High Power, Regenerative Power Generation System for High Altitude Air Platforms

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What Are We Trying To Do?

- Develop an integrated, regenerative power system to support propulsion, payload and internal functions inherent to a long endurance air platform

- Requirements that impact power system design:
  - **Payload Power** - Continuous throughout deployment (15-65 kW)
  - **Propulsion Power** - Dynamic range of 0 kW (calm winds) to 160 kW (70 knot winds)
    > Power is a function of windspeed
  - **Internal Power** - Fans, blowers, fuel processing, thermal management
  - **Environment** - Latitude, longitude, altitude, heading, time of year, winds, temperature, solar flux
  - **Geostationary Flight Performance**
Regenerative Power System
Functional Block Diagram

complete system - includes efficiencies
use existing chart developed for darpa
Traceability of End-to-End System Flows and Efficiencies

AM0 Insolation:
\[ I_{AM0} = 1360 \text{ W/m}^2 \]

Equilibrium temperature determined by surface \( \alpha/c \).
20°C superheat requires \( \alpha/c = 0.12 \) or less

Total direct sun load:
\[ Q_d = \alpha A_{perp} I_{sun} \]

Radiated to/from earth:
\[ Q_{rad} = \varepsilon \sigma A_{surf} (T_f^4 - T_e^4) \]

Albedo:
\[ Q_{alb} = \varepsilon \sigma F_{b,e} A_{perp} I_{sun} \]

\[ Q_{reject} = (1 - \eta_{power}) P + \text{payload loss} \]

PV/Fuel Cell Functional Switch

Bus Controller
\( \eta = 0.98 \)

PV Array
\( \eta = 0.97, 28^\circ \text{C} \)

Crystalline Si PV Array
\( \eta = 0.197, 28^\circ \text{C} \)

CIGS Thin Film PV Array
\( \eta = 0.097, 28^\circ \text{C} \)

470 kW_e

Propulsion System
\( \eta = 0.75 \)

Air Management System
\( \eta = 0.90 \)

Payload
\( \eta = 0.50 \)

Hotel Loads
\( \eta = 0.90 \)

Electrolysis Process
\( \eta = 0.45 \)

\( \text{H}_2 \) Storage (Primary)
\( \eta = 0.18 - 0.35 \)

\( \text{H}_2 \)/Air PEM Fuel Cell
\( \eta = 0.90 \)

HAA Weight and Power Summary

<table>
<thead>
<tr>
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<th>8337</th>
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</thead>
<tbody>
<tr>
<td>Power</td>
<td>7911</td>
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<tr>
<td>520+470 kW, PV + 192 kW, fuel cells</td>
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<tr>
<td>Propulsion</td>
<td>1589</td>
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<tr>
<td>8.80 kW, dc motors 30 ft dia props (5)</td>
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<td>Empennage</td>
<td>2573</td>
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<td>Inverted-Y</td>
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<tr>
<td>Payload</td>
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<td>Internal conditioned</td>
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<td>Helium</td>
<td>4345</td>
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<td>Packaging</td>
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<tr>
<td>Weight - Lift</td>
<td>28755 - 27701</td>
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<td>1084 heavy</td>
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</table>

Included in propulsion: Power = 7.86x10^{-5} V^3
where V is in ft/sec, power is in kW, \( \eta = 0.75 \)
Propulsion power = 16.2 kW at 35 kts (59.07 ft/sec)

Included in air management system:
Power = 40.4 kW per lb mole air delivered at 2 atm
Multiple stage adiabatic compression followed by cooling at constant volume to end state

Payload power: 65 kW constant, input power

Intermittent power requirement 5 kW – fans, pumps

Traceability of End-to-End System Flows and Efficiencies
Functional Elements: Photovoltaic Array

- Thin Crystalline Silicon Photovoltaics
- Thin Film Photovoltaics
Functional Elements:
Fuel Cell

• PEM fuel cell - what are our choices?
**Functional Elements:**

**Electrolysis System**

- Stable efficiency (hydrogen per watt-hour)
  - Wide range of loads
  - Enables efficient $H_2$ and $O_2$ generation over wide range of available power from PV array with single stack
- Peak Generation Rates: 4000 SCFH $H_2$, 2000 SCFH $O_2$
- Waste heat approximately 188 BTU/mole $H_2$
Functional Elements: Reactant Storage

- Hydrogen, oxygen - pressure, efficiency, usage at various winds
- Pressure v. net weight of storage (graph?)
Functional Elements:
Power Management and Distribution

PMAD - from NASA (e.g. SSBC)
Demonstration of Figures of Merit and Performance Metrics:

- Round trip efficiency
- Mass properties (kW/kg)
- Reliability of system for long term (~1 year operation)
- Redundancy path development
- Waste heat/cooling/heating management at 21 km altitude
- Turn down effects, transients
- Development of ‘expert’ system for control
Modified Hydrogenics 24000

- Industrial grade PEM fuel cell test station
- Modifications to enable electrolyzer testing
- 24 kW fuel cell; 30 kW electrolyzer test capability
- Can emulate stacks to test balance-of-plant

Utility Interfaces:
- 208 VAC, 3φY, 80 Amp/φ
- Hydrogen Supply, 100 psi
- Oxygen Supply, 100 psi
- Air Supply, 100 psi
- DI water, 3 lpm, 4 MΩ or greater
- Steam, 360 lb./hour
- Chilled water, 75 lpm, 10°C
- Cooling load, 240,000 BTU

Fuel Cell Test Chamber
- Lexan slide windows
- Electrical and fluids interface panel
- Independent hydrogen alarms safes system

Electrolyzer Test Chamber - Standard 24000 series modified to enable electrolyzer stack testing
- Fully programmable water-cooled electronic load for fuel cell
- 30 kW programmable power supply for electrolyzer

Computer control
- Touchscreen & keyboard inputs
- Removable hard disk
- Can be networked
- Labview-based software
- Expandable data acquisition hardware design
- Monitors all critical parameters

Fluid Flow Control
- Pressure, temperature, RH
- Hydrogen; air or oxygen
- Water or other coolant
- Reactant water
Conclusions

- Development of large scale regenerative power system is feasible

- Key areas:
  - Development of 100 kWe scale fuel cell module
  - Development of higher efficiency fuel processing
  - Improvements in fuel, oxidizer storage efficiency
  - Continued development of photovoltaic systems