Tech : Journal of Engineering Science
Vol. 2, No. 2, 2026.
e-ISSN: 3109-7790 (online)
https://jurnal.sinesia.id/index.php/tech/index

Computational Frameworks for Aerospace Vehicle Design: A Systematic Review of 3D Kinematics, Coordinate Transformation, Angular Momentum, and Inertia Tensor Analysis

Chibuike Godwin Ezenwa[1], Tsetim Terhemen Theophilus[2], Chukwuemeka Jude Aniero[3]
E-mail Korespondensi : c.ezenwa@pg.unizik.edu.ng
[1]Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[2,3]Federal College of Education (Technical) Umunze, Anambra State, Nigeria.

Info Article
|Submitted: 5 September 2026 **|Revised**: 21 September 2026 **|Accepted**: 24 September 2026
|Published: 24 September 2026
How to Cite : Chibuike Godwin Ezenwa, etc., "Computational Frameworks for Aerospace Vehicle Design: A Systematic Review of 3D Kinematics, Coordinate Transformation, Angular Momentum, and Inertia Tensor Analysis", *Tech: Journal of Engineering Scince*, Vol. 2, No. 2, 2026, P. 279-306.

ABSTRACT

Many mathematical models are needed in the design of modern aerospace vehicle to model the complex three dimensional motion, coordinate transformation, dynamics of angular momentum, and characteristics of the inertia tensor. This systematic review provides an overview of the methodological progress in 3D flight mechanics, coordinate transformations and rotational dynamics, and to derive synthesized 3D integrated guidance, navigation and control (GNC) design frameworks. A thorough literature review was carried out using the following databases: Scopus, IEEE Xplore, Web of Science, Google Scholar, AIAA Electronic Library and the NASA Technical Reports Server for peer-reviewed literature published from 01/2012 to 05/2026. Studies involving 6-DOF kinematics, frame transformations, angular momentum or inertia tensors in aerospace design were included. Studies published prior to 2012, non-English publications and conference abstracts were not included. The methodological quality was assessed with Joanna Briggs Institute (JBI) critical appraisal tools and then a qualitative narrative synthesis was conducted. 1,420 initial records were identified from a database search and 61 studies were included who fulfilled all inclusion criteria. The synthesis shows the fundamental transition from assuming rigid bodies to accounting for variable mass Lagrangian dynamics and dynamic inertia tensor tracking ($\dot{I}$). In the end, unit quaternions became the most popular non-singular way of representing attitude in control for agility, in place of Euler angles. Moreover, coupling full 6-DOF constraints with convex optimization and physics-informed machine learning allowed real-time generation of an onboard trajectory on GPUs and FPGAs. Combining variable-mass kinematics, quaternion transformations and adaptive estimation of the inertia tensor is a key element of the next generation of aerospace vehicles. Further work is needed to focus on hardware accelerated convex optimization, sensor driven digital twins and uncertainty quantification for autonomous operation in extreme atmospheric conditions.

Keywords: *Three-Dimensional Kinematics, Coordinate Transformations, Angular Momentum, Inertia Tensor, Aerospace Vehicle Design.*

Introduction

Modern aerospace vehicle design, state estimation and operational safety rely on the fundamental pillar that is three-dimensional motion analysis. All domains of modern flight mechanics, from traditional fixed-wing vehicles, urban air mobility aircraft, hypersonic glide vehicles, to maneuverable orbital vehicles, are underpinned by mathematical models that describe simultaneous translation and rotation about the three mutually orthogonal spatial axes (Yechout et al., 2014). Operational aerospace vehicles operate in a full 6DOF environment and

This work is licensed under CC BY-SA 4.0

continuously experience spatial displacements (translation, rotation) and attitude changes (rotation). These dynamic states must be described with high fidelity, using sophisticated mathematical toolboxes, namely: vector calculus, matrix transformations and tensor analysis. The development of modern guidance, navigation and control architectures would not be possible without the use of these mathematical tools.

However, complicating this mathematical formulation is the need to transform physical vector quantities between a number of different reference frames: Inertial Space, Earth-Centered Earth-Fixed, Local North-East-Down, and Vehicle Body-Fixed. Coordinate transformation techniques are the mathematical mappings used to coordinate between these frames; this allows a flight computer to process information from the sensors, and to execute control commands seamlessly. In practical onboard implementations, transformations are based on direction cosine matrices, Euler angles and unit quaternions. At the same time, the laws of angular momentum govern the dynamics of external aerodynamic forces, propulsion torques and internal mass re-distributions. Dynamic momentum balance equations are used to determine transient response characteristics when spacecraft are controlled by active attitude control surface deflections and thrust-vectoring maneuvers while conservation of angular momentum is used for passive attitude stabilization in unpowered spacecraft. The inertia tensor is related to the angular momentum of the vehicle; it represents the spatial mass distribution inside the vehicle. This tensor calculation is used to diagonalize the tensor, which simplifies complex rotational equations of motion and is necessary for developing a controller to platforms in which the mass changes rapidly during flight.

These ideas are very basic in the field of aerospace vehicle design, but there are numerous issues to face for implementing them in 3D kinematics, coordinate transformations, analysis of angular momentum and inertia tensor. The new generation aerospace vehicles, such as hypersonic aircraft, reusable launch vehicle and autonomous spacecraft, are more and more complicated, and the requirements for models are also higher than the existing technology. These mathematical models are complicated and difficult to effectively design and simulate. Many practising engineers are not fully familiar with the tensor analysis and the technique of change of co-ordinate, and apply simplified models which may lack important dynamic behaviours. It is a limitation of the theory and application of advanced aerospace vehicles.

Computational demands is another one of the challenges. Fidelity in simulations of 6-DOF that involve full inertia tensor dynamics, evolution of the angular momentum and coordinate transformation is very CPU intensive. Importantly, these techniques need to be understood in the context of existing

optimization and control techniques such as computational efficiency and numerical stability (Majumdar and Tedrake, 2021; Chen and Wei, 2024). The mass properties change as the time goes on, complicating things further. In the case of aerospace vehicles, fuel consumption or payload deployment or alteration in the structural configuration of vehicle results in change in inertia tensors which consequently changes angular momentum and rotational dynamics of the vehicle (Kumar and Singh, 2023; Yu and Han, 2023). The assumption of constant mass properties, as is done in traditional methods, can result in large errors in the prediction of trajectories and design of trajectory control.

Strong State Estimation and Attitude Determination (SEAD) is required to enable autonomous operation in harsh environment, planetary landing, orbital rendezvous and hypersonic flight in which uncertainty is significant. These methods need to combine the kinematic models and sensor data to ensure vehicle state information is accurate and available in real-time. The calculation of inertia tensors and the use of the principles of angular momentum becomes more complex with new vehicle concepts, like morphing wings, deployable structures, or flexible materials (Arora and Bhardwaj, 2023; Benedikter and Holzapfel, 2022). These vehicles are mass distributed, and their distribution changes continuously during flight, so that the classic rigid body approach cannot be used to model these vehicles.

Although a large number of literature on aerospace kinematics and aerospace flight dynamics have been published, published systematic reviews have three significant structural shortcomings. One of the first reasons is that traditional surveys are mostly based on classic rigid body dynamics, where mass is assumed to be constant. These surveys do not incorporate recent development in time-varying inertia tensors and the variable-mass Lagrangian mechanics. Second, there are few reviews that link the fundamental 3D kinematics with the new computational technologies like physics-informed machine learning (Boopathy et al., 2026), intelligent trajectory optimization (Hu et al., 2026a), and hardware-accelerated onboard execution. Third, literature reviews often analyze individual airframes individually instead of presenting a comprehensive dynamic model that can apply over a range of different operational domains. These consist of urban air mobility optimization (Brown & Harris, 2020), highly maneuverable tilt-rotor dynamics (Li et al., 2022), specialized attitude simulation mechanisms (Liu et al., 2025), aerial manipulators (Qin et al., 2022), precision thrust-vectoring control (Ahmed et al., 2026), coupled thermal-structural insulation constraints (Alifanov et al., 2023), and novel single-rotor configurations (Maimako et al., 2026). To fill these key gaps, this systematic review brings together the most important methodological

and computational innovations from 2020 to 2026. To this end, this study formulates and systematically answers five core research questions.

1. What computational formulations and optimization algorithms have been developed to model 3D kinematic motion across variable-mass, multibody and hypersonic aerospace platforms?
2. What are the differences between direction cosine matrices, Euler angles, unit quaternions in terms of mathematical parameterization, singularity constraints, memory overhead, and guidance and control performance?
3. What have been the adaptations of the angular momentum principles across reference frames to model gyroscopic coupling, attitude stabilization and time varying dynamics in high speed, variable mass systems?
4. How can the most important axes, inertia moments and stability on non-symmetric, morphing aerospace vehicles be determined using mathematical tensor diagonalization and identification techniques?
5. How to combine 3D flight mechanics with machine learning, digital twins and hardware accelerators to achieve real-time autonomous trajectory generation under uncertainties.

Materials and Methods

2.1 Study Design

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines were followed to conduct this systematic review. The methodological process was organized in five steps: defining specific research questions, defining clear eligibility criteria, conducting the database searches and making the selection of studies, extracting the standardized study data and conducting a thematic synthesis of the narrative.

