TÜBİTAK

3501 – KARİYER GELİŞTİRME PROGRAMI
PROJE BAŞVURU FORMU

Başvuru formunun Arial 9 yazı tipinde, her bir konu başlığı altında verilen açıklamalar göz önünde bulundurularak hazırlanması ve ekler hariç toplam 22 sayfayı geçmemesi gerekmektedir. Dosya depolama/paylaşım sistemlerindeki dosyalara ve/veya web sayfalarına link verilerek proje içeriğinin başvuru formu sınırları dışında ayrı bir alanda paylaşılması halinde, proje bilimsel değerlendirmeye alınmadan iade edilir. Form değişiklikleri izle modunda bırakılmamalı ve yorum içermemelidir. Formun içeriği ayrı bir ek olarak farklı dosyada paylaşılmamalıdır. Proje önerisine ilişkin tüm bilgilerin formda yer alan ilgili bölüme eklenmesi ve formun nihai halinin tek bir dosya olarak başvuru sistemine yüklenmesi gerekmektedir. Değerlendirme potansiyeli, projenin özgün değeri, yöntemi, yönetimi, kariyer geliştirme ve yaygın etkisi başlıkları altında yapılacaktır. Proje önerisi değerlendirme formuna ulaşmak için tıklayınız.

Proje Başlığı: Development of Multi-Fidelity Aeroservoelastic Tools for Next-Generation Load Alleviation and Flutter Suppression in Distributed-Propulsion High-Aspect-Ratio Wings
Proje Yürütücüsü:
Projenin Yürütüleceği Kurum/Kuruluş:

PROJE YÜRÜTÜCÜSÜNÜN TEZ BİLGİLERİ

Proje Yürütücüsünün Yüksek Lisans Tezinin Başlığı ve Yaygın Etkisi (bildiri, makale, kitap bölümü, kitap, vb.) verilir.

Başlık:
Yaygın Etki:

Doktora / Tıpta Uzmanlık Tezinin Başlığı ve Yaygın Etkisi (bildiri, makale, kitap bölümü, kitap, vb.) verilir.

Başlık:
Yaygın Etki:

ÖZET

Türkçe ve İngilizce özetlerin projenin (a) kariyer geliştirme potansiyeli, (b) özgün değeri, (c) yöntemi, (d) yönetimi ve (e) yaygın etkisinin ana hatlarını kapsaması beklenir. Her bir özet 600 kelime ile sınırlandırılmalıdır. Bu bölümün en son yazılması önerilir.

Proje Özeti
Anahtar Kelimeler:

Title :
Summary
Keywords:

1. ÖZGÜN DEĞER

1.1. Konunun Önemi, Projenin Özgün Değeri: Proje önerisinde ele alınan konunun kapsamı ve önemi nitel ve/veya nicel verilerle desteklenerek literatürün eleştirel bir değerlendirmesi ile açıklanır. Projenin literatürdeki hangi eksikliği nasıl gidereceği veya hangi soruna nasıl bir çözüm geliştireceği, literatürdeki çalışmalardan farklı olarak ilgili bilim veya teknoloji alan(lar)ına kavramsal, kuramsal ve/veya metodolojik olarak ne gibi özgün katkılarda bulunacağı açıklanır. Kaynaklar https://tubitak.gov.tr/tr/duyuru/bibliyografik-verilerin-duzenlenmesi sayfasındaki açıklamalara uygun olarak EK-1'de verilir.

High-aspect-ratio (HAR) wings have emerged as a defining feature of next-generation aviation systems in both civil and military sectors. Their aerodynamic efficiency, characterized by reduced induced drag and improved lift-to-drag ratios, enables long-endurance surveillance missions for HALE UAVs, enhanced payload capacity, and lower operating costs for electric and hybrid-electric regional aircraft. These benefits are demonstrated in recent technology demonstrators such as NASA's X-57 Maxwell, Airbus's eXtra Performance Wing, Aurora Odysseus, Boeing SolarEagle and several Turkish HALE UAV platforms. However, this improvement in aerodynamic efficiency comes at the cost of significantly increased aeroelastic sensitivity. As Livne [1] and Livne and Weisshaar [2] noted, slender wings are intrinsically prone to large deformation, low structural damping and strong bending–torsion coupling.

Subsequent analyses reinforced the importance of nonlinear effects. Pan et al. [3] demonstrated that HAR wings exhibit geometric nonlinearities under even moderate load cases, resulting in mode-shape changes, frequency shifts and nonlinear aeroelastic coupling. Zhang et al. [4] showed that the aerodynamic center and elastic axis shift substantially with deflection, producing load distributions that classical linear theories cannot predict. These studies highlight that HAR wings must be analyzed using methods capable of representing large deflection effects, geometric stiffening and potentially nonlinear aerodynamic behavior.

