VSDDL VT-03-s Shadow

General Arrangement

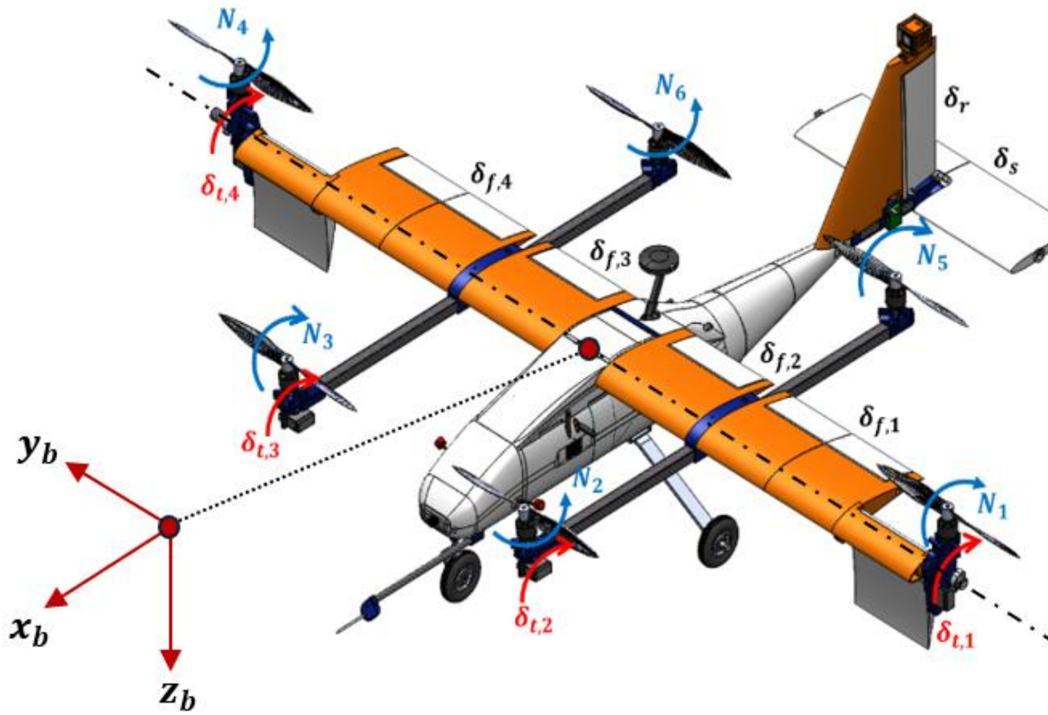

Figure 1 VT-03-s Shadow General Arrangement and Control Effectors

Table 1 VT-03-s Shadow control effectors

#	Symbol	Description	Unit
1	$\delta_{f,1}$	Flaperon, left wing, midboard	deg
2	$\delta_{f,2}$	Flaperon, left wing, inboard	deg
3	$\delta_{f,3}$	Flaperon, right wing, inboard	deg
4	$\delta_{f,4}$	Flaperon, right wing, midboard	deg
5	δ_s	Stabilator	deg
6	δ_r	Rudder	deg
7	$\delta_{t,1}$	Nacelle tilt angle, left wingtip	deg
8	$\delta_{t,2}$	Nacelle tilt angle, front left boom	deg
9	$\delta_{t,3}$	Nacelle tilt angle, front right boom	deg
10	$\delta_{t,4}$	Nacelle tilt angle, right wingtip	deg
11–14	N_1–N_4	Main propeller RPMs	RPM
15–16	N_5, N_6	Lift propeller RPMs	RPM

