DEVORTO
CORPORATION

Building an Aircraft that Never Has to Land

High-Altitude Platform Station (HAPS)

HAPS... What is it?

- A solar-power aircraft
- Collect energy during the day
- Run on batteries at night
- Payload lives in stratosphere

Existing satellites

- Require a rocket launch
- Expensive aerospace products
- Confined to prescribed orbits
- Cannot be upgraded or maintained

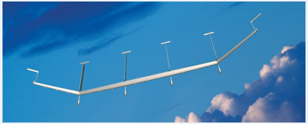
HAPS solves these issues, and...

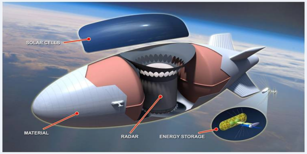
- Provides atmospheric monitoring (climate/weather)
- Low signal latency (ideal for 5G telecomm relay hub)
- Broadband speed data rates (Internet across the planet)

Alternative HAPS Attempts

DARPA

- Spent **$750M** over 15 years
- Both fixed-wing and airship
- All programs **canceled**

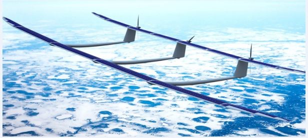




SolarEagle and ISIS

Tier-One Aerospace

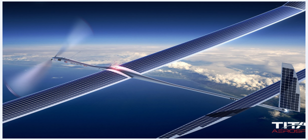
- Fully-optimized fixed-wing
- Several new **exotic** designs
- **None** made it to production



Odysseus and ApusDuo

Tech Giants

- Acquired at **prototype** stage
- Facebook grounds investment
- Google tried using **balloons**

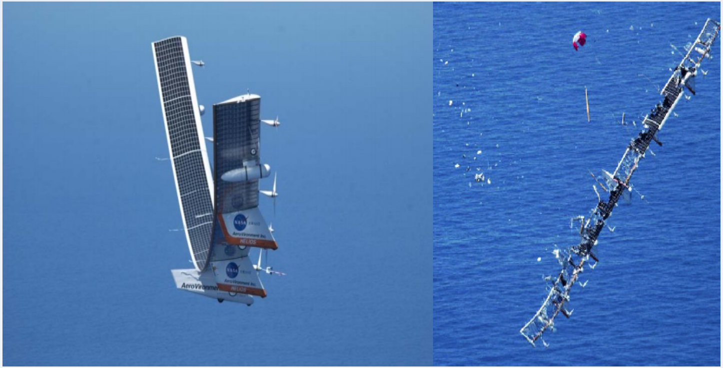


Solara and Aquila

Current HAPS Limitations

Long and slender wings are too flexible!!

- Fixed-wing have already been optimized to their aerodynamic and structural limits
- No room for additional improvement
- Cannot attain goal with current battery and solar technologies
- Current efforts only operate for a couple weeks during the summer at low latitudes (ideal solar conditions)



NASA/AeroVironment *Helios*, with major dihedral deflection from lack of stiffness, and its final outcome

Glider vs Helicopter

- **Glider Attributes**
  - Most aerodynamically efficient aircraft
  - Long slender wings for low induced drag
  - Additional flexibility and bending
- **Helicopter Attributes**
  - Flimsy slender rotor blades
  - Centrifugal stiffness adds rigidity
  - Very inefficient aerodynamics

- **Best of Both Worlds: What if we could...?**
  - Use favorable centrifugal stiffening to mitigate bending moments without extra material
  - Keep hover and vertical takeoff, but use 10x less power than comparable fixed-wing

Introducing the TURN System

Centrifugal stiffening solves aerodynamic/structural problem!

Flight Operation

- Energy mass at wingtips
- Wing is under tension
- No compression loads

System Benefits

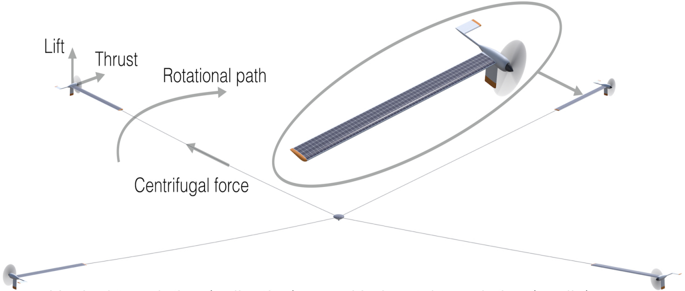
- Half structural weight
- Twice energy storage
- Maximize aspect ratio
- Minimize induced drag
- Thin airfoils (3X L/D)
- Slow rotation (30 s/rev)
- Clean laminar airflow
- Elliptic spanwise load

System operates in a state of rotation

Centrifugal forces keep tethers taught

Props overcome aerodynamic drag

Satellite wing surface produces lift



- Vertical translation (collective)
  - Throttle alters velocity and lift
  - Pitch induces spiral trajectory
- Horizontal translation (cyclic)
  - Relative elevation tilts rotor plane
  - Rudder changes tether tension

Introducing the TURN System (cont.)