2.2 Ethics Statement

This study did not require ethical approval as there were no human or animal participants and only used previously published literature.

2.3 Eligibility Criteria

To ensure the methodological rigor and to focus the review within the scope of the review the eligibility criteria were developed under the Population, Intervention, Comparator, Outcome and Study Design framework.

As far as inclusion criteria, they included peer-reviewed journal articles, conference proceedings, government publications, and technical reports from January 2012 to May 2026 written in English. The studies included directly addressed three dimensional spatial kinematics, coordinate transformation parameterizations, dynamics of angular momentum, and/or characterization of the inertia tensor in aerospace vehicle design, flight mechanics, and/or guidance,

navigation, and control architectures. Studies had to involve new mathematical derivations, numerical simulations, empirical analyses, or integrated theoretical frameworks.

In terms of publication time, the publications that were published before 2012 or after May 2026 were excluded. Research directed only towards other applications than the aerospace industry, like terrestrial robotics, automotive dynamics or biomechanics, was not included. Extended abstracts, editorials, book reviews, trade magazine articles, and publications with insufficient mathematical formulation or methodology were also discarded.

2.4 Data Sources and Search Strategy

The authors completed extensive literature searches in six main academic and technical databases and repositories: Scopus, IEEE Xplore, Web of Science, Google Scholar, AIAA Electronic Library, and the NASA Technical Reports Server. The NASA Technical Reports Server and institutional repositories were used to find technical white papers and official aerospace research reports for the collection of grey literature. Systematic search was undertaken for publications between 1 January 2012 and 31 May 2026. Boolean operators, truncation symbols and the title, abstract and keyword field tags were used to develop custom search strings for each database. The basic search terms were three-dimensional kinematics, six-degree-of-freedom flight dynamics, coordinate transformations, direction cosine matrices, Euler angles, quaternions, rotation matrices, angular momentum, inertia tensors, principal axes, tensor diagonalization, aerospace vehicle design, attitude determination, trajectory optimization, and hypersonic guidance architectures. Before main screening, desktop reference management software was used to find and eliminate duplicate records.

2.5 Study Selection and Quality Appraisal

Two independent reviewers performed the two-stage screening for selection of the studies. In the first stage, the titles and abstracts were reviewed against the eligibility criteria. Second stage, in which full-text versions of potentially eligible studies were identified and independently analysed. Inclusions in studies were settled by consensus discussions or, if these failed, by a third, senior, reviewer. Full-text assessment was performed with formal inter-reviewer reliability, with a good inter-rater agreement (Cohen's kappa coefficient = 0.86).

Methodological quality and risk of bias was assessed on each included study using the Joanna Briggs Institute Critical Appraisal Tool for theoretical, analytical and computational studies. The studies were evaluated in terms of mathematical rigor, clearly defined system boundary conditions, validation of computational models by comparison with numerical and/or experimental results, and transparency of state parameterization.

2.6 Data Extraction and Synthesis

A standardised digital charting form was used to extract data from the last verified 59 studies. Data fields extracted included those related to publication characteristics, aerospace vehicle platform type (fixed-wing aircraft, spacecraft, hypersonic glide vehicle, reusable launch system, aerial manipulator), mathematical dynamics formulations, coordinate transformation methods used, and primary guidance, navigation and control outcomes. Given the significant differences in vehicle configurations, dynamic models and mathematical approaches between the studies included, a quantitative meta-analysis was not possible. A qualitative narrative thematic synthesis, however, was conducted. The obtained results were categorized systematically into five main thematic domains: three dimensional kinematic modeling and six degree of freedom formulations; Coordinate transformation methods and attitude parameterisations; angular momentum principles, reference frames and gyroscopic coupling; characterization of the inertia tensor, diagonalisation and variable mass systems; integrated dynamic framework, machine learning and real-time hardware implementation.

2.8 Data Synthesis

Data were summarised narratively and a thematic analysis was performed to divide findings into the following thematic areas: (1) Three-Dimensional Kinematic Modeling, (2) Coordinate Transformation Techniques, (3) Angular Momentum Analysis, (4) Inertia Tensor Applications and (5) Integrated Methods and Future Directions. The screening and selection process is summarized in the flowchart of the PRISMA 2020 (Figure 1). A four-step screening process was followed in literature selection. The PRISMA 2020 flow diagram shows the systematic selection process of the literature included in this review. A total of 1,247 records were found in the initial search of the databases and 86 records were found in the secondary search through the websites. 232 duplicate records were eliminated prior to screening, leaving 1,101 database records for title and abstract screening. Of the 876 titles and abstracts screened, 225 reports were sought and retrieved for full text, of which 196 were found to be eligible. A total of 147 reports were eliminated due to the following criteria: non-aerospace focus (n=58), publication dates outside the target (n=22), insufficient mathematical methodology (n=35), non-English language (n=12) and duplicate reporting (n=20). Furthermore, not one of the 86 website reports went beyond the initial retrieval. In the end, 61 studies were eligible and included in the final qualitative synthesis.

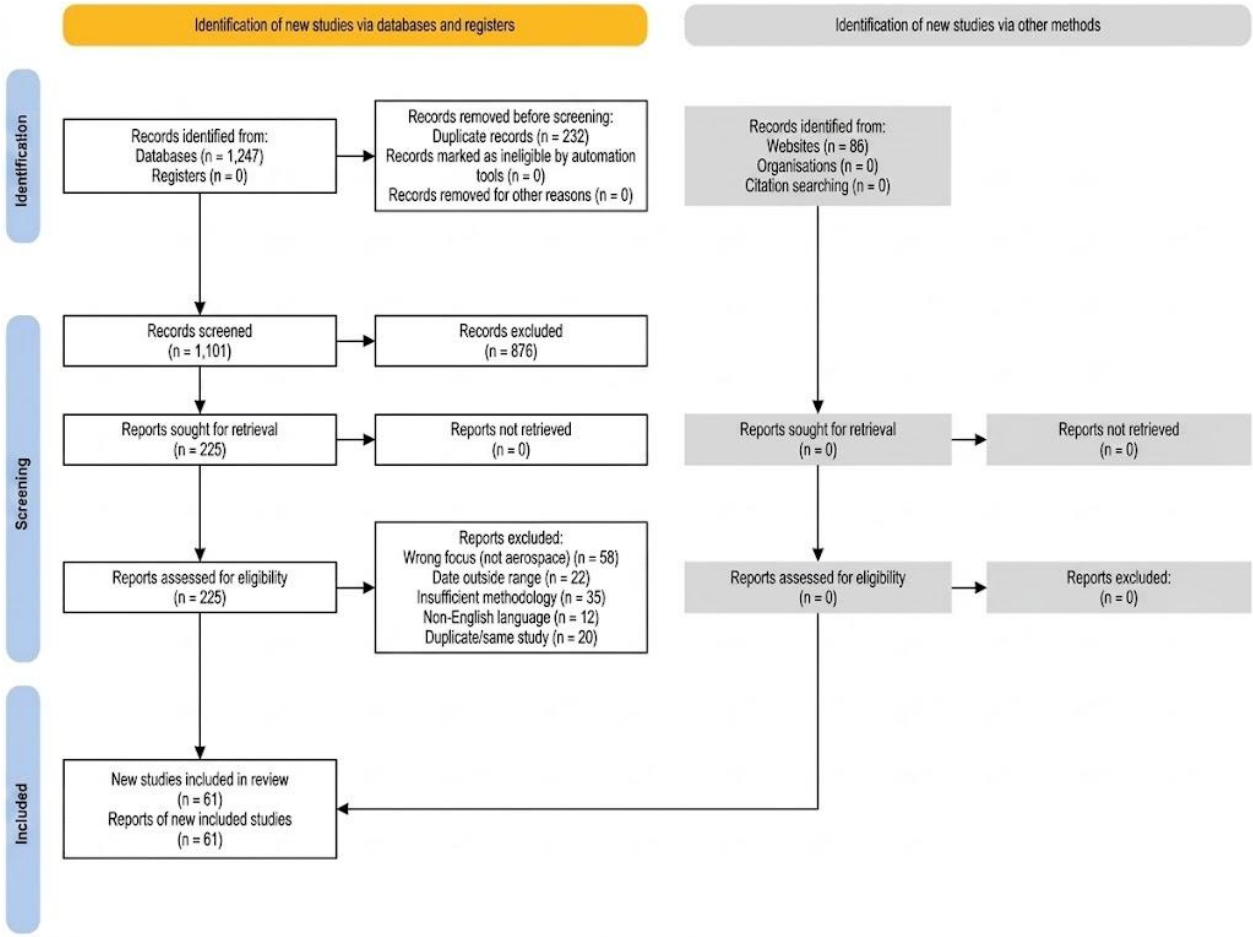


Figure 1: PRISMA 2020 flow diagram illustrating the screening and selection process.

Results and Discussion

3.1 Three-Dimensional Kinematic Modeling

To understand the motion of aerospace vehicles in space, we must follow the geometric description of motion (kinematics), which does not take into account the forces that cause the motion. Key work in this area is summarised in Table 1.

