



U.S. Army Research, Development and Engineering Command

Monolithically Integrated Micro Flapping Vehicles



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Jeffrey S. Pulskamp, Ronald G. Polcawich, Gabriel L. Smith, Christopher M. Kroninger

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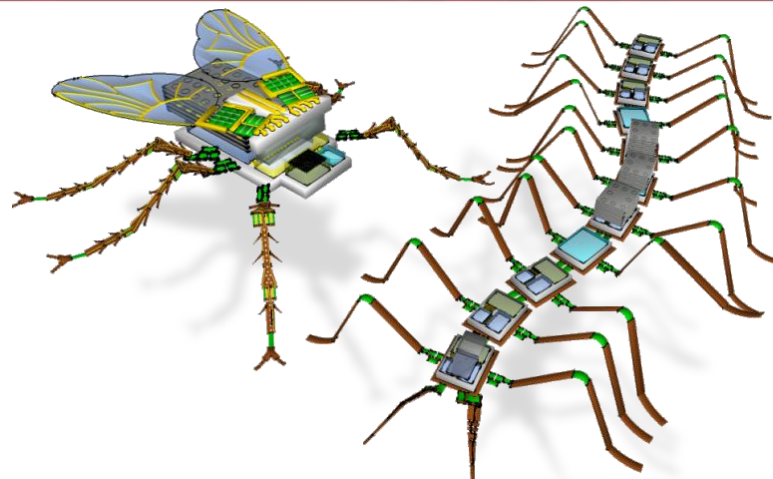


Objective

- Develop and demonstrate technologies to provide the Army a low-cost, low observable, mobile sensor platform

Benefits

- Extreme scale, MEMS enabled platforms can provide unprecedented low-observability & accessibility & integrated multifunctionality at low unit cost



Conceptual illustrations of highly integrated mm-scale low-cost, low observable, mobile sensor platforms for empowering and unburdening the soldier

Technical Barriers

- Biological **mobility** with nontrivial **load bearing**
- Scale-limited **power & energy**
- Simplest systems still require **high degree of integration**
- Design **complexity**

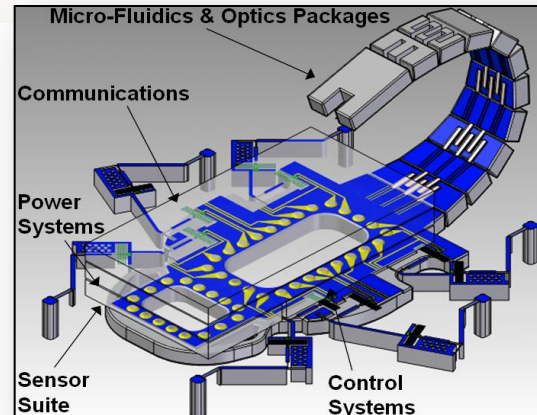
Approach

- Develop high performance **PZT MEMS actuation** and biological-like mechanisms
- **Leverage** thin film batteries and **collaboratively develop** integrated power solutions
- Exploit **MEMS, microelectronics**, and the limited application of standard **packaging**
- **Holistic design** of system, component, device levels

Objective: Provide the Army a low-cost, low observable, mobile sensor platform

Subsystems with PiezoMEMS integration potential:

- Mobility:
- Sensing:
 - Proprioceptive
 - Payload
- Communications:
 - RF MEMS
- Power:
 - Transformers
 - Harvesting
- Control:
 - Mechanical Logic
 - Memory

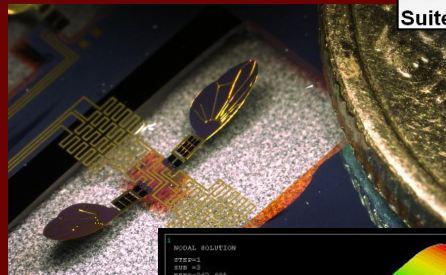


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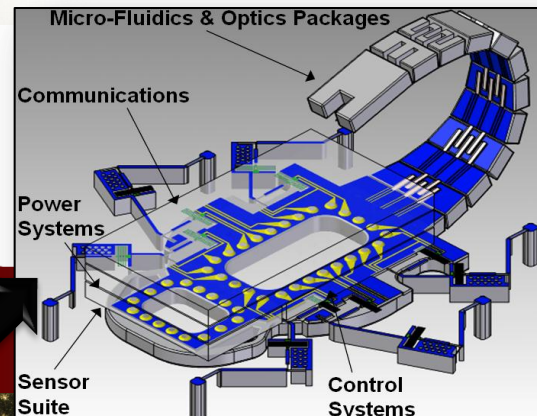
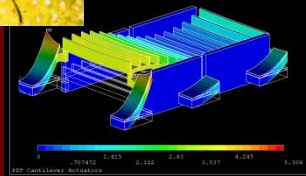
Mm-Scale Flight



Flapping Flight



MEMS Pumpjet





ARL Millimeter-scale Robotics Research

Collaborations with UCSB, IMT, ARL –SEDD, ARL-VTD, ARL-WMRD, UMich, & Penn St.

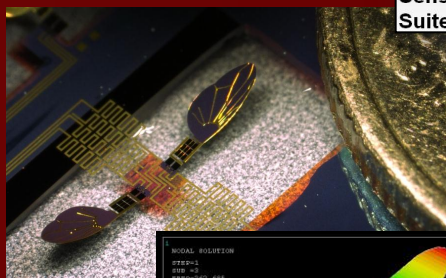


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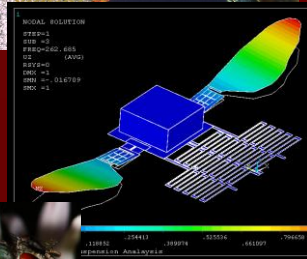
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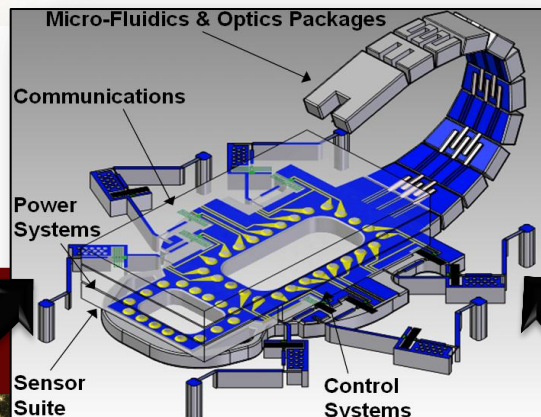
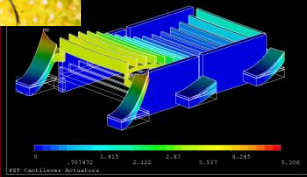
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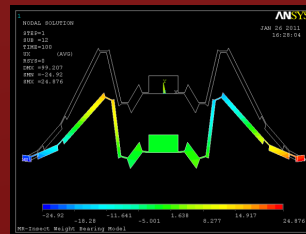


MEMS Pumpjet

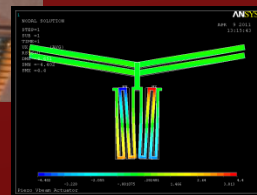
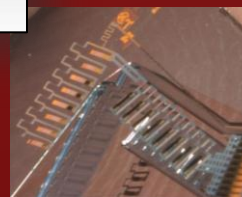


Mm-Scale Ground Mobility

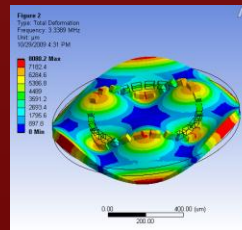
Platform Design



Actuation & Mechanisms



Ultrasonic Motors



Reversible Adhesion



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



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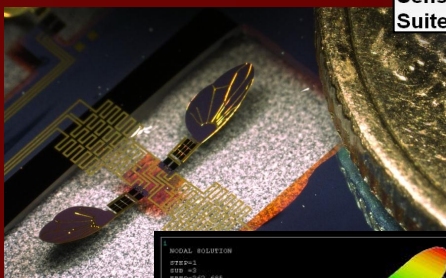


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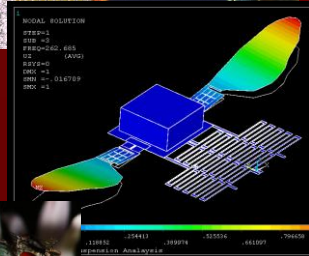
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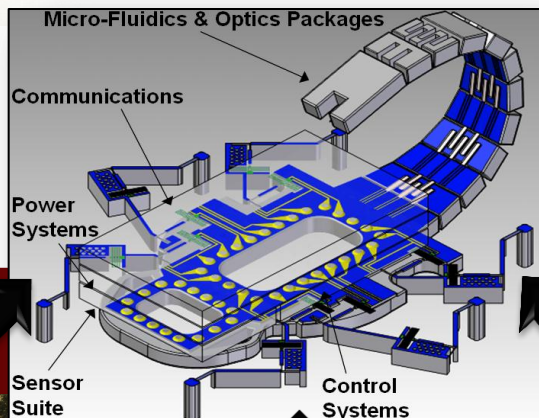
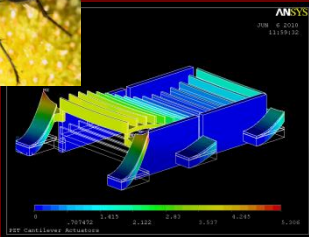
Mm-Scale Flight



Flapping Flight

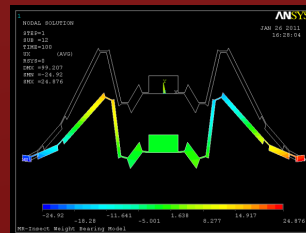


MEMS Pumpjet

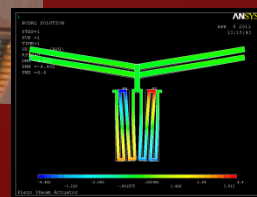


Mm-Scale Ground Mobility

Platform Design

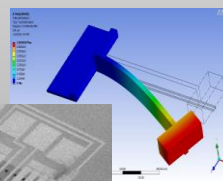
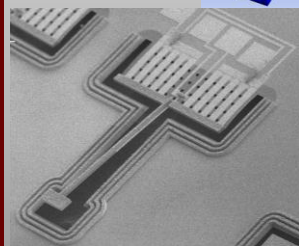