Table 2 VT-03-s Shadow key characteristics

Propulsion	
Motors (×6)	T-MOTOR AM480 650KV
Main Propeller (×4)	APC 15×10 E/EP fixed-pitch
Lift Propeller (×2)	APC 15×4 E/EP fixed-pitch
Main Battery	Hoovoo 10000 mAh 6S LiPo
Avionics Battery	HRB 3000 mAh 4S LiPo
Avionics & Sensors	
Flight Controller	CubePilot Cube Orange
GPS	Here3+ GPS
Airspeed Sensor	MATEKSYS ASPD-4525
LiDAR	TFmini-S
Telemetry	RFD 900X-US
FPV	Walksnail Avatar GT digital
Geometry	
Wingspan	1.7 m / 5.6 ft
Length	1.32 m / 4.32 ft (excluding pitot)
Length	1.60 m / 5.24 ft (including pitot)
Mass Properties	
Gross Weight	7.89 kg / 17.39 lb
Body-fixed axes	forward-right-down
Origin	Nacelle 1,4 pivot axis on CL
x_{cg}, y_{cg}, z_{cg}	$\{0, 0, 6.20\}$ cm / $\{0, 0, 2.44\}$ in
Inertias I_{xx},I_{yy},I_{zz}	1.35, 0.82, 1.72 kg·m^2

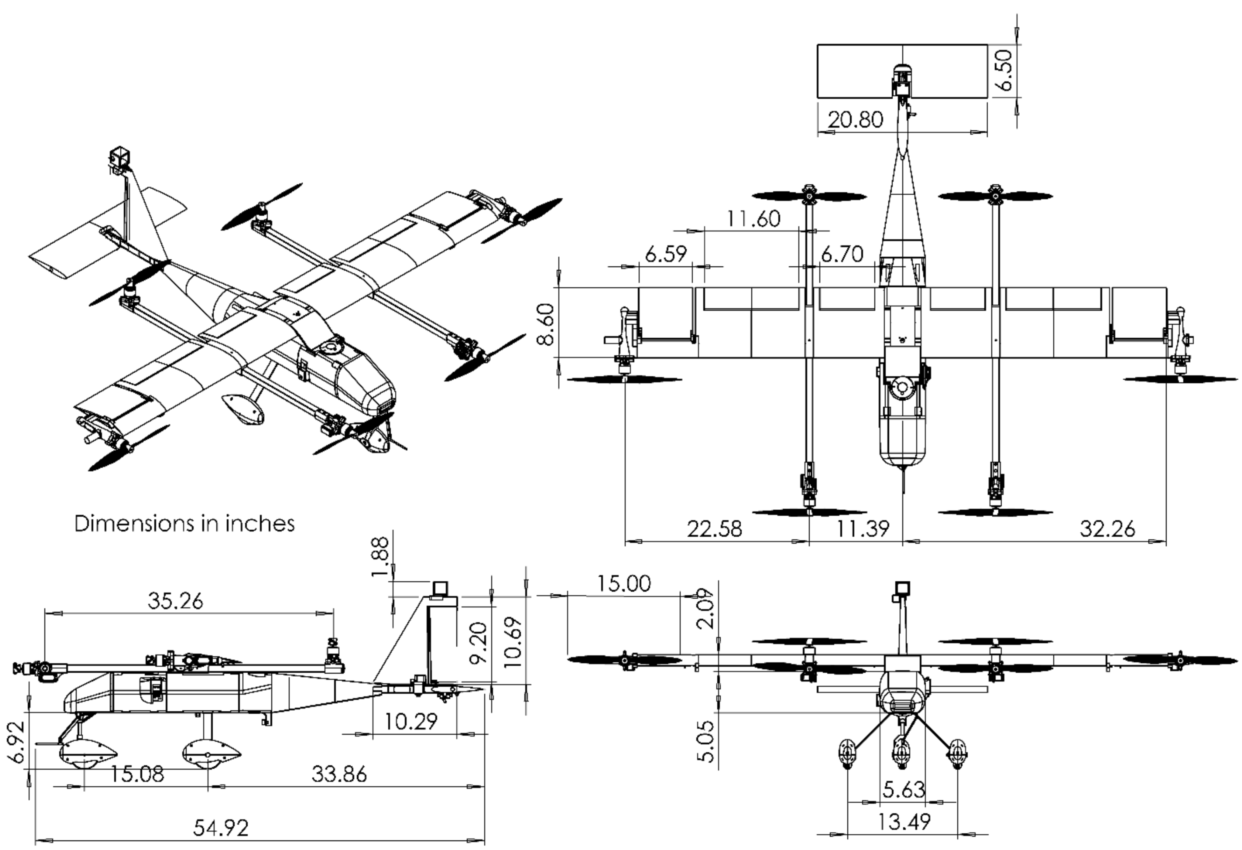

Figure 2: VT-03-s Shadow general arrangement and dimensions

Loading Trim Solutions into the Workspace

Load TrimPointsFull.mat into the MATLAB workspace.