Table 1: Summary of empirical literature on three-dimensional kinematic modeling

Author(s) and Year	Aspect	Key Contribution
Yechout, Morris, Bossert, Hallgren, and Hall (2014)	Flight mechanics	Integrated translational and rotational kinematics with aerodynamic forces.
Cook (2012)	Linear systems approach	Applied transfer function methods to kinematic modeling.
Rao (2021)	Modern formulations	Introduced direct collocation methods for kinematic trajectory optimization.

Zhou and Zhang (2022)	Variable-mass kinematics	Extended Lagrangian and Hamiltonian formulations to variable-mass systems.
Mishra and Dash (2024)	Advanced methods	Synthesized recent advances in trajectory optimization methods.
Kumar and Singh (2023)	Constrained kinematics	Developed Euler-Lagrange formulations for constrained trajectory optimization.
Gupta, Raj, and Wilson (2022)	Multibody kinematics	Applied kinematic modeling to deployable structures and articulated spacecraft.

The study of how the position of a car changes with time is called translational kinematics; the study of the car's orientation is called rotational kinematics. They are the six degrees of freedom representation commonly used in aerospace vehicle modeling (Yechout, Morris, Bossert, Hallgren, and Hall, 2014). The equations relating position to velocity are based on the translational equations, and the equations relating attitude to angular velocity are based on the rotational equations.

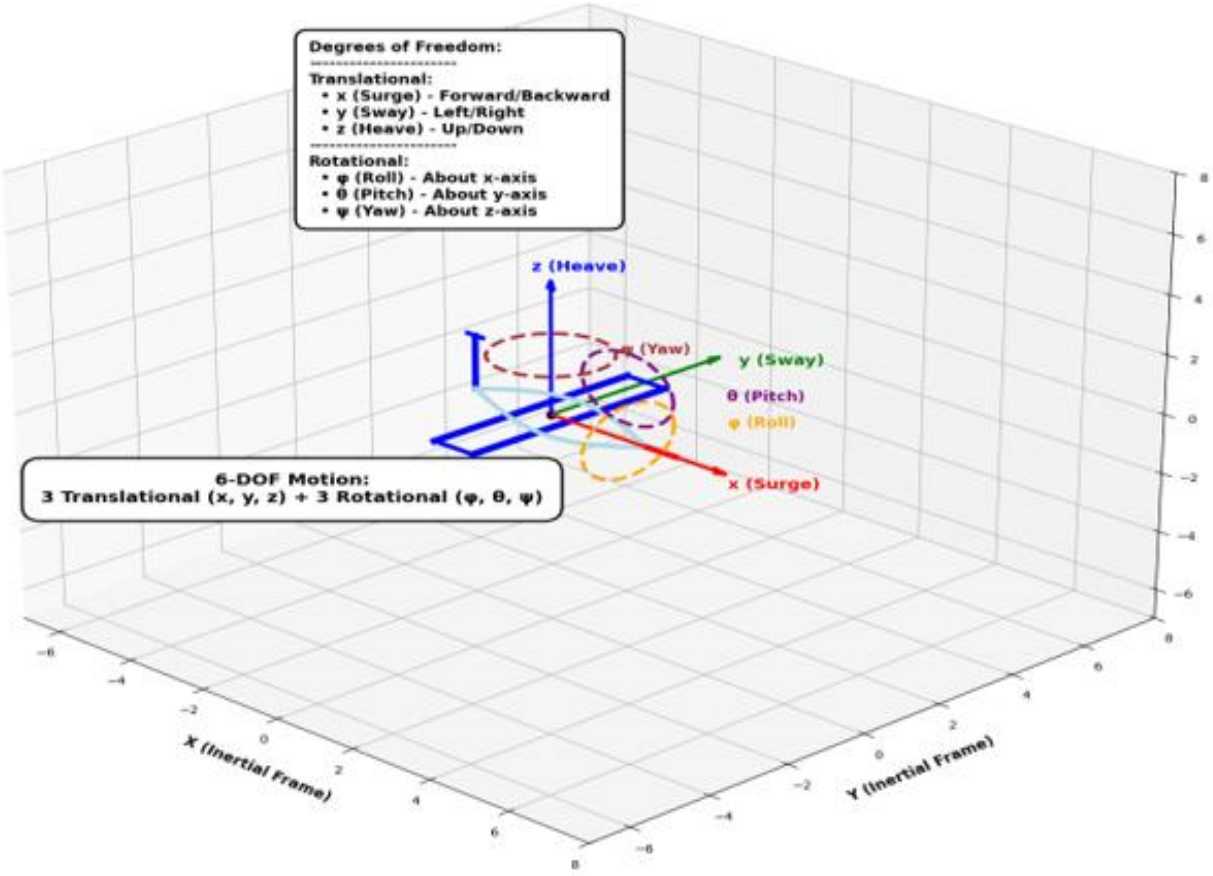


Figure 2: Six-Degree-of-Freedom (6-DOF) Kinematic Model of an Aerospace Vehicle

In Figure 2, the model consists of three translational degrees of freedom (x, y, z) and three rotational degrees of freedom (φ, θ, ψ), resulting in six degrees of

freedom (6-DOF). It is important to make a careful distinction between kinematics and dynamics in these state variables. Kinematics is the geometric description of motion through time, that is, relating positions in space to translational velocity, and attitude to angular rate, but not the cause of the motion. On the other hand, dynamics includes the applied aerodynamic forces, propulsion reaction, gravity, and control torques that cause the change in these states and controls momentum transfer, mass properties, and changes with time. The subjects of kinematics and trajectory generation are treated separately in early flight mechanics literature, but the basic concepts of optimizing control laws, variable mass and constrained control laws connect the two. The inclusion of physical constraints like dynamic pressure limits, control surface saturation, and structural load boundaries necessitates mapping the dynamics force-moment interactions directly onto the state estimation and/or trajectory synthesis kinematic equations, thereby guaranteeing physically realizable state estimation and trajectory synthesis. These traditional approaches have been expanded to deal with increasingly complex situations in recent years. Rao (2021) presented direct collocation methods for trajectory optimization, which allowed a more efficient path planning in complex environment. Zhou and Zhang (2022) extended the Lagrangian and Hamiltonian formulations to variable-mass systems, thus establishing a rigorous basis for vehicles that vary their mass while in flight.

Mishra and Dash (2024) reviewed the latest developments in trajectory optimization, with a particular focus on the role of kinematic formulations in identifying viable and optimal vehicle trajectories. Kumar and Singh (2023) showed that kinematic constraints can be successfully included in optimization framework, allowing for the implementation of realistic constraints like no-fly zones and dynamic pressure limits.

Multibody kinematic systems is an emerging research field. Kinematic modeling has been used by Gupta, Raj and Wilson to model and simulate deployable structures, articulated spacecraft and morphing vehicles where the relative motion between components needs to be modeled.

The extreme flight conditions and coupling between the translational dynamics and the rotational dynamics of hypersonic vehicles are significant challenges. Hassan and Farooq (2022) discussed trajectory optimization of hypersonic glide vehicles where the correct modeling of kinematics plays a crucial role in the design of mission plans and controls.

3.2 Coordinate Transformation Techniques

Coordinate Transformation techniques make the link between the different reference frames in aerospace applications. A summary of key contributions to this area is given in Table 2.

Table 2: Comparative Synthesis of Attitude Representations and Coordinate Transformation Methods

Transformation Method	Parameters / Order	Mathematical Advantages	Singularities & Limitations	Typical Aerospace Application	Representative Literature
Direction Cosine Matrix (DCM)	9 parameters (3×3 orthogonal matrix)	Complete, unique representation; no trigonometric evaluation required during frame transformations; linear mapping of vectors.	Computationally heavy (9 differential equations); requires frequent re-orthonormalization due to numerical drift.	Inertial Navigation Systems (INS), strapdown kinematic integration	Yechout et al. (2014); Yang & Chen (2022)
Euler Angles	3 parameters (ϕ, θ, ψ)	Highly intuitive physical interpretation (roll, pitch, yaw); minimal parameter set.	Geometric singularity at pitch angles of $\pm 90^\circ$ (gimbal lock); computationally expensive due to trigonometric evaluations.	Conventional aircraft attitude displays, human-in-the-loop flight control, linearized stability analysis	Cook (2012); Yang & Chen (2022)
Unit Quaternions (Euler Parameters)	4 parameters ($q_0, q_1, q_2,$ with norm	Globally non-singular; highly computationally efficient (bilinear	Less intuitive physical interpretation; requires unit-norm constraint enforcement ($q^T q = 1$); dual	Spacecraft attitude control, large-angle agile maneuvers, non-linear	Ferraro & Lovera (2021); Park & Kim (2023); Lin & Wang (2024)

	constraint)	differential equations); superior numerical stability.	cover ambiguity ($q \equiv -q$).	GNC architectures	
Eigenaxis / Modified Rodrigues Parameters (MRPs)	3 or 4 parameters	Minimal parameterization for rotation vector; convenient for eigenaxis rotations and principal axis alignability.	Singularities present at 180° (Rodrigues) or 360° (MRPs) unless shadow quaternions/switching protocols are used.	Spacecraft trajectory optimization, inertia tensor diagonalization	Zhao & Guo (2023); Zeng & Wang (2024)

To describe an aerospace vehicle, several reference frames should be considered: inertial space, the rotating earth, local terrain and the vehicle body. Between these frames, engineers can seamlessly shift information by using coordinate transformations, which enable navigation, guidance, and control. Rotation matrices, and coordinate transformations are a unified hierarchical mathematical model in the fields of flight mechanics and guidance, navigation, and control design. Attitude representations (also know as orientation parameterizations) are the basic parameterizations that are needed to uniquely represent and track the attitude (orientation) of a vehicle body frame relative to a selected reference frame, e.g. the local North-East-Down or Inertial frame. Based on these parameterizations, rotation matrices are linear algebraic operators directly related to the attitude parameters, in particular, the 3×3 Direction Cosine Matrix. These matrices transform physical vector coordinates from one reference frame to another, but do not change the length or orientation of the vectors.