Actuation & Mechanisms



Proprioceptive Sensing

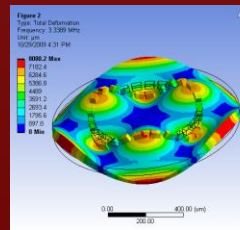
PiezoMEMS Haltere



Leveraged Research

MEMS logic
Integrated Power
RF MEMS

Ultrasonic Motors

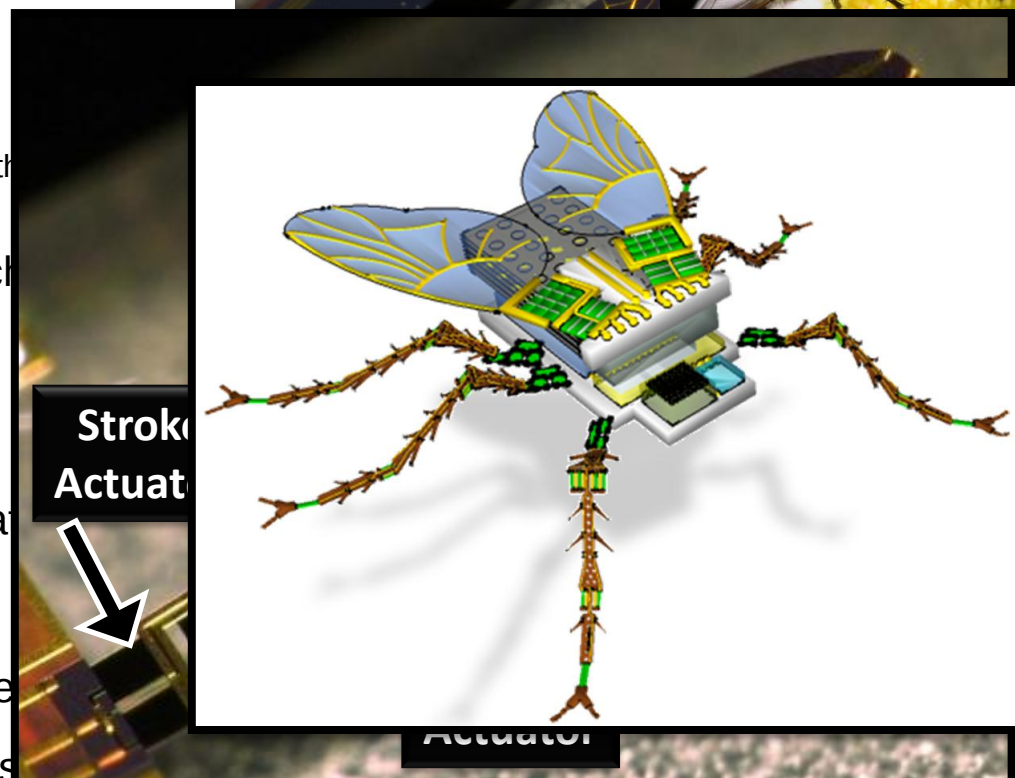


Reversible Adhesion

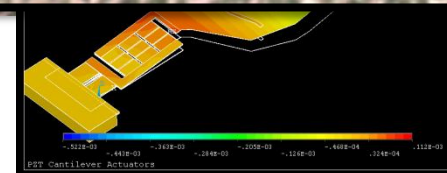


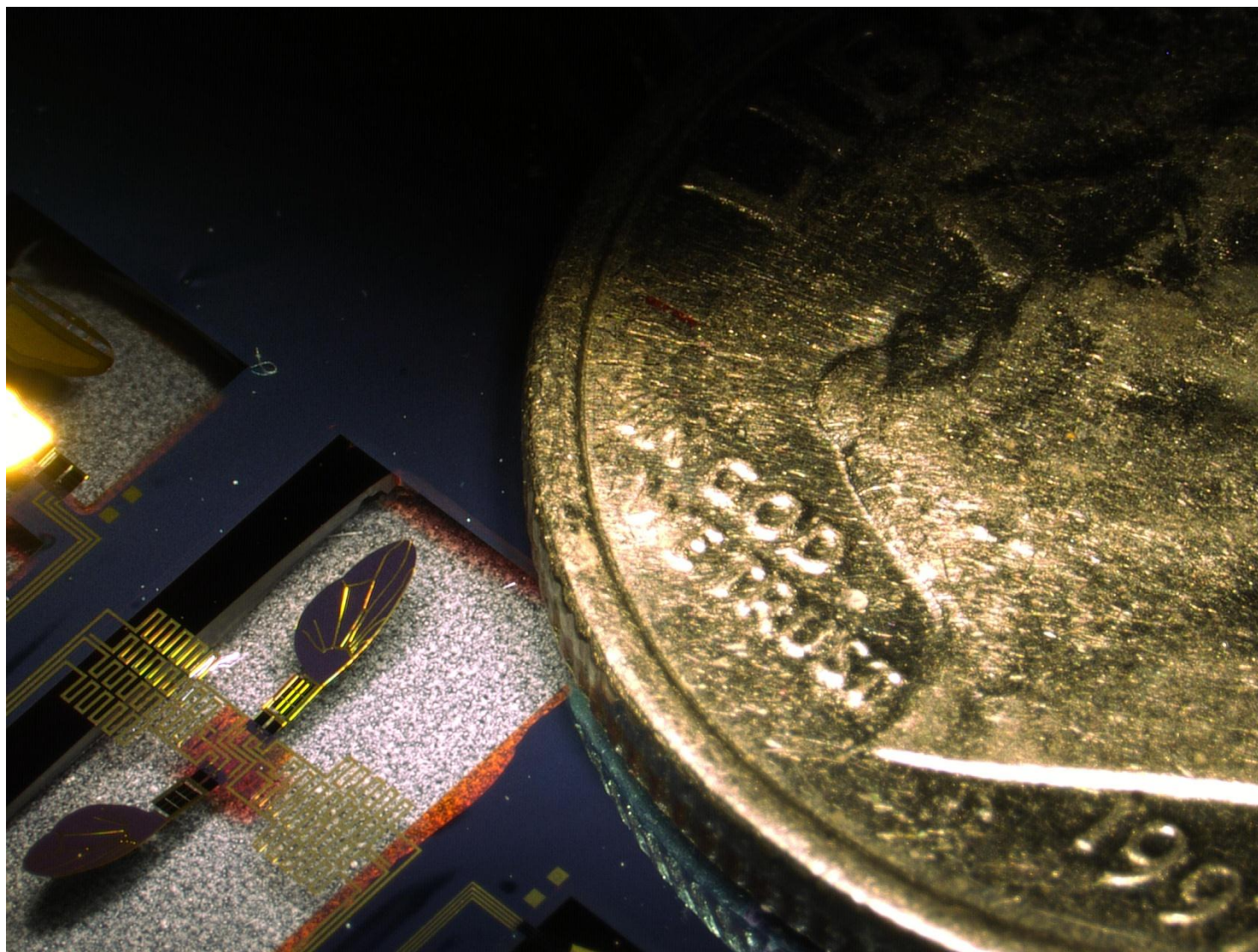
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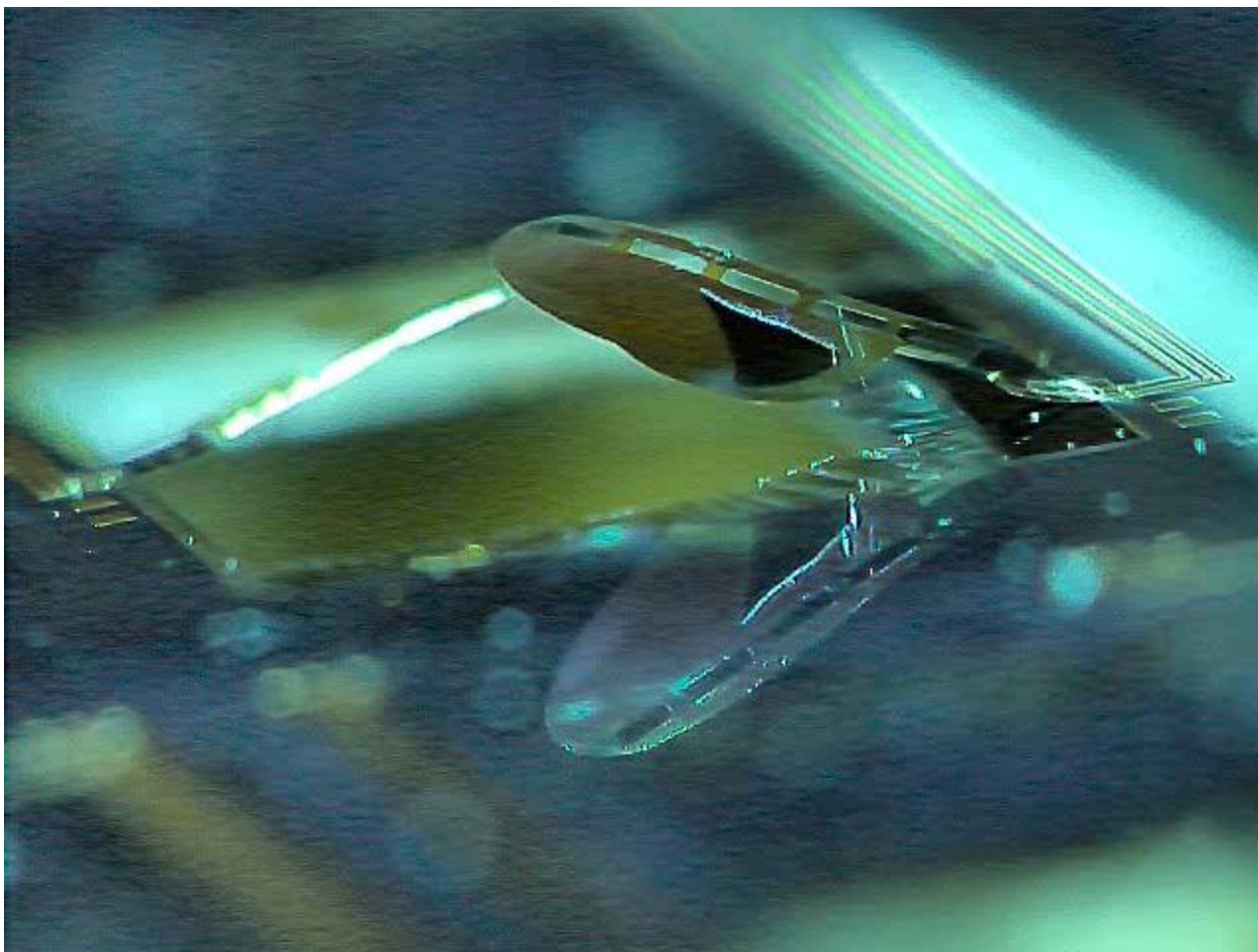
- Internal ARL multi-directorate research
- Goals:
 - Initial (DRI): Feasibility assessment & demonstration
 - Produce lift and flight characteristics similar to the fruit fly in the same size class
 - Current (Mission): Develop enabling technology
- Design:
 - 2 dof actuation
 - Thin film wings reinforced with stiff venation
- Accomplishments:
 - ~120° stroke amplitudes at 10V drive (re)
 - ~45° pitch amplitudes at 25V drive (quas)
 - frequencies similar to fruit fly (150-250Hz)



