**Introduction**

The Pterodactyl unmanned aerial system concept is a short take-off, vertical landing (STOVAL) vehicle that autonomously takes advantage of its morphing capability to gain the flexibility to fit multiple applications. The ultimate goal is a vehicle that can be operated entirely from a pickup truck. The benefits of such a mobile platform are self-evident but it also poses new challenges, particularly in the areas of control, perception and autonomy. These challenges will be expanded on in the future work section.

A typical usage case for the Pterodactyl is as follows. The vehicle is launched with assistance from a spring-launching mechanism on a rail-type device that is no longer than 5. Once airborne, the Pterodactyl acts as a tailless fixed-wing craft and autonomously executes its mission with flight speeds between 35-100 knots. Upon returning to the truck from which it was launched the vehicle performs a rapid climb maneuver in which it transitions to vertical flight. At this point the wings will fold about hinges partway down each wing to form a roughly triangular configuration with three non-parallel thrust vectors. This configuration has several advantages, the most important of which are listed below.

\bullet The linearly independent thrust vectors give complete control over vehicle orientation and that the compact and convex shape

\bullet The compact and convex form factor exposes less area to the wind, improving gust-rejection.

\bullet The wings will be folded about the payload which will help to protect sensitive electronics.

\bullet Much less space is required for landing.

**Simulation**

Currently the Pterodactyl UAS only exists in simulation. Simulation is carried out in Matlab with 1,000 calls to the physics integrator per simulated second and the control law being updated at 100 Hz.   
 **Model Response Control**  
  
The simulation uses a relatively novel control approach called Model Response (or Virtual Model) control. In this approach the orientation of the craft about each of three Euler axes are treated as being independent of each other. The angular displacement and angular velocity about each axis are treated as the state variables that are input into the virtual model’s control system. This system takes the form of a mass-spring-damper system. Using full state feedback, it is trivial to control this virtual system. What this virtual system gives us though is a desired angular acceleration in world coordinates. The three accelerations in world coordinates are then transformed back into body coordinates. The vector of body frame angular accelerations is left-multiplied by the moment of inertia matrix of the vehicle to give the desired torque about each axes. From these torques, the thrust commanded from each rotor can be calculated.  
This method has several advantages, it is asymptotically stable, it is simple to implement, it adapts to modeling error well, it gives a great deal of control over the transient response and largely system independent which makes it easier to test it on many configurations as the design of the vehicle is iterated. One caveat, it is asymptotically stable as long as the virtual model does not call for a thrust that is outside of the vehicle’s capabilities. Future work will emphasize eliminating this criterion for stability by ensuring the virtual model provides an appropriate and reachable response.

**Vehicle Geometry**

It is plain to see form the above consideration that a successful design is heavily dependent on the vehicle’s geometry. For this paper the hinge line angle (\psi) is assumed to be the same for each side though this constraint isn’t required. It will be shown that we can draw conclusions about the parameter selection without relaxing this constraint by taking advantage of the symmetry of the vehicle.

The geometric parameters under consideration are described in figure ***FIGURE***.

To evaluate a given configuration we define a matrix **A** that represents a linear transformation from the space of thrusts to moments about the center of mass of the vehicle. It is important to note that control of the vehicle in hover comes solely from differential thrust of the three propulsors as the propeller blades will have a fixed pitch and the orientations of the thrust vectors relative to the propulsor support structures are fixed.

The column vectors of A corresponding to each propulsor are the cross product of the position of that propulsor relative to the center of mass and the orientation of the thrust vector in body coordinates.

The two most important properties of this matrix are the Euclidean norms of the component row vectors and the condition number. The first property is a metric of the magnitude of the moments that are achievable from the set of available forces. The second property stems from the fact that the commanded thrusts are calculated from the required moments and the inverse of **A** as the condition number is a metric of the invertability of a matrix.

The geometry is also used to numerically approximate the principal moments of inertia of the vehicle. At this stage of vehicle design however this calculation requires too many assumptions about the mass distribution of the vehicle to be of use except to say that the ratio of achievable moment about a body axis to the moment of inertia about that same axis should be maximized so as to improve the response of the vehicle.

**Future Work**

The work described in this paper represents the first step towards constructing the Pterodactyl UAS. Other major areas of work of note are vehicle guidance, forward flight control, mode transition control, autonomous landing, vehicle propulsion, and launch system design and construction.

In its forward flight condition, the vehicle will be controlled using a standard GPS-based autopilot that can be tasked remotely. During transition to vertical flight, the vehicle will first perform a pull-up maneuver so that it is flying almost. Once it establishes vertical flight, it will decelerate to hover and the wings will fold into place with the propulsors still running. A terminal descent is then initiated. A transitional flight controller must be built to handle this phase of flight as it is substantially different from both the forward flight and hover mode.

Terminal descent guidance will be performed using a downward-looking IR camera system and a set of three IR beacons positioned at the landing site. The IR camera system will provide precise guidance corrections to the UAS during terminal descent, and will enable much higher landing accuracy than is currently achievable with GPS-based systems. This is necessary to meet the design goal of landing in such a small area as the mobile deployment platform described above.

Propulsion may be provided either by gas-burning engines, electric motor/propeller combinations, or ducted fans. Trade studies involving propulsion technologies are currently being conducted. A wide range of options are currently feasible, and the ultimate design decisions will hinge on noise, endurance, and weight requirements. Simulation models of the Pterodactyl UAS will incorporate high-fidelity models of the propulsor systems and induced velocity flow over the aerodynamic body.

An important part of the development process will include design of the UAS launch and recovery system. The launcher will consist of a spring-loaded rail which can be fixed to a vehicle such as a pickup truck. A landing fixture will also be designed incorporating IR beacons for terminal guidance and latches that can be attached to the UAS once it has landed for storage and transportation.