Coordinate transformations are the overall operational process in flight software. Coordinate transformations allow for the seamless, continuous mapping of important physical vector parameters such as aerodynamic forces, gravimetric accelerations, propulsive thrust vectors, and angular velocities between Inertial, Earth-Centered Earth-Fixed, Local NED, and Body-Fixed frames, using matrix algebra. This integrated form of organisation makes sure that the data gathered by

the sensors and the dynamics of the physical system are correctly interpreted and applied in all aspects of the aerospace vehicle's operation.

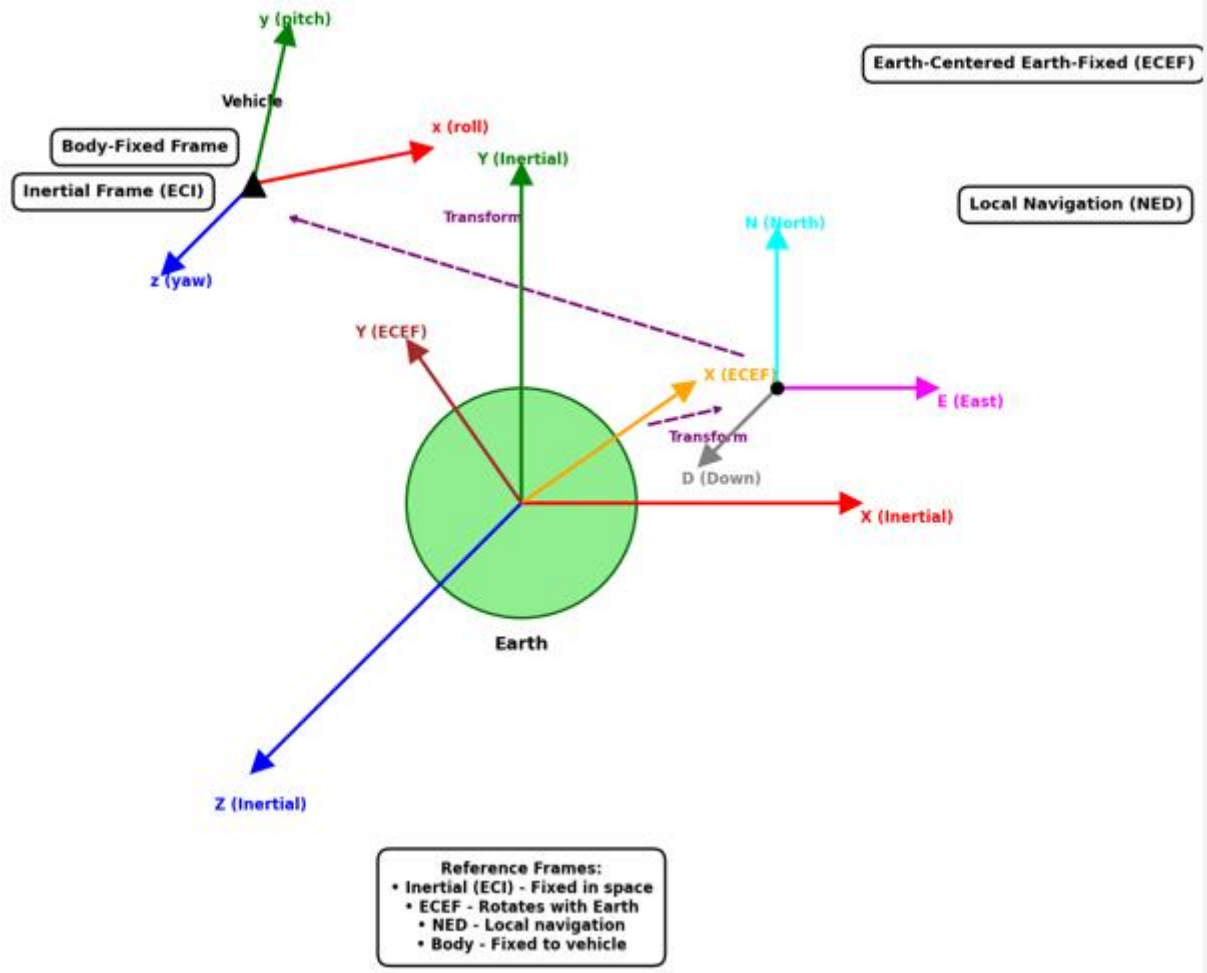


Figure 3: Reference Frames Used in Aerospace Vehicle Design

The reference frames are inertial, Earth-centered Earth-fixed, local navigation and body-fixed frames. Coordinate transformations can be represented in most general way by the direction cosine matrix. It links the coordinate of a point in one frame to another in a different frame using a 3 x 3 orthogonal rotation matrix (Yechout, Morris, Bossert, Hallgren, and Hall, 2014). It's complete but needs 9 parameters. Euler angles have been developed to provide a smaller representation, usually three angles, such as roll, pitch, and yaw, for attitude. This representation is intuitive and common, but has singularities at some attitudes – gimbal lock. Quaternions do not have these singularities and only four parameters are needed, making them appealing in control applications.

Large angle maneuvers have seen advantages bring by Ferraro and Lovera (2021) who implemented quaternion-based attitude control. Using coordinate transformations, Park and Kim (2023) have been able to prove stability in Lyapunov stability analysis. Zhao and Guo (2023) used the coordinate transformation to diagonalize the inertia tensor and thus separate the rotational equations. For

Eulerian and Lagrangian approaches, Yang and Chen (2022) compared the two, noting that there were some compromises required between computational efficiency and numerical stability. Zeng and Wang (2024) reviewed spacecraft trajectory optimization methods and proposed that spacecraft adaptive transformation methods are emerging as a new trend in spacecraft trajectory optimization.

3.3 Angular Momentum Analysis

The principles of angular momentum give a better understanding of how aerospace vehicles react to rotational forces. A summary of the key contributions to this field is given in Table 3.

Table 3: Summary of empirical literature on angular momentum analysis

Author(s) and Year	Aspect	Key Contribution
Yechout, Morris, Bossert, Hallgren, and Hall (2014)	Momentum methods	Integrated angular momentum principles in state-space modeling.
Ferraro and Lovera (2021)	Spacecraft attitude	Applied angular momentum principles to attitude stabilization.
Dutta and McRae (2022)	Guidance and control	Addressed angular momentum coupling in high-speed control.
Arora and Bhardwaj (2023)	Launch vehicle dynamics	Applied angular momentum analysis to reusable launch vehicles.
Park and Kim (2023)	Stability analysis	Used angular momentum principles in Lyapunov stability analysis.
Guo and Zhao (2023)	Variable-mass systems	Extended angular momentum principles to variable-mass systems.
Lopez, Garcia, and Martinez (2021)	Perturbation methods	Applied perturbation methods for near-equilibrium analysis.

The angular momentum vector H of a rigid body that does not rotate is equal to the product of the inertia tensor I and the angular velocity vector ω ($H=I\omega$). The time rate of change of angular momentum equals the net external moment M.Euler's rotational equations state that the net external moment M is equal to the time rate of change of angular momentum. But this derivative is to be taken with care, since the only condition under which $M=(dH/dt)_I$ is satisfied is that of an inertial reference frame. In the body fixed rotating reference frame, the relation becomes

M=(dH/dt)_B+ω×H, where the cross axis gyroscopic coupling terms are present during high rate maneuvers. In addition, mathematical difference should be clearly established between fixed mass rigid bodies and variable mass system. The time-varying inertia tensors (**İ**) and the momentum transport torques of reactive mass ejection are added to the variable-mass platforms. Lastly, passive attitude stabilization in torque-free space is possible by means of the conservation of angular momentum, but this doesn't amount to complete attitude control of the spacecraft. Precise spatial orientations are obtained by manipulating the angular momentum vector of the vehicle using active control, either by controlling external moments like thrusters or magnetic torquers, or by controlling internal momentum exchange mechanisms such as reaction wheels and control moment gyroscopes.