Two degree of freedom actuation

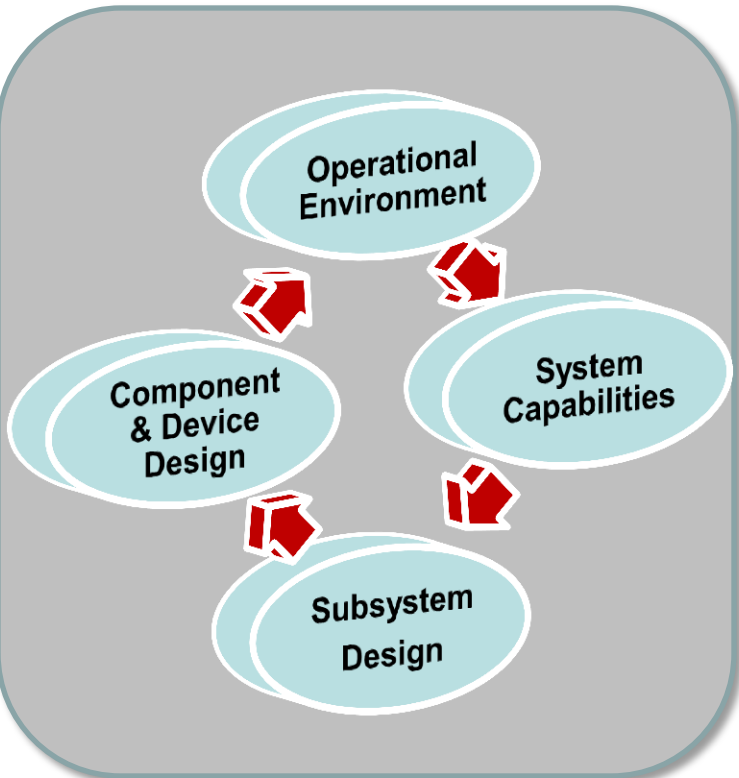






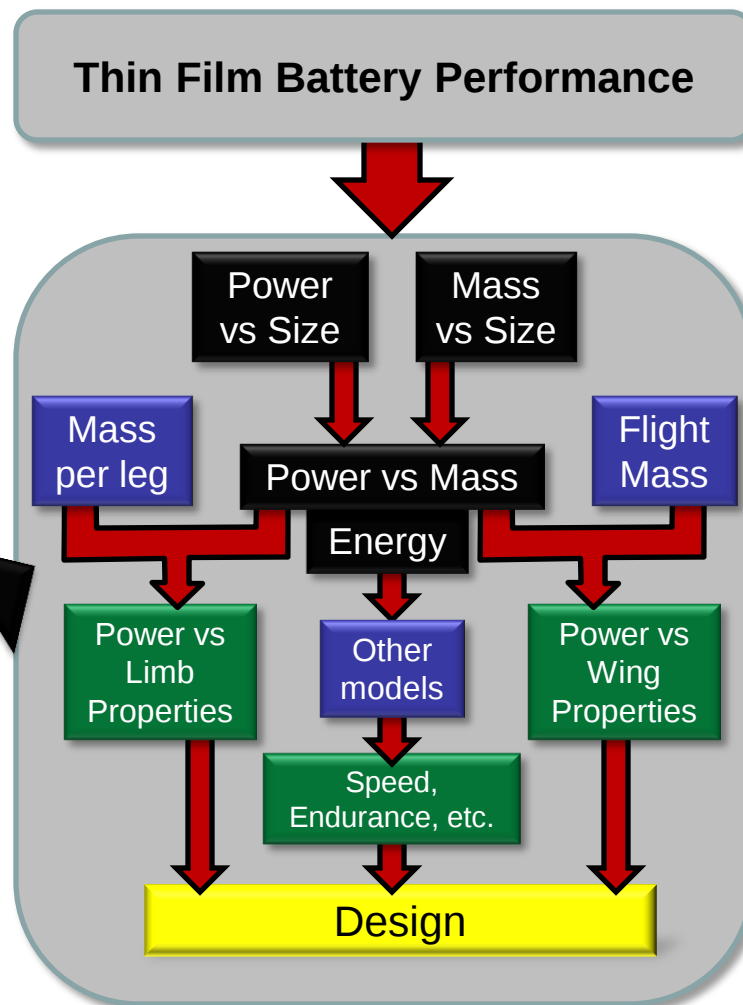
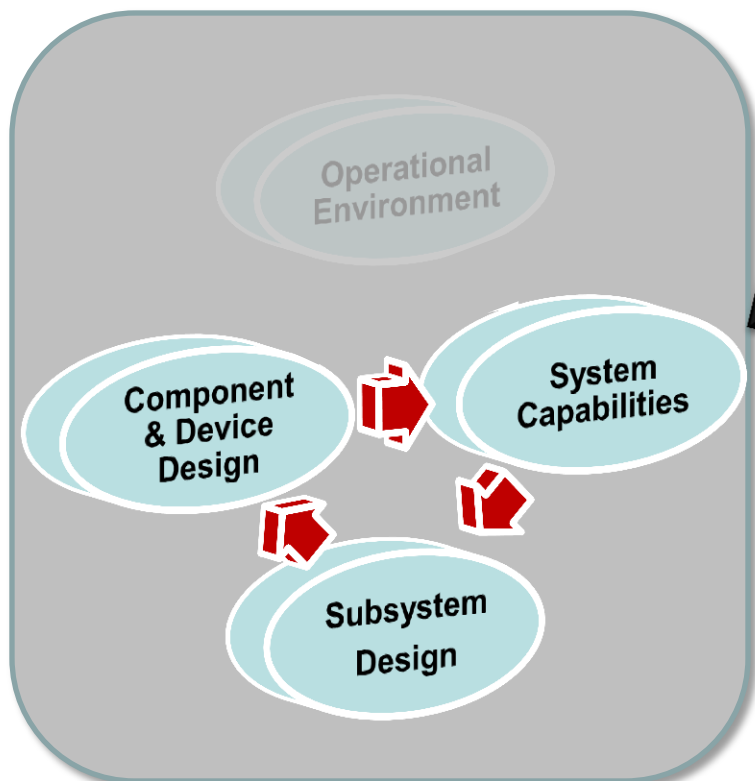
Key System-level Questions:

- Power
- Load Bearing
- Framing the Mobility Design Problem



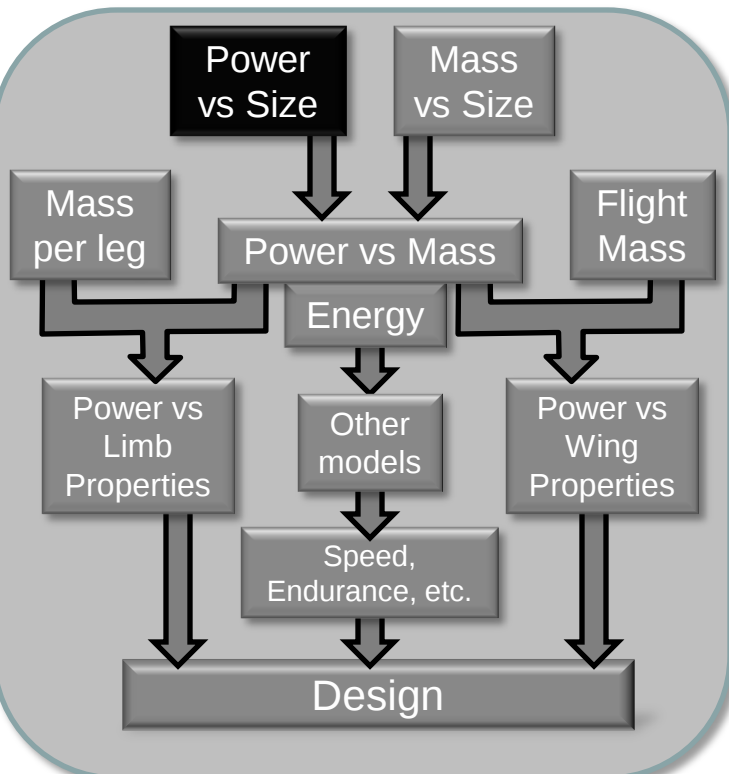
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- **Framing the Mobility Design Problem**