Type “TrimPoints” to get the table of trim solutions. The trim points in this package go from hover (0 kt) to forward flight (50 kt).

The columns appearing in the trim table are the following:

- CaseNum: the case number
- WtCode: a name for what weight configuration the trim point is for. All data provided is for the aircraft’s default flight configuration
- exitflag: success/failure of the trim algorithm in trimming the aircraft. Positive numbers 1+ indicate *fmincon* success criteria were met
- Res: residual of equations of motion and other constraints enforced during trimming. Machine zero values indicate a valid trim solution
- FVAL: value of the objective function that was minimized during trimming
- ALT: altitude in ft
- MACH: Mach number
- KEAS: knots, equivalent airspeed
- KTAS: knots, true airspeed
- AOA: angle of attack (deg)
- BETA: sideslip angle (deg)
- FPA: flightpath angle (deg)
- FPARate: rate of change of flightpath angle (deg/s)
- FPM: rate of climb (feet per minute)

- ULAT: normalized roll axis control effort [-1,+1]

- ULON: normalized pitch axis control effort [-1,+1]

- UDIR: normalized yaw axis control effort [-1,+1]

- n14: RPM of propellers 1-4

- n56: RPM of propellers 5 and 6

- dnac: common component of nacelle 1-4 deflection (deg), where 90 deg corresponds to vertical orientation and 0 deg corresponds to horizontal orientation

- UTrimVec: vector containing the following elements [ULAT, ULON, UDIR, n14, n56, dnac], used for obtaining trim. See control allocation logic for how UTrimVec elements relate to the control effector states.

- PHI: bank angle (deg)

- THETA: pitch angle (deg)

- HDG: heading (deg)

- TRK: ground track (deg)

- TurnRate: turn rate (deg/s)

- nxz: load factor in the body-fixed x-z plane (g-units)

- ny: load factor along the body-fixed y-axis (g-units)

- RH: flightpath curvature in horizontal plane (m)

- RV: flightpath curvature in vertical plane (m)

- P1kW – P6kW: power consumption of propulsors 1-6 (kW)

- TotPwrkW: total power of all propulsors combined (kW)
- CL: lift coefficient sanity check (for testing)
- CD: drag coefficient sanity check (for testing)
- Cm: pitching moment sanity check (for testing)
- LD: lift to drag ratio sanity check (for testing)
- RPM1 – RPM6: propulsor 1-6 individual RPM
- TW: ratio of propulsor thrust to aircraft weight
- TWV_F: vertical component of thrust to weight ratio
- TWH_F: horizontal component of thrust to weight ratio
- TW_MP: main propulsor (1-4) thrust to aircraft weight
- TW_LP: lift propulsor (5-6) thrust to aircraft weight
- Q1-Q6: aerodynamic torques of propulsors 1-6 (Nm)
- Controls: List of control effectors. Columns are in the order described in Table 1.
- X: 12 x 1 state vector comprising the following elements in order
  u (m/s), v (m/s), w (m/s): body-fixed translational velocities
  p (rad/s), q (rad/s), r (rad/s): body-fixed roll, pitch, and yaw rates
  ϕ (rad), θ (rad), ψ (rad): roll, pitch, heading Euler angles,
  x (m), y (m), z (m): North-East-Down flat-Earth position coordinates
- Residuals: individual residuals to be driven to zero during trimming
- Vehicle: the vehicle structure containing all information about the vehicle required to evaluate its nonlinear model

- FltCon: repeated information about the flight condition

- LinModel: linearized model (discussed separately)