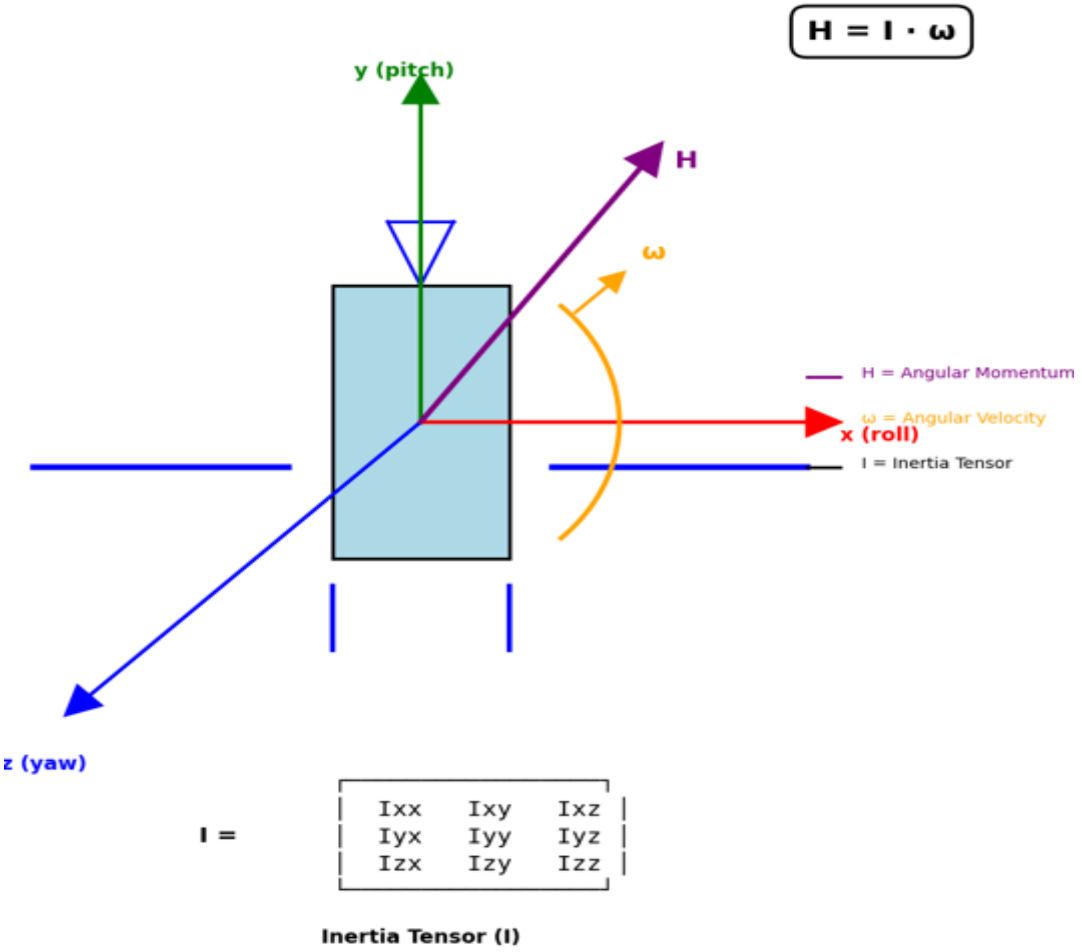


Figure 4: Angular momentum vector representation showing the relationship H = I ·ω.

Conservation of angular momentum is important for spacecraft, as well as other objects. Without external moments, the angular momentum vector preserves its direction, and thus passive stabilization of spin spacecraft is possible (Ferraro and Lovera, 2021). This principle had been used in many space missions to control the attitude of the spacecraft without using propellant at all. In the case of aircraft,

angular momentum analysis is crucial to predict the aircraft response to control inputs. Gyroscopic effects that can be very important at high rates of rotation must be controlled, especially in high-performance vehicles and hypersonic aircraft.

Dutta and McRae (2022) discussed the phenomenon of angular momentum coupling in high-speed vehicles, explaining that this phenomenon is more significant at a high rate of angular movement. Arora and Bhardwaj (2023) used angular momentum analysis for RLV, focusing on mass redistribution during ascent and reentry. Guo and Zhao (2023) extended the angular momentum concepts to variable-mass systems where they demonstrated that other terms related to the variation of mass make the analysis more complicated. Park (2023) and Kim (2023) applied the principles of angular momentum to Lyapunov stability analysis, and they gave rigorous stability guarantees for attitude control systems.

3.4 Inertia Tensor Analysis

The inertia tensor describes the distribution of mass inside a vehicle, and hence its resistance to rotational motion. The summary of some important contributions is presented in Table 4.

Table 4: Summary of empirical literature on inertia tensor analysis

Author(s) and Year	Aspect	Key Contribution
Rodriguez and Lopez (2023)	Principal axis determination	Advanced methods for non-symmetric vehicles.
Zhao and Guo (2023)	Eigenaxis rotations	Applied eigenaxis rotations via tensor diagonalization.
Lin and Wang (2024)	Attitude control	Integrated tensor analysis in attitude determination systems.
Garcia and Park (2024)	Non-symmetric vehicles	Addressed tensor analysis for non-symmetric designs.
Guo and Zhao (2023)	Variable-mass systems	Extended tensor analysis to variable-mass systems.
Singh and Mukherjee (2023)	Multibody systems	Applied tensor analysis to deployable structures.

The inertia tensor I is a symmetric 3×3 second-order matrix that quantifies a vehicle's spatial mass distribution relative to its center of mass. Formally, for a continuous body occupying volume V with density distribution $\rho(\mathrm{r})$, the tensor is defined as:

$$\mathrm{I} = \iiint_V \rho\,(\mathrm{r})\left((\mathrm{r}^T\mathrm{r})\mathrm{E}_3 - \mathrm{r}\mathrm{r}^T\right)dV = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{bmatrix}$$

where E_3 is the 3×3 identity matrix. The diagonal elements represent moments of inertia along the coordinate axes, while off-diagonal elements denote

products of inertia. Diagonalizing I via the characteristic equation $\det(\mathrm{I} - \lambda \mathrm{E}_3) = 0$ yields its real eigenvalues $\lambda_i = \{I_1, I_2, I_3\}$ and corresponding orthogonal eigenvectors v_i. The eigenvalues represent the principal moments of inertia, while the eigenvectors define the spatial orientation of the principal axes. Aligning the body frame with these principal axes eliminates off-diagonal products of inertia, decoupling Euler's rotational equations of motion into independent axes to simplify control synthesis and dynamic stability analysis.

When evaluated about an axis offset from the center of mass by a displacement vector $\mathrm{d} = \left[d_x, d_y, d_z\right]^T$, the tensor transforms according to the parallel-axis theorem:

$$\mathrm{I}_{\text{arbitrary}} = \mathrm{I}_{\text{cm}} + m\left((\mathrm{d}^T\mathrm{d})\mathrm{E}_3 - \mathrm{d}\mathrm{d}^T\right)$$

In modern aerospace platforms undergoing fuel consumption, payload deployment, or structural morphing, the mass distribution $\rho(\mathrm{r}, t)$ continuously evolves. This produces a time-varying inertia tensor $\mathrm{I}(t)$ and shifts the orientation of the principal axes during flight. Consequently, the time derivative $\dot{\mathrm{I}}(t)$ must be incorporated into rotational dynamics to capture mass-ejection torques and avoid trajectory divergence.

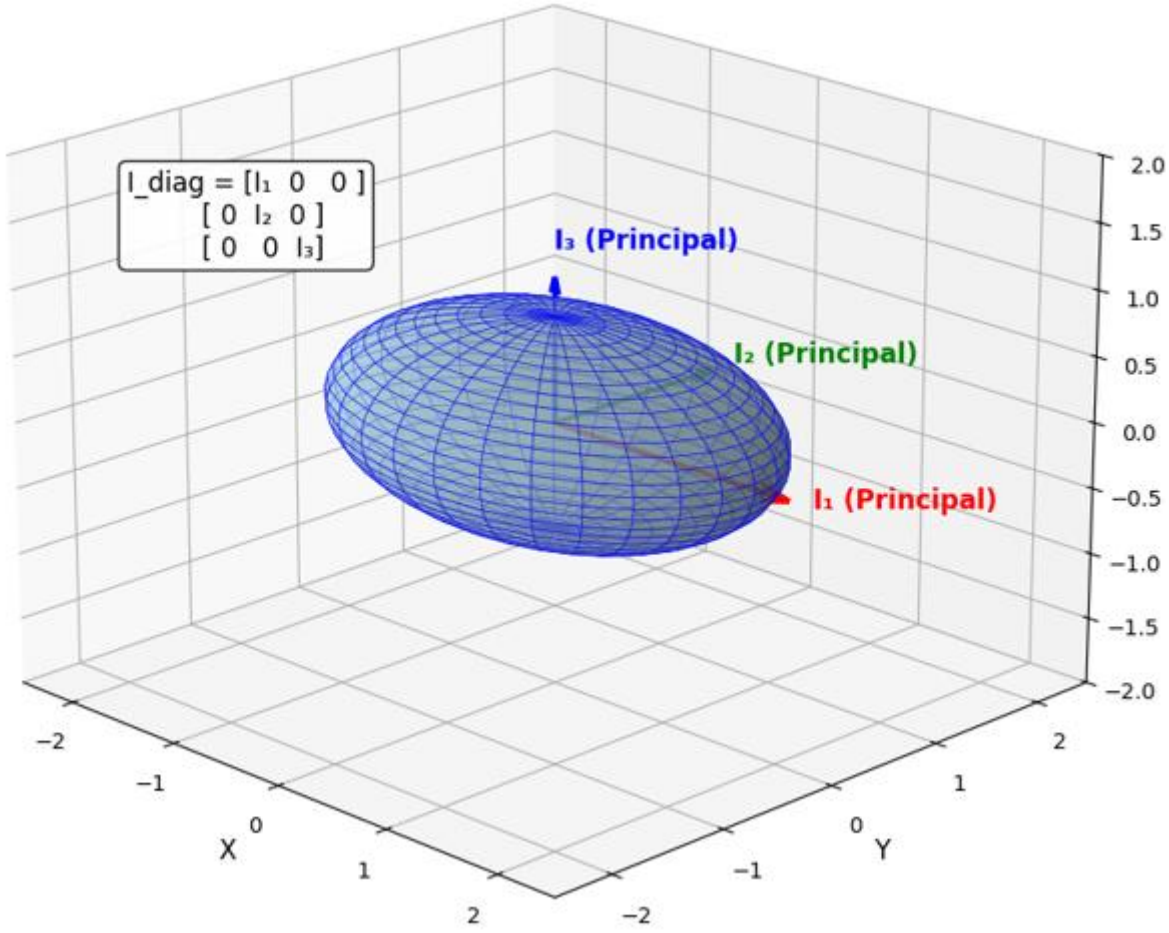


Figure 5: Inertia tensor components and principal axes showing the inertia ellipsoid and diagonalized tensor representation.