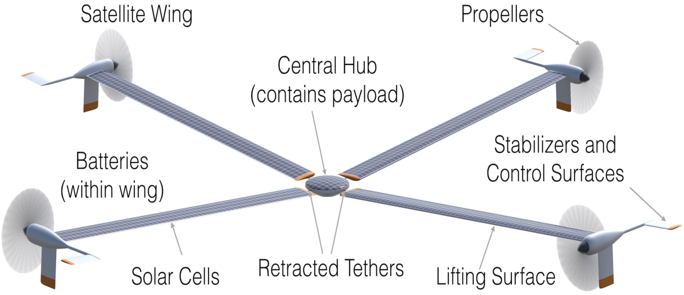
Centrifugal stiffening solves aerodynamic/structural problem!

Takeoff/Landing

- Tethers retract within hub
- Rise above obstructions
- Extend, then fly to POI

Operational Benefits

- Propulsion uses 40X less power: quieter acoustics, min heat signature, smaller visual profile.
- Large bulky payloads in hub are not subjected to parasitic cruise drag.
- Smaller wingspan than comparable sized aircraft



Solar cells store energy in batteries within each satellite

Radio communication between bodies

Research

NASA	**NASA** NAIC Phase I	Modeled aerodynamic and structural considerations to assess HAPS feasibility
VIRGINIA	**UVA** Dissertation	Developed nonlinear multibody dynamic models and nested adaptive control architectures
AFRL THE AIR FORCE RESEARCH LABORATORY LEAD I DISCOVER I DEVELOP I DELIVER	**AFRL** SBIR Phase I	Geometric programming to optimize large payload combustion engine alternative embodiment
CIT CENTER FOR INNOVATIVE TECHNOLOGY	**CIT** CRCF Grant	Prototype developed custom avionics and validated nonlinear system dynamics from simulations
AFWERX	**AFWERX** STTR Phase I	Prototype developed custom AHRS algorithms and refined inner-loop control law

Awarded $475,000 of R&D funding, 6 peer reviewed journals/articles, 5 issued patents, $175k pre-seed funding

NASA NIAC: TURN Sizing

	sUAS	Camera	Small AT-Sat	AT-Sat
Geometry				
Diameter - Outer (ft)	70	200	400	800
Diameter - Inner (ft)	56	160	320	640
Span (ft)	7	20	40	80
Chord (ft)	0.5	1.0	1.0	1.5
Aspect Ratio	18.7	26.7	53.3	71.1
Forces				
Rotational Rate (rpm)	20	7	4	2.25
Satellite Tip Velocity (ft/sec)	73	73	84	94
Centrifugal Acceleration (g's)	4.52	1.58	1.03	0.65
Wing Angle vs Horizon (deg)	-15	-12	-12	-18
Tether Tension (lbf)	62	122	256	823
Weights				
Gross Weight (lbf)	39.2	226.8	592.5	2187.7
Satellite Weight (lbf)	13.3	60.5	158.0	583.3
Payload Weight (lbf)	3.9	22.7	59.2	218.7
Swept Disk Loading (lbf/ft^2)	0.028	0.020	0.013	0.012
Drag and Power				
Induced Drag (lbf)	133	646	1363	4835
Parasite Drag (lbf)	18	101	303	1294
Tether Drag (lbf)	9	35	180	602
Power Required (watts)	159	783	1847	6734
Specific Power (watts/lbf)	4.07	3.45	3.12	3.08

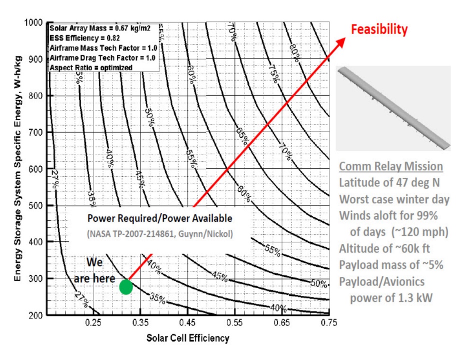
Considered designs at different scales, efficiency increases with vehicle size