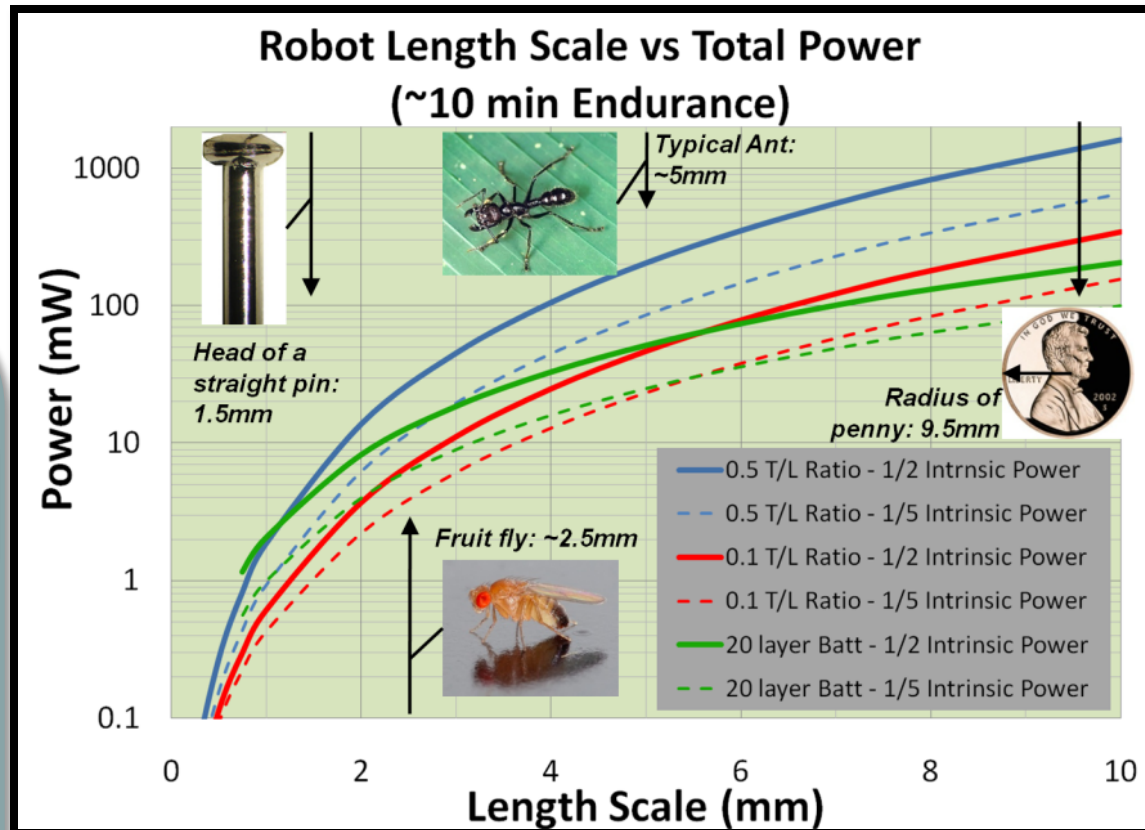


Key System-level Questions:

- **Power**
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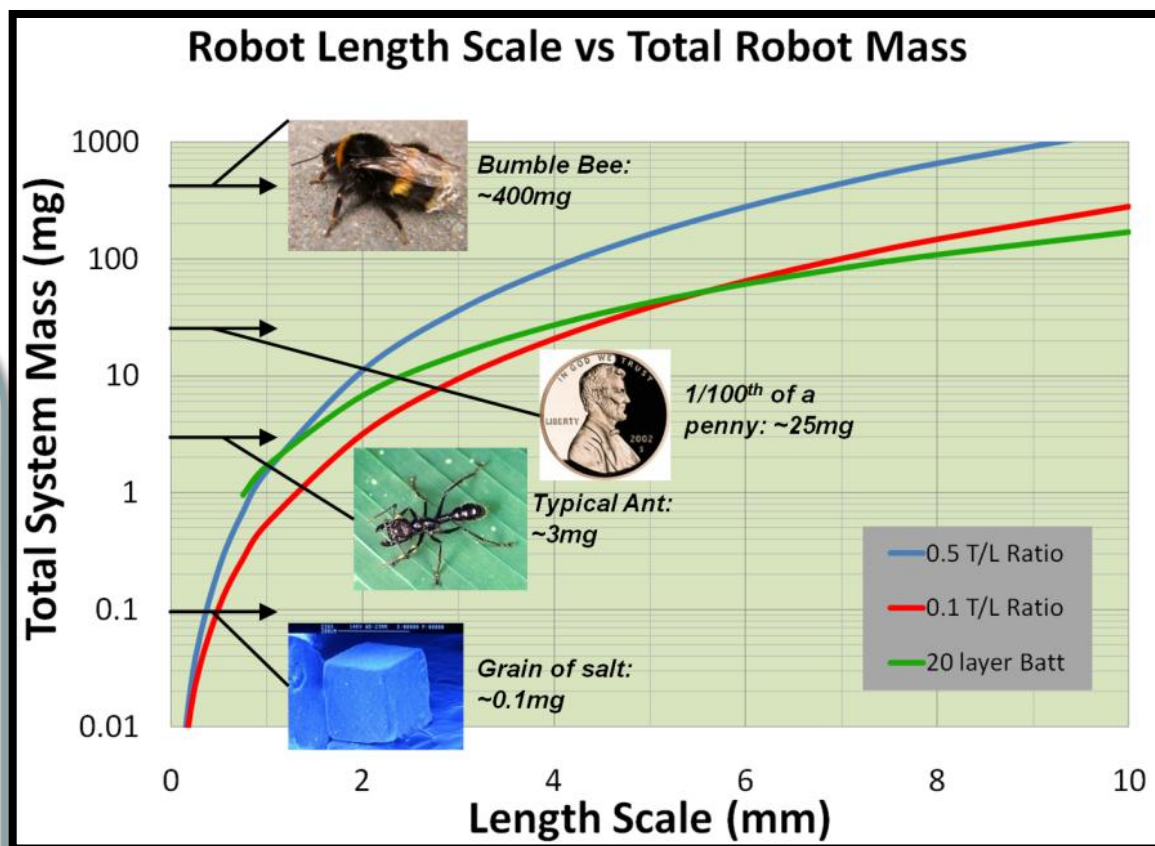
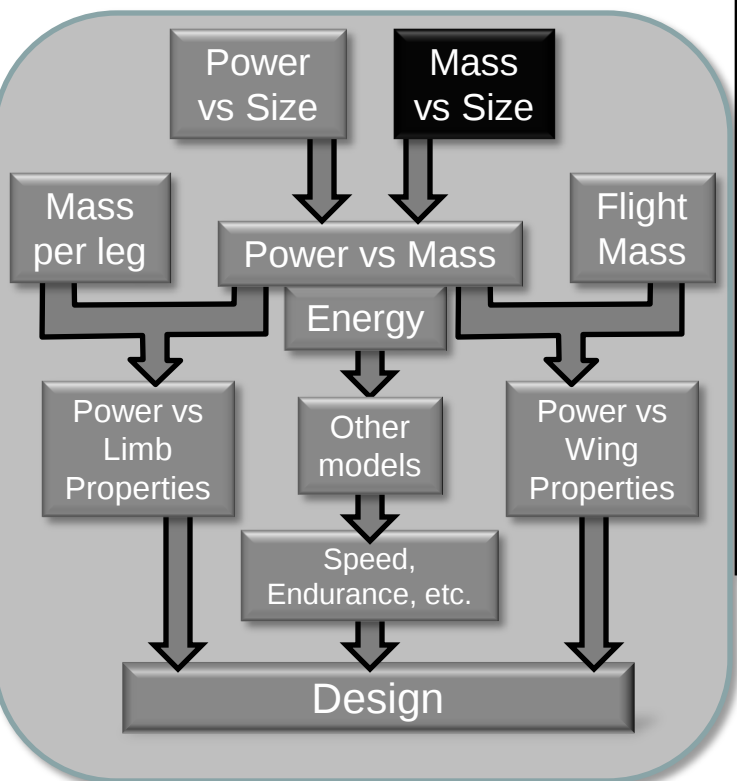
Power Numbers based on demonstrated Thin Film Battery Technology



~10 to 1000 mW available at millimeter-scale

Key System-level Questions:

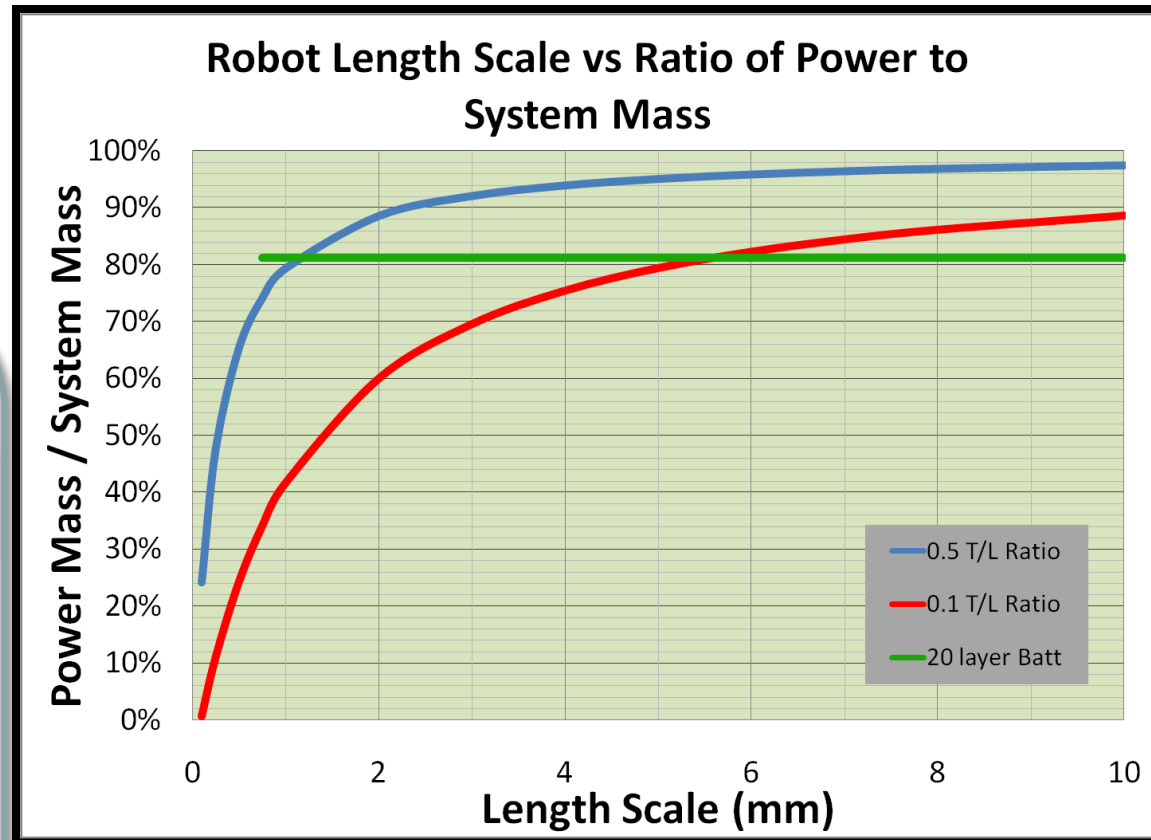
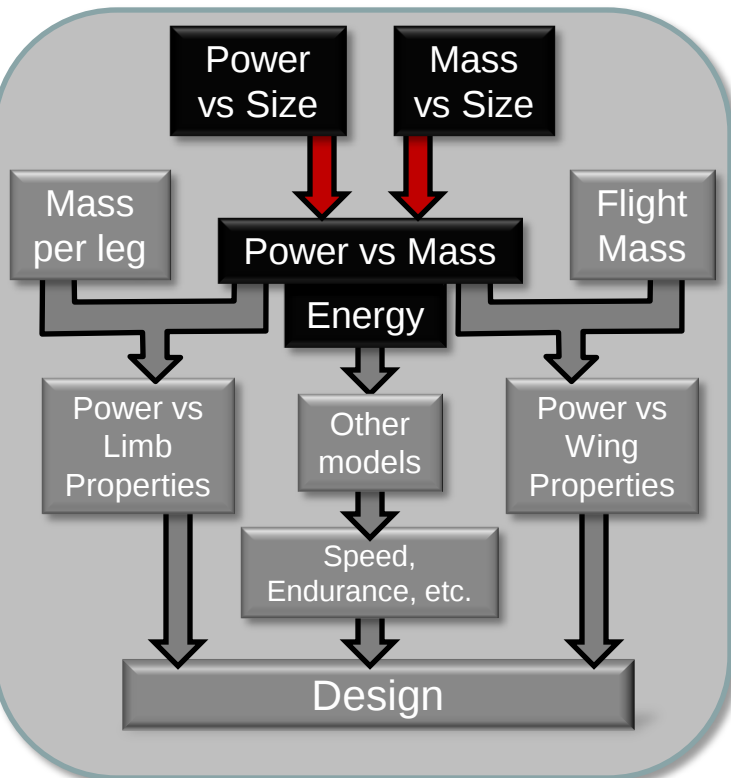
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~10 to 1000 mg likely at millimeter-scale

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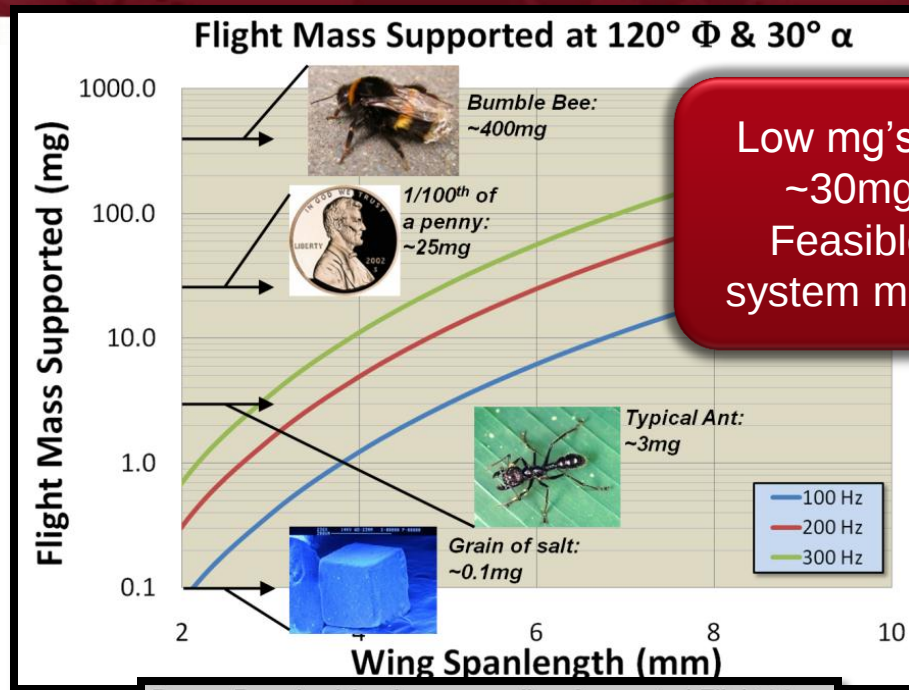
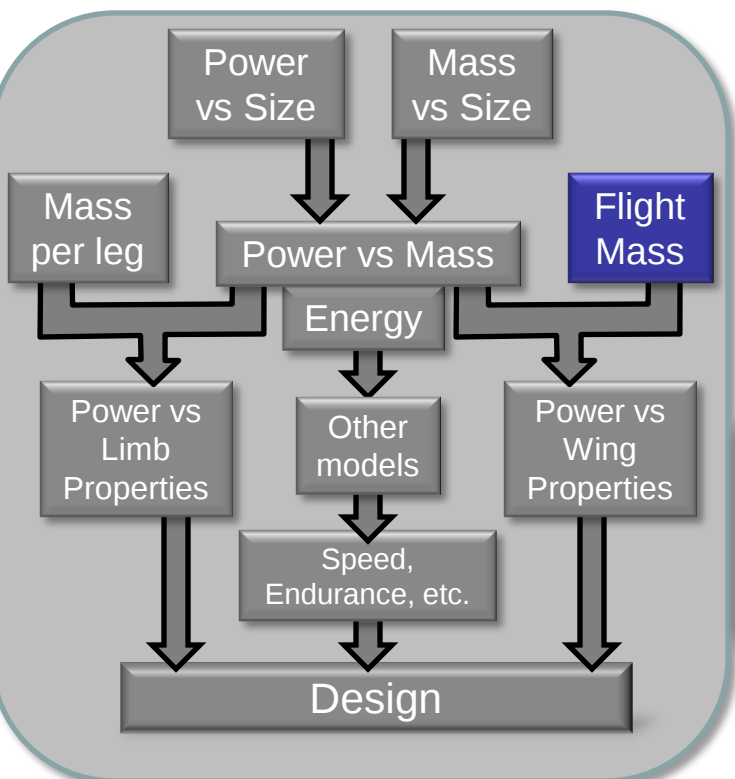
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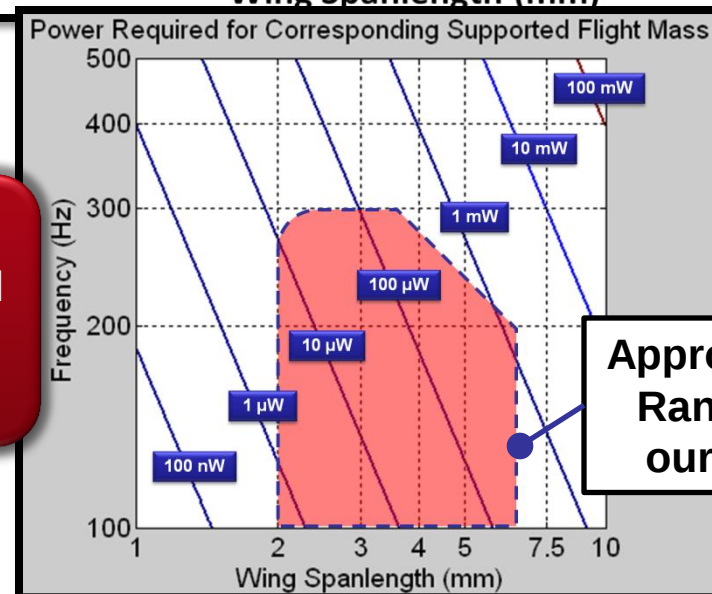
Platform mass to be dominated by mass for power

Key System-level Questions:

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- **Load Bearing**
- Framing the Mobility Design Problem