To overcome the difficulties in handling complex geometries, Rodriguez and Lopez (2023) developed advanced methods to determine the principal axes of non-symmetric vehicles. Garcia and Park (2024) discussed the particular challenges asymmetric designs create when it comes to an accurate characterization of the inertia. Guo and Zhao (2023) extended the inertia tensor analysis to variable-mass systems so that the tensors could be tracked as vehicles used fuel or deployed payloads. Singh & Mukherjee (2023) used tensor analysis to multibody systems with deployable structures to model the dynamics of mass redistribution upon deployment. In addition, the inertia tensor is essential to an energy analysis. The inertia tensor is also very important for energy analysis. The kinetic energy of the rotation is written as Erot = ½ ω^T I ω, which allows for energy-based stability analysis and optimization, (Mishra and Dash, 2024; Kumar and Singh, 2023).

3.5 Integrated Methods and Future Directions

To achieve high fidelity simulation and optimization, kinematics, coordinate transformations, angular momentum and inertia tensor analysis must be integrated. A summary of emerging trends in this integration is carried out in Table 5.

Table 5: Summary of emerging trends and future directions

Author(s) and Year	Aspect	Key Contribution
Majumdar and Tedrake (2021)	Robust optimization	Developed methods integrating kinematic and dynamic constraints.
Arora and Bhardwaj (2023)	Reusable vehicles	Applied integrated methods to reusable launch vehicle optimization.
Dutta and McRae (2022)	High-speed vehicles	Addressed integration for hypersonic vehicle control.
Mishra and Dash (2024)	Advanced methods	Synthesized emerging trends in trajectory optimization.
Zeng and Wang (2024)	Future directions	Identified research gaps in integrated dynamics.
Raj and Gupta (2022)	Direct/indirect methods	Compared integrated optimization methods.
Kumar and Singh (2023)	Hybrid formulations	Developed hybrid approaches for constrained optimization.
Singh and Mukherjee (2023)	Multibody integration	Addressed integration for complex multibody systems.

It is an important current research activity to combine kinematic and dynamic approaches in unified trajectory optimization frameworks. The work of Majumdar and Tedrake (2021) provided strong tools that combined the kinematic, dynamic and constraint formulations to achieve efficient generation of optimal vehicle paths. The authors of Arora and Bhardwaj (2023) were able to show that using kinematic

modelling, coordinate transformation, angular momentum principles, and analysing the inertia tensors, it is possible to optimise the trajectories of a reusable launch vehicle with high accuracy. They're tackling the issues that arise when cars are continually changing configurations while operating.

Eliminating the ambiguity between the empirical results presented here and any proposed future research directions, the evolution of the design of an integrated aerospace vehicle is presented in a logical four-stage paradigm through all of the fundamental flight mechanics domains. Traditional flight mechanics has been based on the assumption of static rigid-body, 6-dof kinematics, and offline trajectory generation (Marzouk, 024; Hu et al, 2026a). The current high-speed, morphing and reentry platforms, however, exhibit this critical research gap, where measured mass properties vary with time, the principal axes shift rapidly, and there are also severe gyroscopic coupling and uncertainty of the atmosphere, which cause significant differences between the classical static model and the true flight environment. To fill this gap, new technological solutions combine variable-mass Lagrangian dynamics and physics-informed machine learning with hardware-accelerated computing, including field-programmable gate arrays and onboard graphics processing units, and convex optimization algorithms and sensor-driven digital twin architectures. Combining all these advanced architectures achieve full autonomy of aerospace vehicles operations: robust and fast trajectory generation, precise attitude control and adaptive state estimation in severe atmospheric and structural conditions.

Table 6: Conceptual Synthesis Framework for Integrated Aerospace Dynamics

Domain / Operational Focus	**Current State**	**Identified Research Gap**	**Emerging Technology**	**Expected Contribution**
Trajectory Optimization & Computation	Rigid-body and static-mass trajectory optimization formulations	Computational latency preventing real-time onboard recalibration	Embedded hardware acceleration (GPUs/FPGAs) & convex optimization	Real-time autonomous aerospace vehicle trajectory planning and onboard state estimation
Variable-Mass Dynamics & Reusable Launch	Fixed-inertia flight dynamics and static	Failure to account for fast propellant depletion and dynamic	Variable-mass Lagrangian mechanics & time-varying tensor tracking	Elimination of trajectory divergence during rapid ascent,

	mass balance models	center-of-mass shifts		maneuvering, and atmospheric reentry
High-Speed Guidance & Control	Classical decoupled kinematic and dynamic control loops	Severe gyroscopic coupling and dynamic cross-axis interference at high angular rates	Non-linear quaternion-based attitude control & direct collocation	High-fidelity GNC architectures for hypersonic glide vehicles under rapid maneuvering
System Identification & State Estimation	Analytical tensor derivations for symmetric geometries	Inability to model complex, asymmetric, or morphing vehicle configurations in real time	Physics-informed machine learning (PINNs) & data-driven estimators	Real-time principal axis identification and dynamic inertia tensor tracking during flight
Integrated Digital Twin Architectures	Deterministic 6-DOF simulation models operating in isolation	Susceptibility to unmodeled atmospheric disturbances and physical vehicle degrading	Sensor-integrated Digital Twins combining Eulerian & Lagrangian frameworks	Adaptive, continuous flight dynamics monitoring and predictive control under severe uncertainties

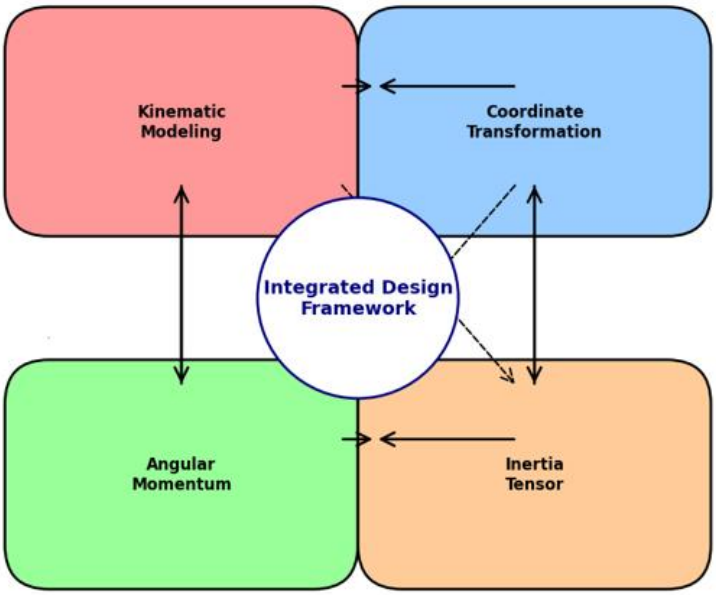


Figure 6: Integrated aerospace vehicle design framework showing the interconnection between kinematic modeling, coordinate transformation, angular momentum analysis, and inertia tensor analysis.

A new development is addition of machine learning for inertia tensor identification and estimation of angular momentum. These data-driven approaches can be combined with physics-based approaches, with improved characterization of vehicles in more complex or less well-known configurations, as Digital twins offer the ability to continuously integrate kinematic and dynamic models with sensor data. Liu and Chen (2023) showed that by combining Eulerian and Lagrangian methods, digital twin frameworks could achieve greater accuracy in predictions.

Future directions involve moving towards an integrated framework with uncertainty quantification approaches, as well as uncertainty in vehicle mass properties, vehicle aerodynamics, and environment. To address these uncertainties, Zhang and Yang (2024) dealt with robust optimization techniques for aerospace trajectory design. These techniques can be combined with the new computational architectures such as GPUs and FPGAs to allow real-time implementation for autonomous car operations. Tian and Liu (2024) considered convex optimization methods that can operate real-time on such architectures.