The rapid electrification of aviation systems amplifies these challenges. Distributed electric propulsion (DEP) introduces multiple propeller slipstreams, dynamically modulated flowfields and non-uniform aerodynamic loading along the span. Yang et al. [5] showed that slipstreams drastically increase sectional lift and modify pressure distributions. Borer et al. [6] found that even small variations in propeller RPM or placement can significantly alter the slipstream's aerodynamic footprint. Wu et al. [7] investigated the aeroelastic response of highly flexible wings influenced by distributed propellers. Their study highlighted that the slipstream effects significantly impact aerodynamic load distributions, which in turn alter the dynamic response and structural mode interactions. Böhnisch et al. [8] identified whirl-flutter risks associated with slender wings equipped with distributed propulsion. Their work revealed that wing flexibility can both stabilize and destabilize whirl flutter depending on propeller placement and shaft stiffness, underlining the complex coupling between aeroelastic and propulsion-induced dynamics.

In parallel with DEP developments, morphing wing technologies are being considered to address HAR aeroelasticity. Cheung et al. [9] experimentally verified that folding wingtips can reduce root bending moments of a flexible HAR wing by more than 10% under gust excitation. Ullah et al. [10] analyzed spanwise load control using distributed flaps and found significant reductions in peak gust loads. Composite tailoring represents another passive strategy. Cesnik et al. [11] and Stodieck [12] demonstrated that tailored anisotropic composite layouts can induce bend–twist coupling, offering a passive approach to flutter suppression and structural load mitigation. By carefully aligning fiber orientations and using non-symmetric laminate stacking, this coupling enables the structure to twist in response to bending loads, naturally adapting its aerodynamic response. Cesnik et al. validated this effect on high-aspect-ratio wings, while Stodieck showed that tow-steered composites can precisely control coupling behavior, reinforcing the practical potential of aeroelastic tailoring in lightweight, flexible wing designs.

These developments collectively demonstrate that the future of aircraft design is shifting toward deeply integrated structure–aerodynamics–propulsion–control systems. This integration fundamentally changes the aeroservoelastic (ASE) problem. Traditional ASE frameworks assume steady propulsion effects, small deflections and uniform inflow, none of which are valid for flexible DEP-equipped HAR wings. A modern aeroelastic analysis framework must capture multi-directional interactions between aerodynamics, structure, DEP slipstreams, morphing devices and active control inputs.

2. State of the Art and Remaining Challenges

2.1 Aeroelastic modeling and aerodynamic limitations

Even though aeroelastic modeling has progressed significantly, gaps remain in accurately representing the elasticity and aerodynamics of slender DEP wings. Dagilis and Kilikevičius [13] developed an enhanced vortex-lattice method (VLM) specifically for flexible aircraft and showed that such lifting-surface models can approximate large-deflection effects, but only with careful calibrations. Torregrosa et al. [14] proposed a multi-fidelity workflow that integrated reduced-order aerodynamic models with CFD data, demonstrating substantial improvements in accuracy compared to single-fidelity approaches.

Yet high-fidelity CFD and FSI simulations such as those presented by Carrion and Palacios [15] provide the only reliable means of capturing the full nonlinear behavior. Raza et al. [16] reviewed state-of-the-art multi-fidelity aeroelastic simulation strategies and emphasized that high-fidelity FSI is essential to capture nonlinear aerodynamic effects, but too computationally intensive for design optimization or controller synthesis. Thus, no single modeling fidelity is sufficient.

2.2 DEP Aerodynamics and ASE Integration

Distributed electric propulsion fundamentally alters the aerodynamic environment around a flexible wing. Unlike conventional propulsion systems that generate relatively uniform inflow conditions, DEP produces multiple overlapping slipstreams whose strength, trajectory and unsteady characteristics vary along the span and across flight conditions. Lei et al. [5] showed that propeller slipstreams can significantly enhance local lift by increasing the effective dynamic pressure over specific sections of the wing, particularly when strong aerodynamic coupling exists between the propulsion system and airframe. Borer et al. [6] demonstrated that subtle changes in propeller placement or rotational speed can substantially influence the aerodynamic footprint of the slipstream, affecting both lift distribution and overall propulsion–airframe integration. Building on this, Wu et al. [7] investigated DEP-equipped large-deformation wings and found that slipstream-induced load concentrations shift the elastic axis and change modal characteristics. These works collectively illustrate that DEP not only changes the magnitude of aerodynamic loads but also redistributes them in a way that fundamentally reshapes aeroelastic behavior.

DEP also introduces new unsteady aerodynamic modes. Propeller-induced vortices, periodic inflow from blade passage and rotor–wing mutual interference generate oscillatory force components that do not fit neatly into the assumptions of classical unsteady aerodynamic theories. Most DLM-based aeroservoelastic models assume quasi-uniform inflow, linearized wake effects and small perturbations. None of these assumptions hold under strong slipstream influence, where local Mach number, angle of attack and effective flow curvature differ substantially from the baseline flowfield. The study by Wang et al. [8] further demonstrated that whirl-flutter mechanisms can be activated or amplified when propeller shaft dynamics couple with nearby elastic modes. These findings suggest that traditional gust models and unsteady aerodynamic kernels cannot capture the physics of DEP-induced disturbances without significant modification.