Low mg's to
~30mg
Feasible
system mass

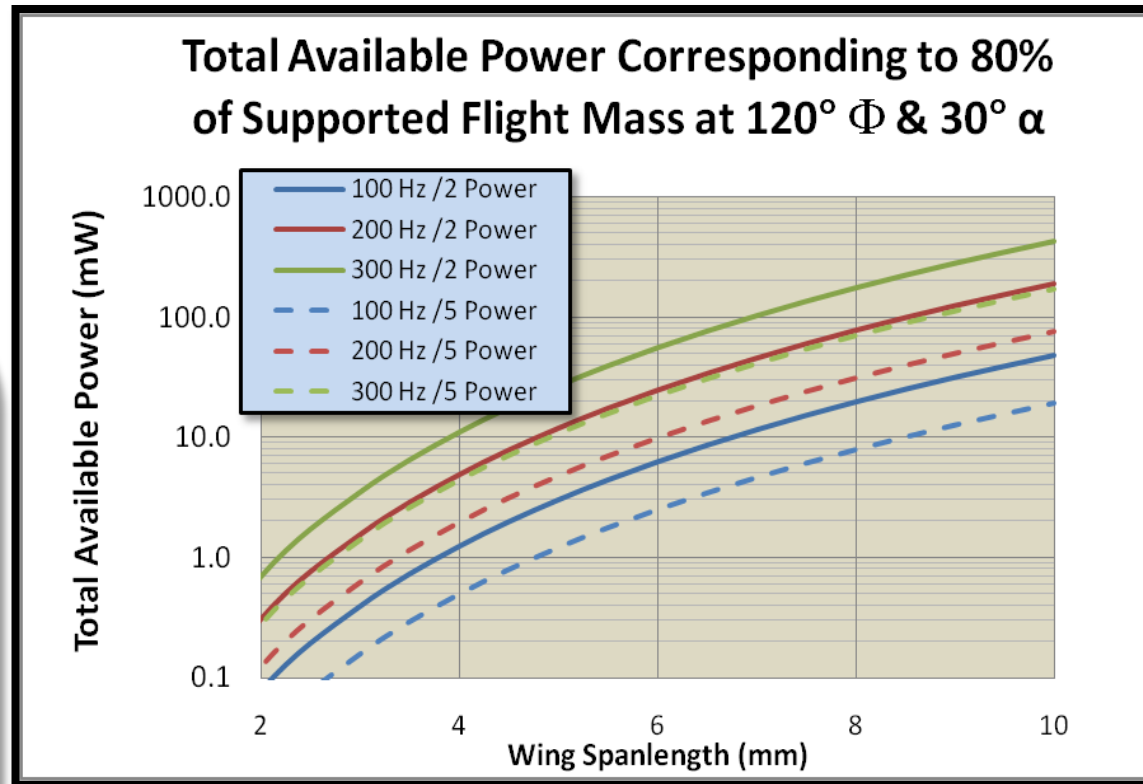
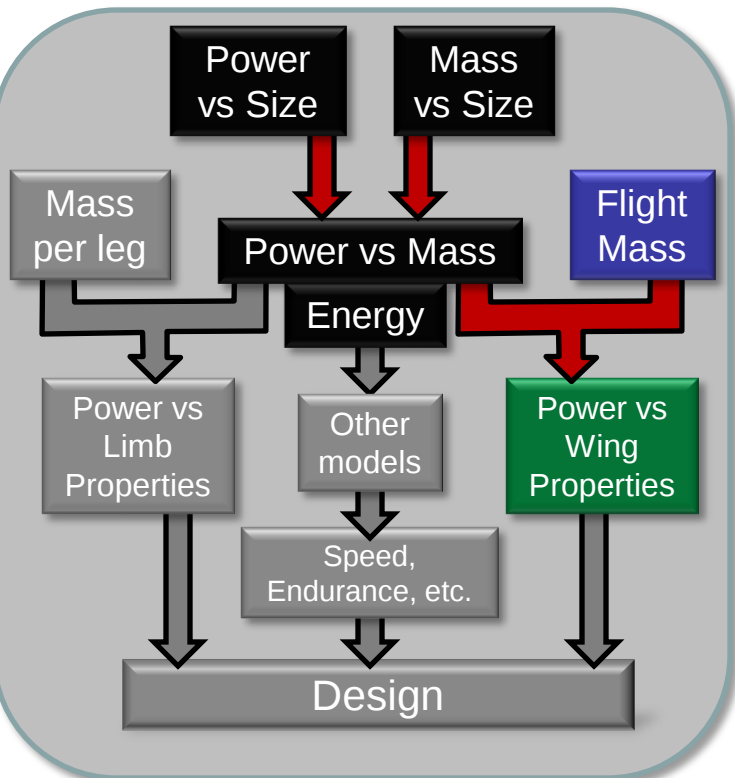


<1mW
Mechanical
Power
Required

Approximate
Range for
our work

Key System-level Questions:

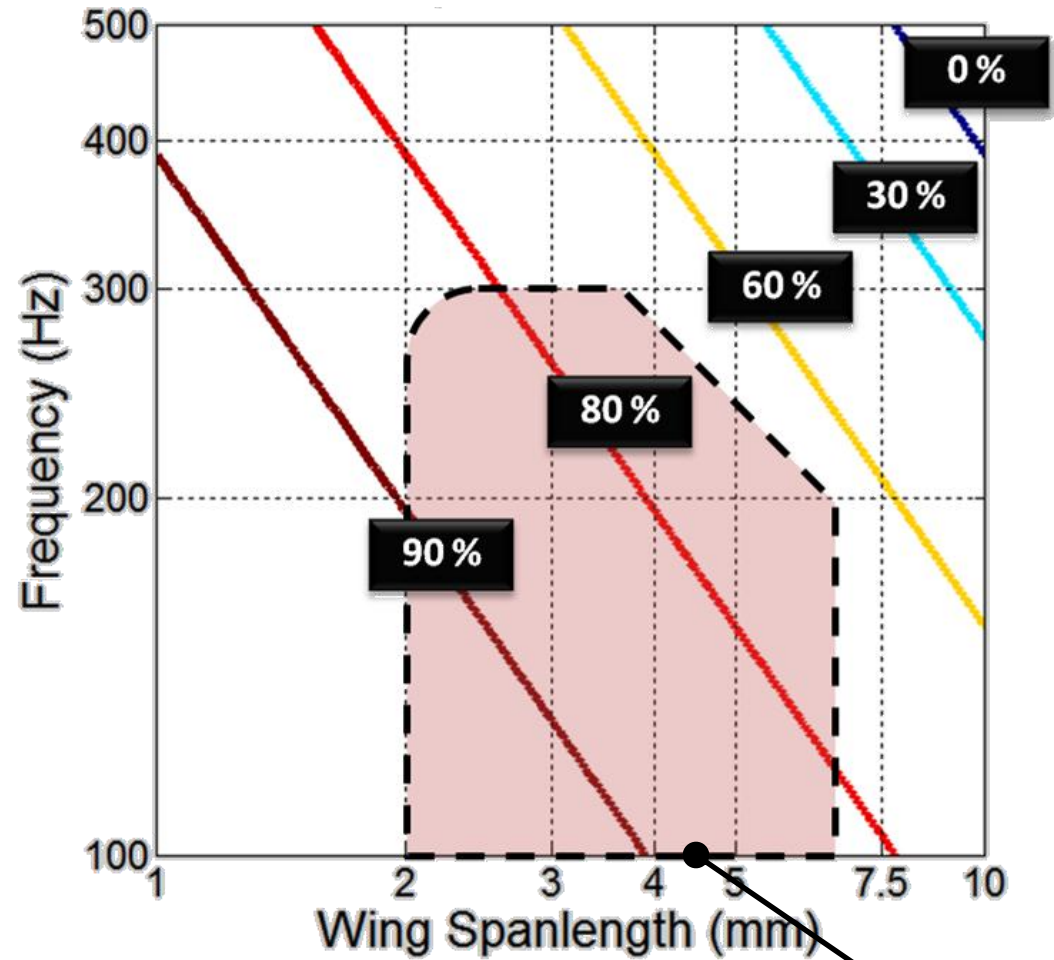
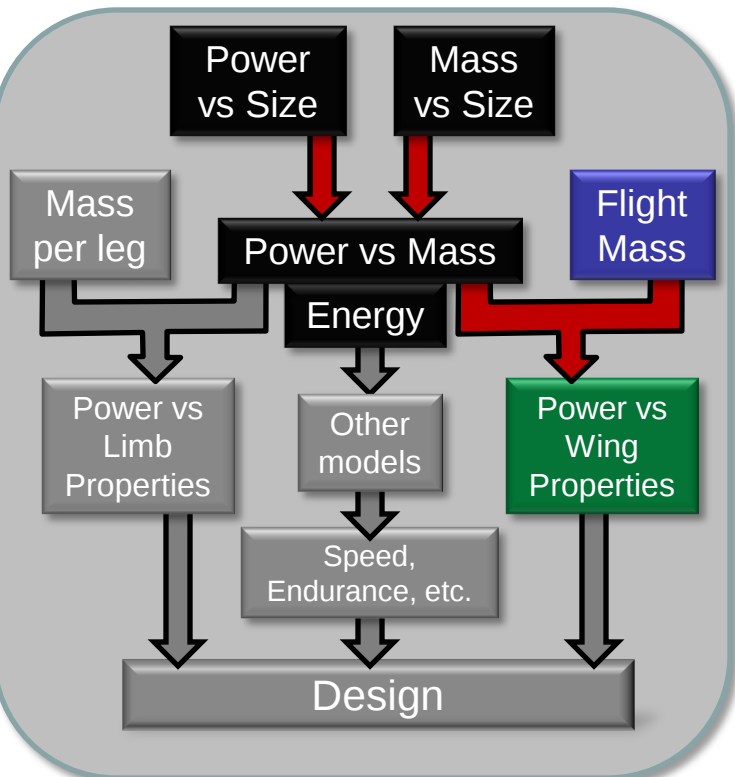
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Low mW's to ~30mW available battery power can be supported by expected flight forces

Key System-level Questions:

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- Framing the Mobility Design Problem



< 20% of available battery power required to fly

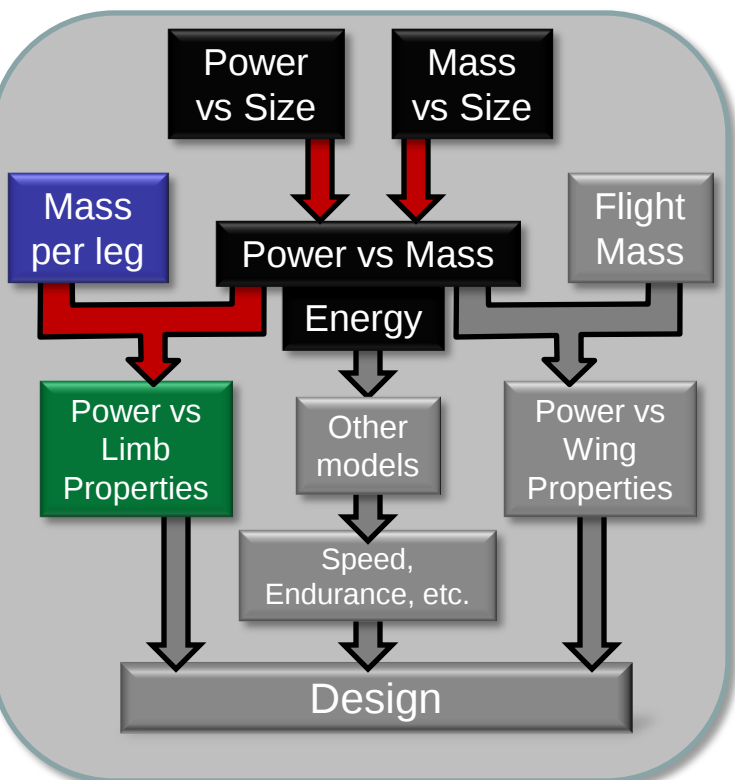
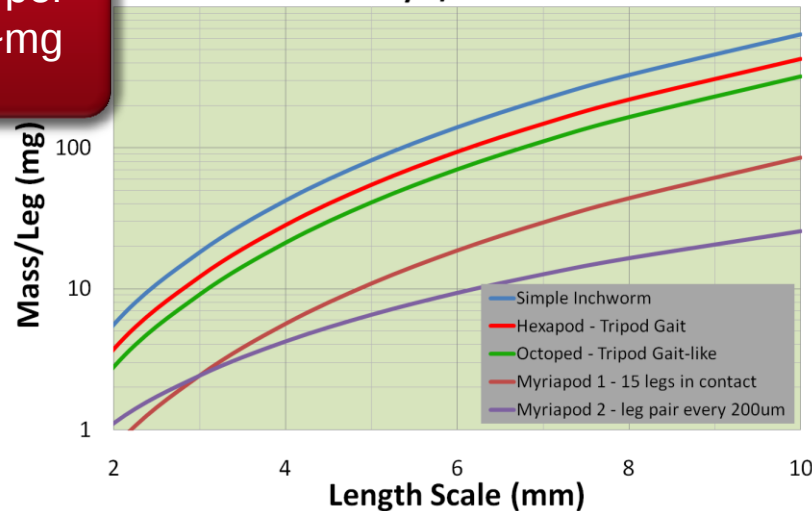
Approximate Range for our work