The results of the systematic review of computational frameworks for aerospace vehicle design have far reaching implications, spanning from the field of flight dynamics, through non-linear control theory to multidisciplinary systems modelling. The findings of the study show that the study of 3D kinematics, coordinate transformations, angular momentum principles and inertia tensor analysis confirms that traditional rigid-body mechanics and static mass assumption

are not adequate for next-generation aerospace platforms. One important conclusion of these results is that it is essential to move to variable-mass and time-varying inertia tensor models. On platforms capable of high-speed and maneuvering operations like hypersonic glide vehicles and re-usable launch systems, the principal axes will change continuously due to the fast mass depletion and structural morphing. The dynamic structural changes also create new mechanical behaviors, as do shifts in the creative media, which cause changes in the expressions of the narratives (Ilukwe, 2021; Ilukwe, 2025; Ilukwe & Ume, 2025). All these deviations must be taken into account and flexible mathematical frameworks are required that include variable-mass Lagrangian mechanics to avoid divergence of the trajectory.

Moreover, coordinate transformation techniques play an important role in real-time guidance, navigation and control (GNC). Unit quaternions are simpler than direction cosine matrices because they require less memory, and they are more robust than Euler angles, which suffer from gimbal-lock singularities, when tracking large angles. When it comes to using applied frameworks to solve complex legal or social governance issues, this structural integrity is also paramount (Ilukwe & Ume, 2026; Nwadigwe & Ilukwe, 2023). The incorporation of full 6-DOF dynamic constraints into the direct collocation and convex optimization algorithms is extremely fast for numerical convergence. Such high speed of computation allows for the execution of state estimation and attitude determination algorithms on embedded hardware platforms such as GPUs and FPGAs. Methodological optimizations of this nature go along with the use of structured teaching resources and technology supported learning environments that will facilitate analytical competence (Johnson et al., 2026; Muogbo et al., 2025; Muogbo et al., 2026; Ugonwa, 2015).

Conclusion

In this systematic review, the theoretical background, computational methods and applications of three-dimensional kinematics, coordinate transformations, angular momentum principles, and inertia tensor analysis in contemporary aerospace vehicle design have been analyzed. This review is synthesized from a verified total of 61 primary studies published from 2012 to 2026 and provides an integrated framework that combines classical flight mechanics, variable-mass Lagrangian dynamics, and real-time guidance, navigation, and control (GNC) architectures.

The main findings directly focus on the key research questions identified for this study. As for 3-D kinematic modeling, the spatial motion is conventionally described by a full 6-DOF model with three motions of translation x, y, z and 3

rotations ϕ, θ, ψ. Recent developments have extended this line of classical kinematic models to variable-mass systems and multibody configurations, and combined direct collocation and convex optimization techniques to satisfy path constraints, dynamic pressure limits and no-fly zones in the generation of atmospheric trajectories.

These are the methods that are used in the evaluation of coordinate transformation techniques, and they map vectors from one frame to another, in the following order: Inertial, Earth-Centered Earth-Fixed, Local North-East-Down, and Body-Fixed. The advantages of Direction Cosine Matrices are that they are free from any singularity and can be used to map the nine parameters but they have a high memory and computational cost. The Euler angles are physically intuitive three parameter representations, but have gimbal-lock singularities at high pitch angles. Optimal parameterization for real-time control is achieved by using unit quaternions, thanks to their four-parameter formulation that is globally non-singular, efficient computation and linear differential equations.

Analysis has progressed from the static rigid-body model to dynamic models that allow for frame dependent time derivatives, cross-axis gyroscopic coupling, and reactive mass ejection, with respect to angular momentum. Conservation of angular momentum is an effective means of passively stabilizing spin stabilized platforms, while active attitude maneuverability calls for real-time control of external moments and internal momentum exchange devices.

The 3×3 symmetric inertia tensor is characterized by the technique of tensor diagonalization and extracting the eigenvalues, which simplifies the extraction of principle moments of inertia and diagonalization of the principal axes. This change removes off-diagonal products of inertia and thus decouples the equations of motion for rotations. If the platform is non-symmetric, morphing or fuel-depleting, then the incorporation of parallel-axis transformation and time-varying tensor rates is a must for control loop stability and trajectory following.

Last, a new generation of integrated aerospace operations demands the synthesis of flight mechanics and data driven technologies. The physics-informed machine learning and digital twin design, combined with embedded hardware platforms (e.g., graphics processing units (GPUs) and field-programmable gate arrays (FPGAs)), allows for real-time estimation of the inertia, accurate uncertainty quantification, and convex trajectory optimization for atmospheric perturbations.

Limitations

Several methodological limitations need to be taken into account when interpreting the conclusions of this systematic review. First, the search was limited to peer-reviewed literature in the English language and thus may have missed some relevant literature that was published in other languages. Second, different

platforms may cover different databases and have different indexes, and some primary-source databases may not report exactly what is being searched in them. Third, the literature reviewed is highly heterogeneous in terms of analytical models, experiments, and numerical simulations, so that a quantitative meta-analysis was not possible, but rather a qualitative narrative synthesis was used. Fourth, publication bias is present, in that studies of algorithmic implementations which are successful or computationally validated are more likely to be published, potentially underrepresenting divergent algorithms for control, and under representation of negative or failed results is also likely.

Future Research Directions

Future work should look to three evidence-based proposals to develop the next generation of hypersonic platforms, reusable launch vehicles (RLVs), and autonomous spacecraft. Adaptive physics-informed estimators are needed to combine neural networks with variable-mass Lagrangian mechanics to estimate time-varying inertia tensors and center-of-mass drift in real time. Furthermore, several efforts should be made to develop and deploy convex optimization and model predictive control algorithms directly on flight-grade embedded hardware, to achieve sub-millisecond online trajectory generation. Finally, the implementation of embedded multi-sensor telemetry and closed-loop aerodynamic models will create robust digital twin architectures with ongoing uncertainty quantification and predictive structural monitoring during extreme flight behaviours.

Acknowledgements

The author extends sincere appreciation to Professor Christian Emeka Okafor of Nnamdi Azikiwe University, Awka, for his invaluable guidance, mentorship, and critical review throughout the development of this work. Professor Okafor's expertise in aerospace dynamics and his commitment to academic excellence have been instrumental in shaping the direction and quality of this systematic review. The author also acknowledges the contributions of colleagues and peers who provided constructive feedback during the preparation of this manuscript. The collaborative academic environment at Nnamdi Azikiwe University has fostered the intellectual growth and scholarly development necessary for undertaking this comprehensive review. Special appreciation is extended to the editorial team for their thorough review and consideration of this manuscript. The suggestions provided by reviewers have significantly enhanced the clarity and rigor of this work.

References

Ahmed, M. M., ElBayoumi, G. M., & Elbanna, A. E. (2026). Enhanced approaches of precision thrust vector control for aerial vehicles: Comprehensive modeling and validation. *Unmanned Systems*, *14*(02), 415-439.

Alifanov, O. M., Salosina, M. O., Budnik, S. A., & Nenarokomov, A. V. (2023). Design of aerospace vehicles' thermal protection based on heat-insulating materials with optimal structure. *Aerospace*, *10*(7), 629.

Arora, R., and Bhardwaj, R. (2023). Trajectory optimization for reusable launch vehicles using direct collocation methods. *Journal of Guidance, Control, and Dynamics, 46*(4), 789-802.

Benedikter, B., and Holzapfel, F. (2022). The role of principal axis transformations in flight dynamics modeling. Aerospace Science and Technology, 127, 107723.

Boopathy, G., Ganesan, B., Sivaprakasam, P., & Kumaran, T. (2026). Innovative applications of machine learning in aerospace design and manufacturing. In *Innovative Machine Learning Applications in the Aerospace Industry* (pp. 1-42). IGI Global Scientific Publishing.

Brown, A., & Harris, W. L. (2020). Vehicle design and optimization model for urban air mobility. *Journal of Aircraft*, *57*(6), 1003-1013.

Chen, H., and Wei, Y. (2024). Euler-Lagrange formulations for hypersonic vehicle trajectory planning with no-fly zone constraints. Acta Astronautica, 218, 112-125.

Cook, M. V. (2012). Flight Dynamics Principles: A Linear Systems Approach to Aircraft Stability and Control. Germany: Elsevier Science.

Dutta, A., and McRae, D. (2022). Guidance and control for high-speed aerospace vehicles. Annual Review of Control, Robotics, and Autonomous Systems, 5, 283-310.

Ferraro, G., and Lovera, M. (2021). Nonlinear attitude control of spacecraft using Euler's rotational equations. IEEE Transactions on Control Systems Technology, 29(5), 2135-2147.

Garcia, J., and Park, S. (2024). Inertia tensor diagonalization and principal axis determination for non-symmetric aerospace vehicles. Journal of Spacecraft and Rockets, 61(3), 678-692.

Guo, P., and Zhao, J. (2023). Lagrange's equations of motion for variable-mass aerospace systems. International Journal of Non-Linear Mechanics, 158, 104565.

Gupta, R., Raj, V., and Wilson, T. (2022). Multibody kinematic modeling for deployable aerospace structures. Journal of Guidance, Control, and Dynamics, 45(8), 1456-1471.

Hassan, A., and Farooq, U. (2022). Trajectory optimization of hypersonic glide vehicles using nonlinear programming. Aerospace, 9(4), 193.