NASA NIAC: Feasibility

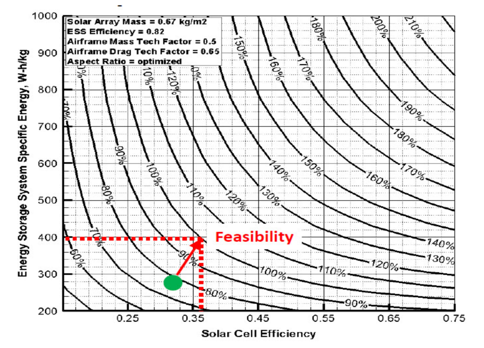
Evaluated aerodynamic/structural relationships dictating HAPS feasibility

Special thanks to Mark Moore for Pareto frontier analysis (2014 study)

`https://ntrs.nasa.gov/api/citations/20180008624/downloads/20180008624.pdf`



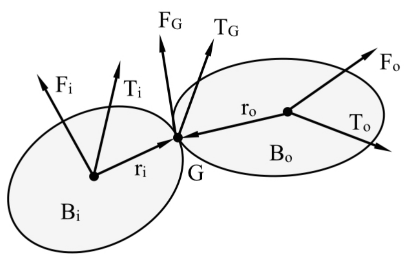
Flying Wing (Helios) cannot satisfy mission



TURN nearly feasible w/ batt/solar from 2014

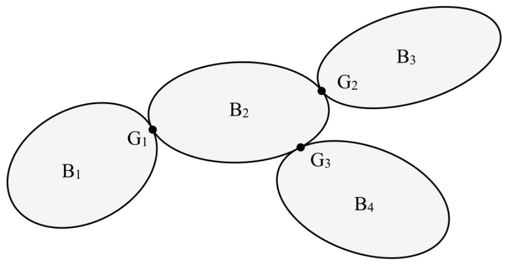
Dissertation: Nonlinear Multibody Dynamics

Two Rigid Bodies



$$J_i\dot{\omega}_i = T_i - \omega_i \times J_i\omega_i + T_G + r_i \times F_G$$
$$J_o\dot{\omega}_o = T_o - \omega_o \times J_o\omega_o - T_G - r_o \times F_G$$
$$m_i\dot{v}_i = F_i + F_G, \qquad m_o\dot{v}_o = F_o - F_G$$
$$v_G = v_i + \omega_i \times r_i = v_o + \omega_o \times r_o$$
$$\dot{v}_i + \dot{\omega}_i \times r_i + \bar{\omega}_i r_i = \dot{v}_o + \dot{\omega}_o \times r_o + \bar{\omega}_o r_o$$

Multiple Rigid Bodies



$$\begin{bmatrix} J & 0 & R \\ 0 & M & I \\ R^T & I^T & 0 \end{bmatrix} \begin{bmatrix} \dot{\omega} \\ \dot{v} \\ F \end{bmatrix} = \begin{bmatrix} \mathcal{T} \\ \mathcal{F} \\ \mathcal{C} \end{bmatrix}$$

Parameter Matrices: M and J

Connectivity Chart Matrices: I and R

Dissertation: Control Methodology

- **Stabilization for Satellite**
  - Local control for each "aircraft"
  - Manages satellite states (rot frame)
  - Full state feedback control law
- **Inner-Loop for Tether Arm**
  - Commands relative sat positions
  - Tethers influence forces on hub
  - Output feedback control law
- **Outer-Loop for Central Hub**
  - Waypoint navigation
  - More inputs than states
  - Merge two control modes
  - Complementary filter