Key System-level Questions:

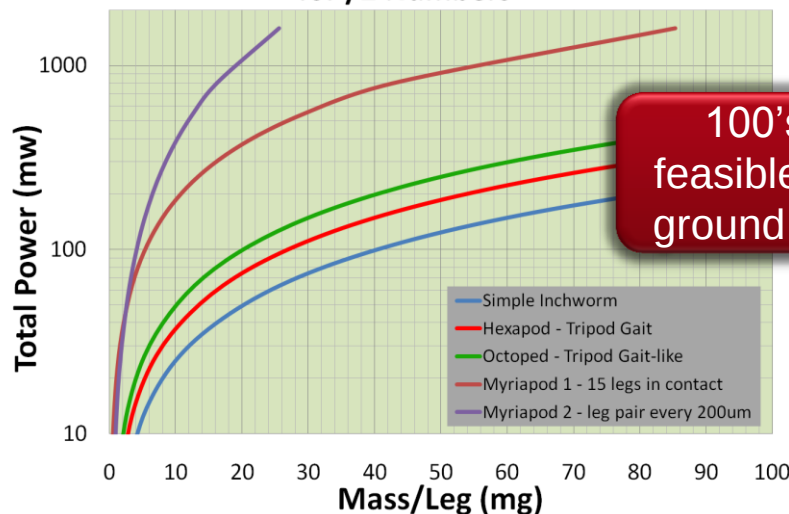
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Mass supported per leg range from ~mg to ~600mg

Robot Length Scale vs Mass Supported Per Leg
for Battery T/L of 0.5



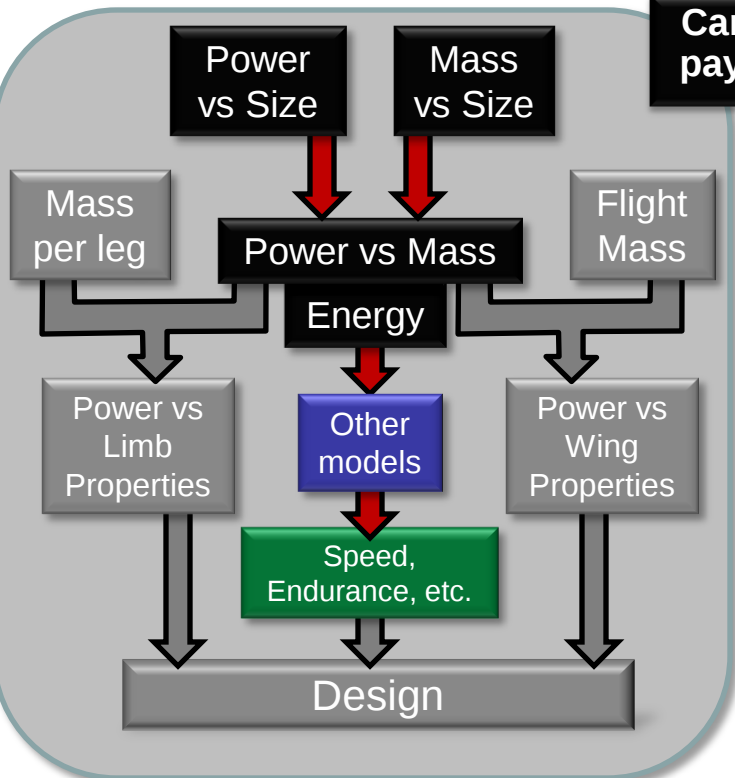
Robot Mass Supported Per Leg vs Total Power
for /2 Numbers



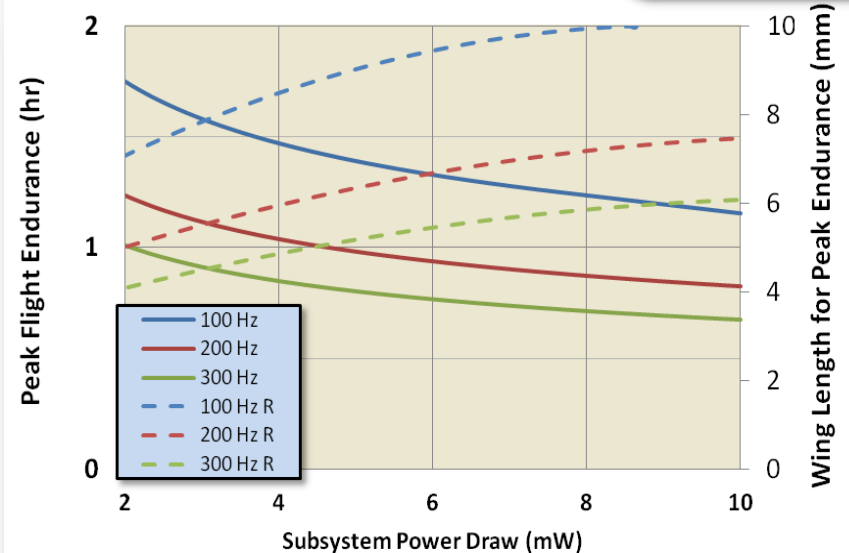
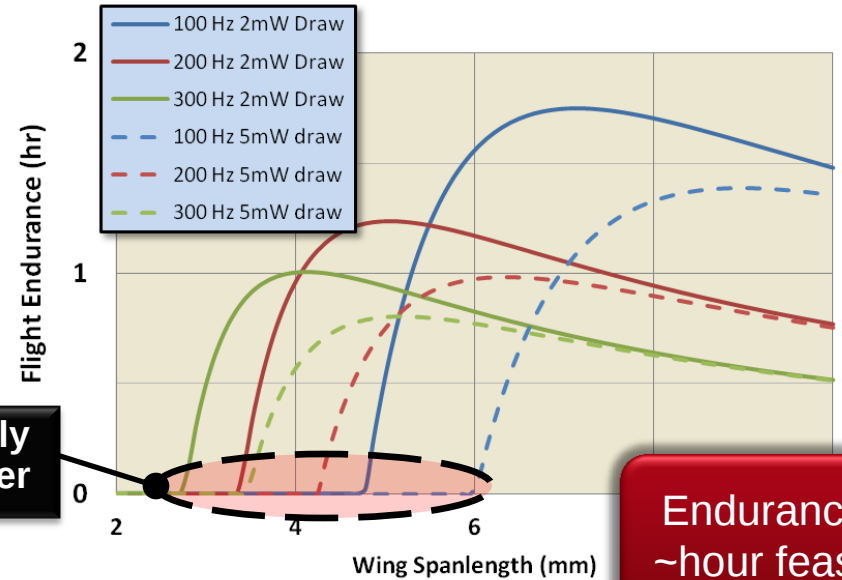
100's mW to >Ws
feasible to support with
ground mobile systems

Key System-level Questions:

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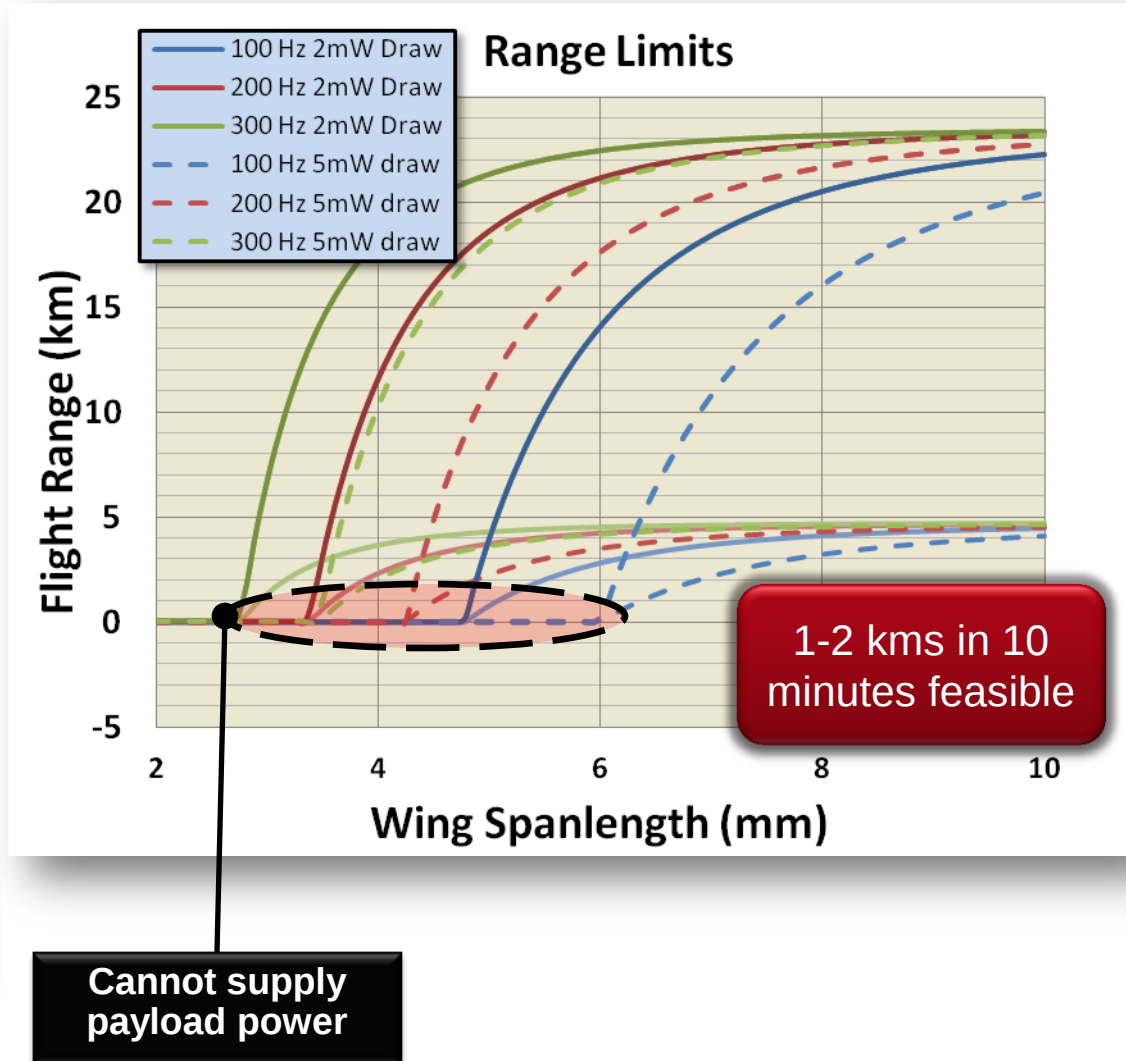
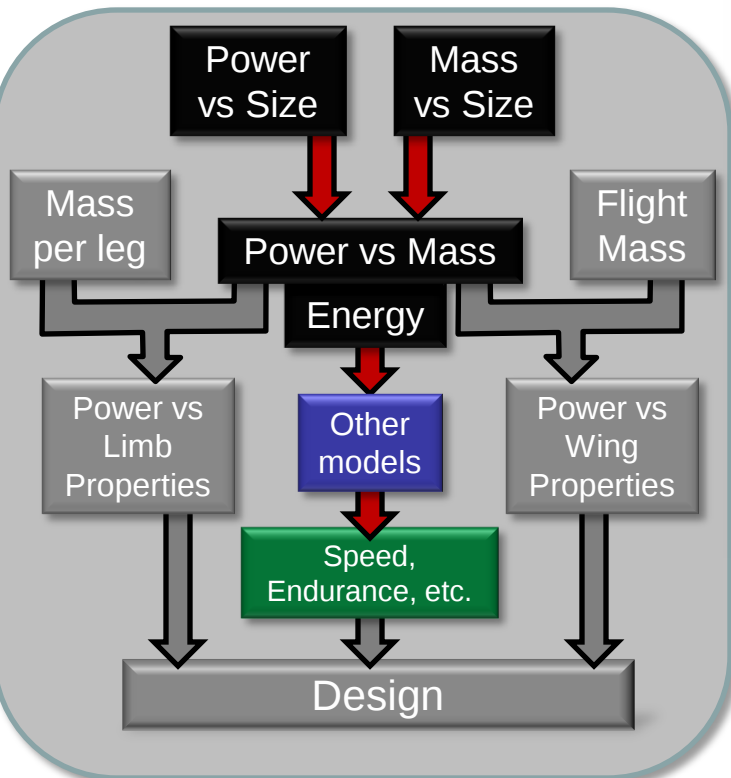


Cannot supply payload power

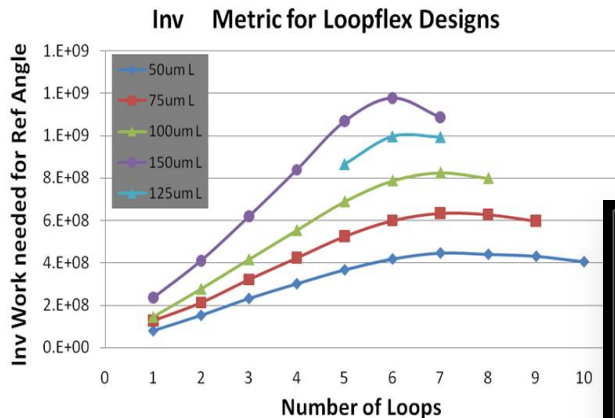


Key System-level Questions:

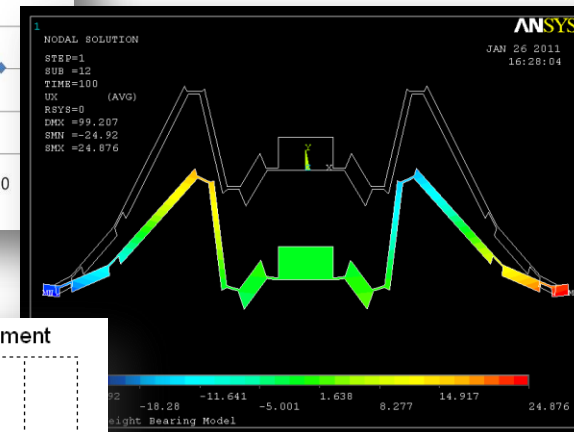
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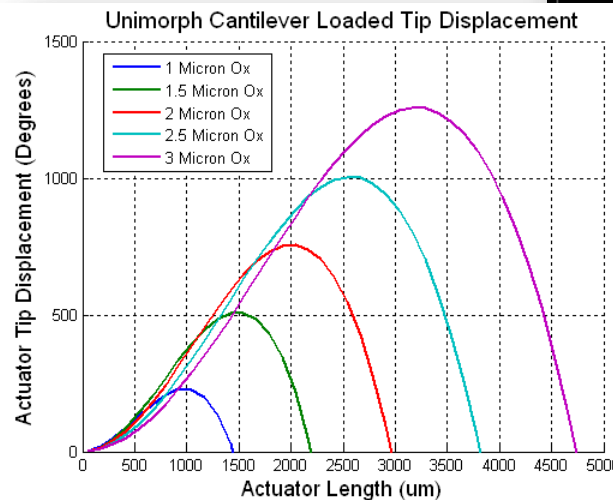
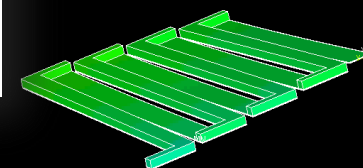
Enables analytical &
numerical model based
Design within system
context



Insect Load Bearing FEA

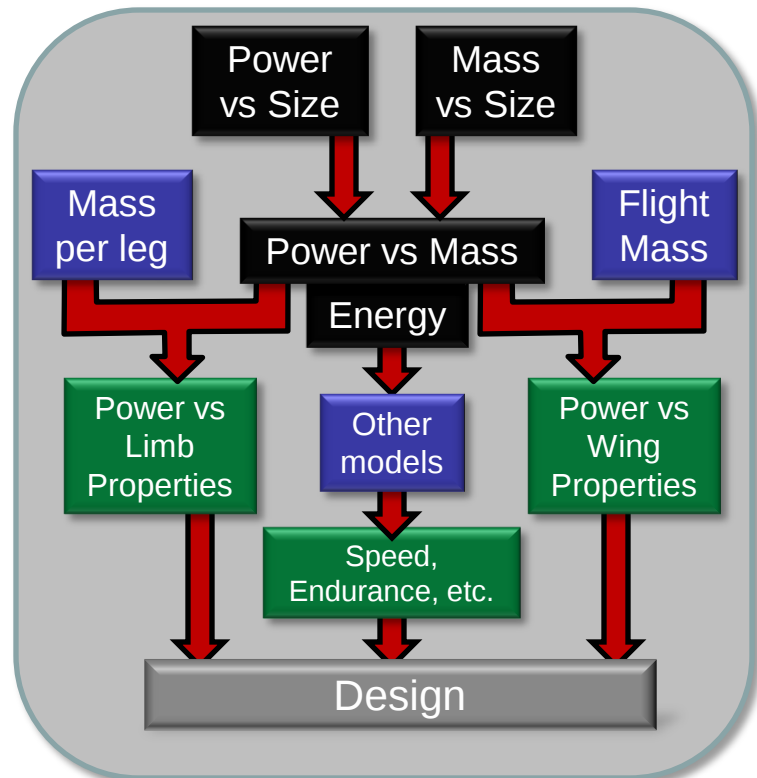


Rotational Actuator Design- FEA



At mm-scale:

- Batteries alone:
 - ~10 to 1000 mW available Power
 - ~10 to 1000 mg Mass
 - Platform dominated by power mass
- Flight:
 - <30mg system mass
 - <30mW available battery power can be supported by flight forces
 - < 20% of available power required to fly
 - Several hours endurance feasible
 - 1-2 kms in 10 minutes feasible
- Ground:
 - Mass/leg range from ~mg to ~600mg
 - 100's mW to >Ws feasible to support with ground mobile systems



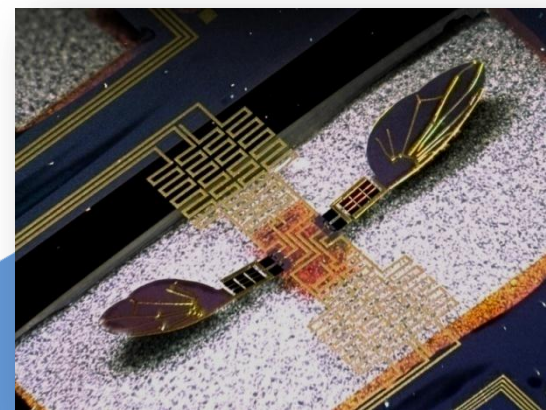
Daedelus Systems & UMD



Harvard



ARL



**10's g
(10's cm-scale)**

**100's mg
(cm-scale)**

**10's mg
(mm-scale)**