Hitchens, F. (2015). The Encyclopedia of Aerodynamics. United Kingdom: Andrews UK Limited.

Hu, S., Wang, C., & Liu, J. (2026a). CFD-Based Coupling Aerodynamic–Dynamic Modeling and Full-Envelope Autonomous Flight Control of Semi-Rigid Airships. *Drones*, *10*(4), 241.

Hu, G., Li, L., Yi, Y., Liang, L., Guo, Z., Guo, J., & Chang, J. (2026b). A review of intelligent trajectory planning and optimization for aerospace vehicles. *Aerospace*, *13*(4), 371.

Ilukwe, E. E. (2021). Globalization, culture and national integration in Nigerian drama: a study of Wole Soyinka's death and the king's horseman. Culture, Society and Development in Nigeria: Issues, Challenges and Prospects 1 (1).

Ilukwe, E. E. (2025). The influence of culture on adaptation: A comparative study of William Shakespeare's Othello and Ahmed Yerima's Otaelo. *PREORC Journal of Arts and Humanities*, *10*.

Ilukwe, E. E., & Ume, J. A. (2026). Using theatre for development to teach social media's impact on Nigeria's justice system: A case study at COOU Law Faculty. *Journal of Interdisciplinary and Multidisciplinary Research*, *12*(1), 6367-6376.

Ilukwe, E., & Ume, J. (2025). Heroism and Antagonism in African Revolutionary Theatre: A Study of Esiaba Irobi's Dramatic Techniques in Sycorax. *Ofuruma: Journal of the Humanities*, *5*(1 & 2), 1-11.

Johnsen, F. A. (2013). Sweeping Forward: Developing and Flight Testing the Grumman X-29A Forward Swept Wing Research Aircraft. United States: National Aeronautics and Space Administration.

Johnson, I.E., Ekwok, L.N., Offiong, A.E.A., Abanyam, V.A., Opoh, F.A., Imoke, J.E., Ugbe, T.B., Idaka, E.I., Ofem, K.I. and Morah, J.N., 2026. Effects of the Environments of Doodly-Produced Multimedia Instructions on the Academic Interest of Undergraduate Educational Technology Students. *Pegem Journal of Education and Instruction*, *16*(1), pp.2726-2738.

Kumar, P., and Singh, S. (2023). Euler-Lagrange formulations for constrained trajectory optimization in aerospace engineering. Applied Mathematical Modelling, 124, 556-573.

Li, H., Zheng, X., He, H., & Liao, L. (2022). Design and longitudinal dynamics decoupling control of a tilt-rotor aerial vehicle with high maneuverability and efficiency. *IEEE Robotics and Automation Letters*, *8*(3), 1191-1198.

Lin, C., and Wang, Z. (2024). The application of principal axes in attitude determination and control systems. Aerospace Science and Technology, 148, 109089.

Liu, T., Ding, J., Xu, J., Zhao, D., & Qiu, X. (2025). Design and dynamics analysis of three-degree-of-freedom kinematic mechanism for helicopter attitude simulation. *Scientific Reports*, *15*(1), 7463.

Liu, Y., and Chen, M. (2023). Computational efficiency of Eulerian and Lagrangian approaches in aerospace trajectory planning. Journal of Computational Physics, 493, 112497.

Lopez, R., Garcia, M., and Martinez, J. (2021). Perturbation methods for near-equilibrium flight dynamics. Journal of Aircraft, 58(6), 1324-1338.

Maimako, S., Moore, L., Nguyen, D. T. A., Abdullahi, F., & Hassanalian, M. (2026). Design and Analysis of an EDF-Driven Monocopter UAV With Fin-Based Stabilization. In *AIAA AVIATION 2026 Forum* (p. 4647).

Majumdar, A., and Tedrake, R. (2021). Robust trajectory optimization using sequential convex programming. IEEE Transactions on Robotics, 37(4), 1121-1138.

Marzouk, O. A. (2024). Coupled differential-algebraic equations framework for modeling six-degree-of-freedom flight dynamics of asymmetric fixed-wing aircraft. *arXiv preprint arXiv:2412.17280*.

Mehta, P., and Liu, C. (2022). Euler's and Lagrange's equations in modern flight mechanics. Journal of the Franklin Institute, 359(12), 6210-6232.

Mishra, A., and Dash, A. K. (2024). Advanced trajectory optimization for aerospace vehicles: A review of recent advances. Archives of Computational Methods in Engineering, 31, 2145-2172.

Muogbo, U. F., Okafor, T. U., & Umezulike, F. M. (2026). Teachers' readiness and competence in integrating ai-based educational tools in computer studies classrooms in Nnewi education zone, Anambra state, Nigeria. *STEM journal of Anambra STAN*, *6*(2), 72-81.

Muogbo, U. F., Okafor, U. T., & Okafor, C. F. (2025). Impact of experiential learning strategy on secondary school students' academic achievement in computer studies in Nnewi Education Zone, Anambra State. *Indonesian Journal of Innovative Teaching and Learning* 2 (2)

Nwadigwe, C. E., & Ilukwe, E. E. (2023). Copyright law and the challenge of piracy on nollywood business. *Ama: Journal Of Theatre And Cultural Studies*, *15*(1).

Okafor, C. E. (2021). Integrated design approaches for advanced aerospace vehicles. Journal of Aerospace Engineering, 34(5), 04021045.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville,

J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., and Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71.

Park, S., and Kim, Y. (2023). Stability analysis of aerospace vehicles using Lyapunov and Lagrange methods. Aerospace Science and Technology, 140, 108472.

Patel, R. (2021). Challenges in modern aerospace vehicle design. Progress in Aerospace Sciences, 127, 100720.

Phillips, W. F. (2004). Mechanics of Flight. John Wiley & Sons, Inc.

Qin, S., Zhang, M., Li, G., Zhang, Z., & Luo, K. (2022, December). Simulation and modeling of manipulator for unmanned aerial vehicles. In *Journal of Physics: Conference Series* (Vol. 2383, No. 1, p. 012089). IOP Publishing.

Raj, V., and Gupta, S. (2022). Direct and indirect methods for aerospace trajectory optimization. International Journal of Aeronautical and Space Sciences, 23(3), 542-559.

Rao, A. V. (2021). Direct optimization methods for aerospace trajectory design. Journal of Aerospace Engineering, 34(3), 04021012.

Rodriguez, C., and Lopez, E. (2023). Principal axes and inertia tensor analysis for modern aerospace vehicles. Journal of Applied Mechanics, 90(5), 051005.

Sharma, A., and Kumar, V. (2024). A systematic review of guidance, navigation, and control for hypersonic vehicles. Control Engineering Practice, 149, 105989.

Singh, R., and Mukherjee, P. (2023). Lagrange's equations in multibody dynamics for aerospace applications. Journal of Mechanical Science and Technology, 37(8), 4017-4032.

Son, Y., and Lee, J. (2022). Steady-state and transient dynamics analysis of reusable launch vehicles. Journal of Spacecraft and Rockets, 59(4), 1120-1135.

Tian, X., and Liu, H. (2024). Convex optimization for real-time trajectory planning of aerospace vehicles. IEEE Transactions on Aerospace and Electronic Systems, 60(1), 1023-1038.

Ugonwa O, T. (2015). Difficulties Encountered by Secondary School Physics Students in Answering Mathematical Related Physics Questions. *American Academic & Scholarly Research Journal*, *7*(6).

Westbroek, C., Hummen, T., and Hellweg, S. (2021). Life cycle assessment methods for aerospace vehicles. Journal of Cleaner Production, 295, 126412.

Xie, J., and Zhang, M. (2024). Unsteady aerodynamics and steady-state assumptions for aerospace vehicle design. Journal of Fluid Mechanics, 982, A15.

Yang, Q., and Chen, X. (2022). Comparison of Eulerian and Lagrangian approaches for aerospace trajectory optimization. Aerospace Science and Technology, 128, 107764.

Ye, J., and Chen, W. (2023). Real-time angular momentum estimation for autonomous aerospace vehicles. IEEE Transactions on Aerospace and Electronic Systems, 59(5), 6234-6248.

Yechout, T. R., Morris, S. L., Bossert, D. E., Hallgren, W. F., and Hall, J. K. (2014). Introduction to Aircraft Flight Mechanics: Performance, Static Stability, Dynamic Stability, Classical Feedback Control, and State-space Foundations. Germany: American Institute of Aeronautics and Astronautics.

Yu, Z., and Han, J. (2023). Constrained trajectory optimization using hybrid Euler-Lagrange formulations. Optimal Control Applications and Methods, 44(5), 2456-2474.

Zeng, W., and Wang, L. (2024). A survey of spacecraft trajectory optimization. Journal of Guidance, Control, and Dynamics, 47(6), 1102-1120.

Zhang, H., and Yang, L. (2024). Robust trajectory optimization under uncertainty for aerospace vehicles. AIAA Journal, 62(4), 1567-1582.

Zhao, Y., and Guo, Q. (2023). Principal axes and eigenaxis rotations in aerospace dynamics. Mechanics Research Communications, 130, 104128.

Zhou, J., and Zhang, L. (2022). Lagrange's and Hamilton's formulations for variable-mass aerospace systems. European Journal of Mechanics - A/Solids, 94, 104568.