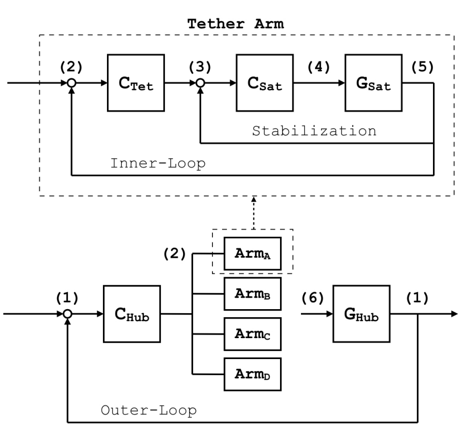


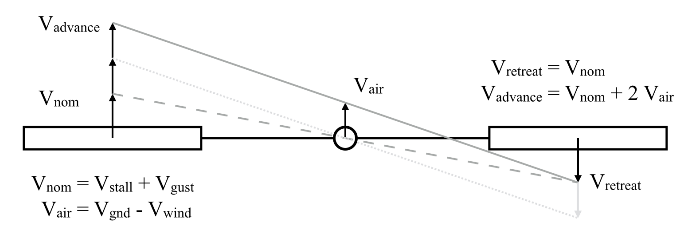
Figure notes: (1) Inertial states; (2) Desired hub forces; (3) Satellite positions; (4) Satellite force/moment; (5) Satellite states; (6) Actual hub forces.

AFRL: Geometric Programming Model

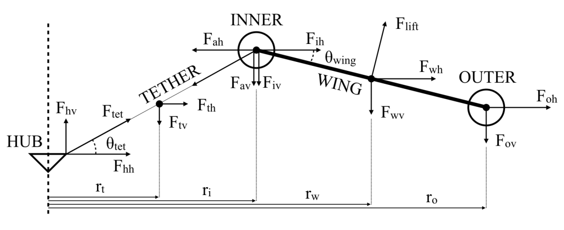
$$f(x) = c x_1^{a_1} x_2^{a_2} \cdots x_n^{a_n}, \quad c > 0$$

$$g(x) = \sum_{k=1}^{K} c_k x_1^{a_{1k}} x_2^{a_{2k}} \cdots x_n^{a_{nk}}, \quad c_k > 0$$

$$\begin{array}{ll} \texttt{min} & g_0(x) \\ \texttt{subject to} & f_i(x) = 1, \quad i = 1, \ldots, m \\ & g_i(x) \leq 1, \quad i = 1, \ldots, n \end{array}$$

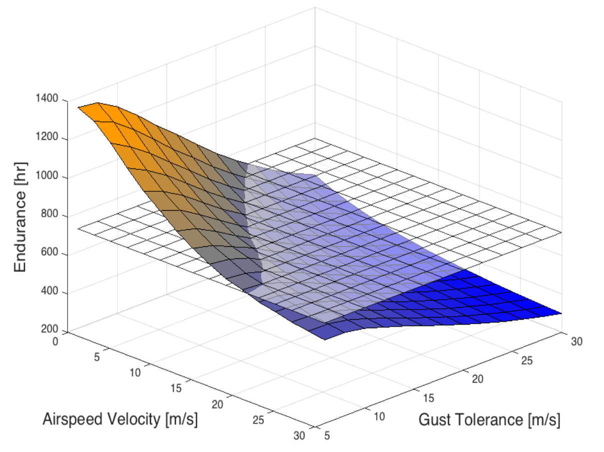


- Log transformation ensures convexity
- Global minimum with linear solvers
- Optimize thousands of system variables
- Must be modeled as monomials/posynomials
- How to express TURN within this structure?
- What physical constraints bound the problem?

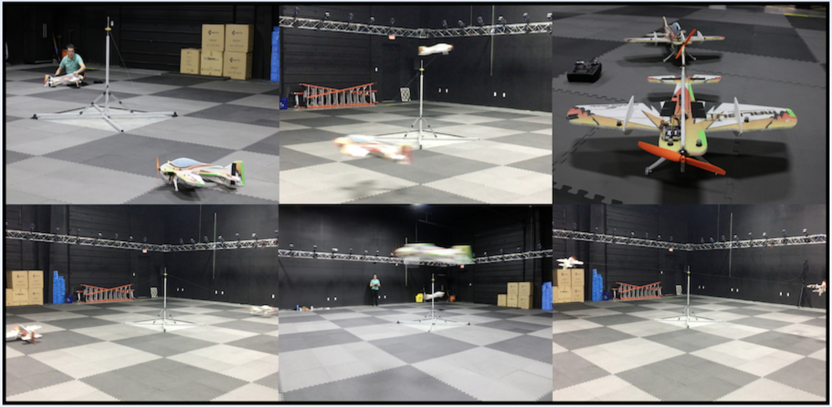


AFRL: Combustion Endurance Plot

- **Solicitation**
  - 250-pound 2000-watt payload
  - Operational altitude 15k-18k feet
  - Desired a seven-day endurance
- **Research**
  - Too low for solar (small wing)
  - Modified models for fuel burn
  - GPKit optimized flight envelope
- **Result**
  - Closed two designs with ICE
  - Group4: 250lb / 30-day endurance
  - 6X increase over mission goal
  - Group3: 75lb / 7-day endurance
  - 7X increase over ScanEagle