- Xinflow: 7 x 6 matrix of propulsor inflow states. The columns are, in order, inflow states of propulsors 1, 2, ..., 6 (see **Figure 1** for numbering). The rows are the inflow states in the following order: (1) v_0 (mean inflow, m/s), (2) v_{1c} (longitudinal inflow gradient, m/s), (3) v_{1s} (lateral inflow gradient, m/s), (4) χ (wake skew), (5) S (wake spacing), (6) κ_c (longitudinal wake curvature), (7) κ_s (lateral wake curvature)

Understanding the contents of the linearized models

The linearized model for trim solution "k" can be accessed as

TrimPoints.LinModel(k)

The contents are the following:

- X0long: state vector of longitudinal states at the trim condition,
  $X_{0,long} = \{u_0, w_0, q_0, \theta_0, x_0, z_0\}^T$

- X0lat: state vector of lateral states at the trim condition,
  $X_{0,lat} = \{v_0, p_0, r_0, \phi_0, \psi_0, y_0\}^T$

- U0: control effector values at the trim condition

- A, B: System and control matrices corresponding to LTI system
  $\Delta\dot{X}^{12\times1} = A^{12\times12}\,\Delta X^{12\times1} + B^{12\times16}\,\Delta U^{16\times1}$

- Along (A_{long}), Blong (B_{long}): System and control matrices corresponding to LTI system $\Delta\dot{X}_{long}^{6\times1} = A_{long}^{6\times6}\,\Delta X_{long}^{6\times1} + B_{long}^{6\times16}\,\Delta U^{16\times1}$

- Alat (A_{lat}), Blat (B_{lat}): System and control matrices corresponding to LTI system
  $\Delta\dot{X}_{lat}^{6\times1} = A_{lat}^{6\times6}\,\Delta X_{lat}^{6\times1} + B_{lat}^{6\times16}\,\Delta U^{16\times1}$

- A_StabAxes, Along_StabAxes, Alat_StabAxes: The A-matrices when the linearization is done with respect to stability axes. These can be used to analyze dynamic stability through eigenvalue analysis.

- Alongnd, Alatnd: Non-dimensionalized forms of the A_{long}, A_{lat} matrices that can be used for eigenvector analysis.

- Ref: struct containing the velocity, reference longitudinal length, and reference lateral length used for non-dimensionalization

- G: Matrix G is the linearization of the control allocation logic used and relates $\Delta U^{16\times1}$ to $\Delta U_{cv}^{6\times1}$ as

$$\Delta U^{16\times1} = G^{16\times6}\,\Delta U_{cv}^{6\times1}$$

where $U_{cv}^{6\times1} = \{u_{lat}, u_{lon}, u_{dir}, n_{14}, n_{56}, \delta_{nac}\}^T$, whose trim values are found in the previously described UTrimVec

$U_{cv}^{6\times1}$ makes it convenient to define control laws for the normalized roll control effort (u_{lat}), pitch control effort (u_{lon}), yaw control effort (u_{dir}), main propulsor RPM (n_{14}), lift propulsor RPM (n_{56}), and nacelle angle (δ_{nac})

Introducing the above into the LTI models yields the following LTI models that are suitable for time-domain simulation with control laws that determine $U_{cv}^{6\times1}$

To simulate full 12-state (longitudinal + lateral) system

$$\boldsymbol{\Delta\dot{X}^{12\times1} = A^{12\times12}\,\Delta X^{12\times1} + B^{12\times16}\,G^{16\times6}\,\Delta U_{cv}^{6\times1}}$$

To simulate the 6-state longitudinal model

$$\boldsymbol{\Delta\dot{X}_{long}^{6\times1} = A_{long}^{6\times6}\,\Delta X_{long}^{6\times1} + B_{long}^{6\times16}\,G^{16\times6}\,\Delta U_{cv}^{6\times1}}$$

To simulate the 6-state lateral model

$$\boldsymbol{\Delta\dot{X}_{lat}^{6\times1} = A_{lat}^{6\times6}\,\Delta X_{lat}^{6\times1} + B_{lat}^{6\times16}\,G^{16\times6}\,\Delta U_{cv}^{6\times1}}$$

Notes: See ControlAllocator.m script for details on control allocation scheme used