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Modelling of 12-DoF Parachute – Riser – Payload System Dynamics using Kane's method

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Abstract

Dynamic behaviour of parachutes is highly complex and characterised by non-linear, time dependant Fluid Structure Interaction, which is computationally intensive and hence not a viable option for incorporating into 6-DoF trajectory simulations. The paper describes modelling of a "***Computationally efficient, High Fidelity Multi-Body***" Parachute – Riser – Payload system, capable of simulating trajectory from parachute deployment till parachute separation. The differential equations of motion, including the kinematical and kinetic relationships are derived using the matrix form of Kane's method, which avoids the typical complexity involved in symbolic derivations, available in published literature. The matrix formulation is extended to cater to variable mass systems, specifically to simulate the parachute opening transients, where the Parachute-Riser-Payload system acts as a constant mass system with variable mass bodies.

Kane's matrix form of equations describing the dynamics of variable mass multi-body system is derived from Lagrange-Cayley equations for variable mass systems described in Hurtado et.al [4] using d'Alembert's principle and extended to matrix form based on Stoneking's [6] formulation. The differential equation in matrix form is shown in Equation (1),

$$\left(\boldsymbol{\Omega}^{\boldsymbol{T}}[\boldsymbol{I}]\boldsymbol{\Omega}+\boldsymbol{V}^{\boldsymbol{T}}[\boldsymbol{m}]\boldsymbol{V}\right)\dot{\boldsymbol{u}}=\boldsymbol{\Omega}^{\boldsymbol{T}}\left(\{\boldsymbol{M}\}-[\boldsymbol{I}]\{\boldsymbol{\alpha}_{\boldsymbol{r}}\}-[\dot{\boldsymbol{I}}]\{\boldsymbol{\omega}\}-\{\boldsymbol{\omega}\}\times([\boldsymbol{I}]\times\{\boldsymbol{\omega}\})\right) +\boldsymbol{V}^{\boldsymbol{T}}\left(\{\boldsymbol{F}\}-[\boldsymbol{m}]\{\boldsymbol{a}_{\boldsymbol{r}}\}-[\dot{\boldsymbol{m}}]\{\boldsymbol{v}\}\right) \tag{1}$$

where, Ω and V are the partial angular velocity and linear velocity matrices, $\{\alpha_r\}$ and $\{a_r\}$ are the remained angular acceleration and linear acceleration vectors, $\{M\}$ and $\{F\}$ define the generalized force and moment matrices of the system, $[I]$ and $\{m\}$ are the inertia and mass matrices of the system and u defines the column vector, comprising of generalized speeds for the system. A generalized reactive thrust is added as component of active force acting on the system, to simulate the effects of mass ejection or absorption, on kinetics of the system.

The formulation is applied to model the dynamics of 12-DoF Parachute Riser Payload system (PRPS) consisting of payload and parachute linked using an elastic riser having non-zero mass as shown in Fig. 1.

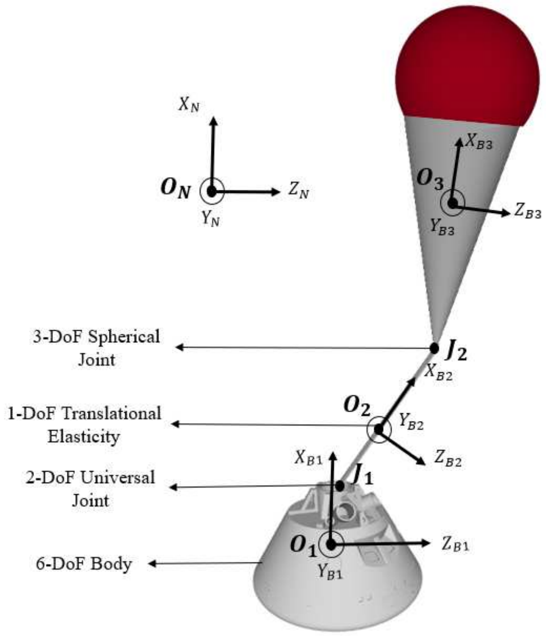

Figure 1: Illustration of Coordinate Frame and 12-DoF System model

The model is validated with published literature results (Fallon et.al [2]) formulated using Newton Euler method. Furthermore, realistic end to end simulations considering simplistic models for wake effects and energy modifications due apparent mass, are carried out with the model and results demonstrating the typical characteristic motion of the system during descent regime of flight are presented.

The modular matrix formulation of PRPS system ensures that the model can easily be extended to cluster of parachutes, by extending the derived velocity, mass-inertia and force matrices for multiple parachutes (considering each parachute as separate bodies and modelling the contact aerodynamics).

References

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