CIT CRCF: Avionics Development



Developed custom avionics, tested coordinated flight maneuvers, used VICON ground truth to validate multibody models and controller architecture

AFWERX: Testing Standard AHRS

AHRS Overview

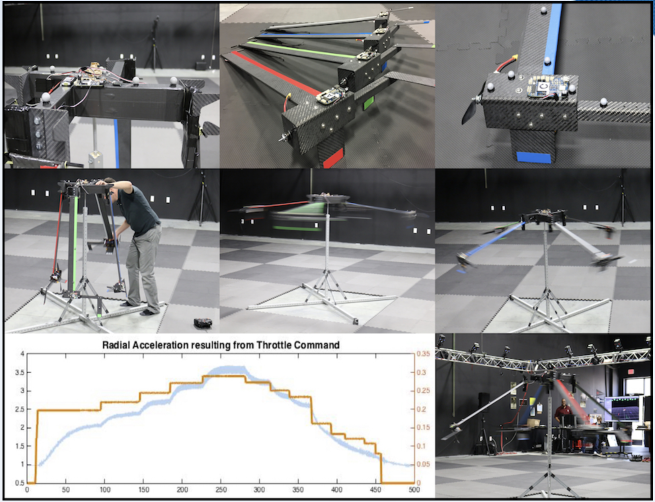
- No sensor for roll/pitch/yaw
- MEMS 9-DOF: accel, gyro, mag
- Attitude Heading Reference System
- Data fusion estimation algorithm

Standard AHRS Algorithms

- Integrate rate gyro (bias drift)
- Complimentary filter with gravity
- Magnetometer delivers 3D solution

Problem for TURN

- TURN also has radial acceleration
- Accelerometer sees gravity/radial
- Need transformation matrix to isolate the two (need R/P/Y)



AFWERX: Custom AHRS Development

AHRS Results

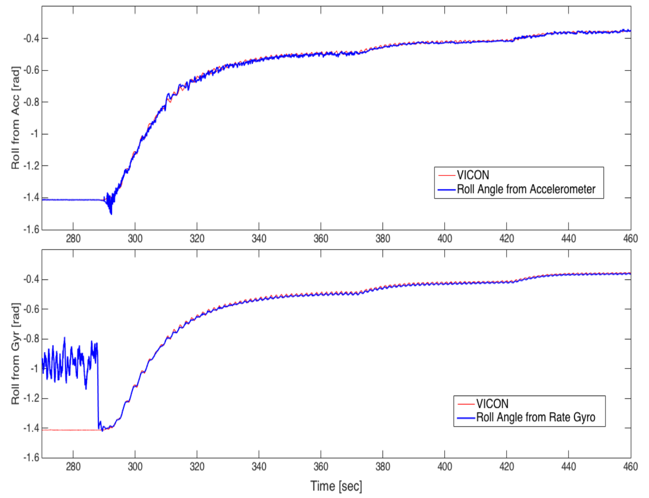
- Developed custom AHRS solution
- More robust that standard AHRS
- Algorithm remains trade secret

Inner-Loop Control Deficiency

- Need fast cyclic response
- But moving a large battery mass
- Original control law works against the natural system dynamics

Inner-Loop Control Revision

- TURN wants to move a certain way
- Modify reference tracking signal
- Control law augments that dynamic
- Control mod remains trade secret



Team

Justin Selfridge, PhD
Founder and CEO

Seven years at NASA Langley;
Adaptive control development and experimental aircraft design;
Four years full-time on TURN R&D

Ken Karklin
Advisor: Business Operations
Former COO of AeroVironment;
Operations for six product lines

Al Waddill
Advisor: Product Sales
President Groen Bro Aviation;
25 years Head of Sales

Mark November
Advisor: Talent Acquisition
Built successful teams from tech startups to hydroelectric dams

Industry Partners

ATI ADVANCED TECHNOLOGIES INCORPORATED
AN EMPLOYEE OWNED COMPANY
www.advancedtechnologiesinc.com

DARcorporation
Design • Analysis • Research
www.darcorp.com

SAXON Aerospace
www.saxonunmanned.com

Explainer Video

Link to Video: `https://youtu.be/gtswjAczq6A`

Persistent flight is mankind's last great aviation milestone

Devorto will deliver the backbone for the next telecommunications industry

www.devorto.io