An additional complexity arises when considering DEP as a control actuator. The control authority of each propeller depends not only on its thrust level but also on the nonlinear aerodynamic response of the surrounding flow.

Tantaroudas et al. [18] developed a reduced-order modeling framework tailored for control design of flexible, free-flying aircraft, demonstrating that accurate representation of aeroelastic dynamics requires incorporating interactions between structural flexibility and aerodynamic loads. Although their study did not focus exclusively on distributed electric propulsion (DEP), the insights into reduced-order modeling of coupled aerodynamic–structural systems highlight the limitations of traditional aeroservoelastic frameworks. In DEP-equipped configurations, such limitations become more pronounced due to the complex interplay between structural deflection, local aerodynamics, and non-uniform propeller inflow. As the wing bends under load, effective inflow angles into the propellers change, modifying thrust levels and slipstream distributions, which in turn alter the aeroelastic response. This nonlinear feedback loop challenges conventional control strategies and underscores the need for modeling approaches capable of capturing such multi-way coupling in a form suitable for closed-loop control synthesis.

Finally, the research community has yet to establish validated parametric models that reflect how propeller slipstream effects vary over the flight envelope. Stanford et al. [17] highlighted that DEP-induced load increments are highly sensitive to airspeed, angle of attack and propeller rpm. Without integrated aerodynamic–structural–propulsion models, control strategies cannot robustly account for such variations. The absence of these models also limits our ability to design MIMO aeroservoelastic controllers that treat DEP actuators and morphing devices within a unified framework. This project addresses these gaps by developing a comprehensive aeroservoelastic formulation that embeds DEP-induced forces directly into the state-space representation.

2.3 Disconnection among passive, semi-active and active load-management strategies

Composite tailoring [11], [12] provides passive load alleviation through bend–twist coupling. Morphing strategies such as folding and twisting wingtips [9], [10] add semi-active control authority, and modern controllers such as MPC and H_∞ designs [19] provide active mitigation. Yet these methods have not been studied jointly for DEP-equipped HAR wings, leaving a significant gap in understanding coupled behavior.

2.4 Multi-Fidelity Modeling

A crucial challenge in modeling aeroservoelastic behavior of HAR wings with DEP is the need to integrate multiple levels of fidelity without compromising accuracy or computational feasibility. Flexible-wing aerodynamics exhibit inherently multi-scale behavior: fast aerodynamic transients, intermediate propeller-slipstream effects and slower structural modes coexist and interact. Dagilis and Kilikevičius [13] demonstrated that enhanced vortex-lattice models can approximate large-deflection behavior but still require careful correction to capture strong coupling effects. Torregrosa et al. [14] showed that reduced-order aerodynamic models calibrated with high-fidelity CFD can achieve prediction accuracy close to full-order solutions, especially for low-frequency modes. These studies highlight that lower-fidelity models are viable only when systematically updated based on higher-fidelity data.

The study by Raza et al. [16] reviewed multi-fidelity aeroelastic practices and emphasized that no single method is sufficient across all flight regimes. High-fidelity FSI simulations provide the necessary detail for capturing nonlinear aerodynamic behavior, such as slipstream deformation and dynamic stall, but their computational cost prohibits their direct use in controller synthesis or design optimization. Mid-fidelity approaches such as panel-method-based aeroelastic solvers can handle large parameter sweeps but lack the ability to represent propeller–wing interactions or nonlinear structural dynamics. Low-fidelity or reduced-order models, such as DLM-based state-space representations, offer computational efficiency but cannot include DEP-induced phenomena unless properly extended.

Multi-fidelity modeling is not only an efficiency strategy but also a methodological necessity. For DEP-equipped HAR wings, no single fidelity captures all relevant physics:

- High fidelity is required to understand how slipstreams reshape pressure fields locally.
- Mid fidelity is needed for flight-envelope-level load assessment and structural response prediction.
- Low fidelity is essential for aeroservoelastic controller synthesis and stability analysis.

Maathuis et al. [20] argued that the success of multi-fidelity frameworks depends on the ability to propagate information between models in a mathematically consistent manner. This requires calibration of mid-fidelity aerodynamic databases using CFD-derived corrections, systematic updating of modal parameters using high-fidelity structural models and generation of reduced-order models that retain the dominant coupled physics. Without these calibration loops, multi-fidelity frameworks can produce misleading results because each fidelity level may interpret the same physical phenomenon differently.

Another challenge is the representation of nonlinear structural behavior. Mu et al. [21] demonstrated through flight tests that flexible flying wings experience significant geometric nonlinearities even under modest flight loads. Nonlinear deflections change the effective angle of attack locally, which in turn affects DEP slipstream interactions. High-fidelity models can capture such effects but cannot be used in routine control analysis. Therefore, nonlinear behavior must be approximated in reduced-order models through modal updating, polynomial interpolation or data-driven correction techniques. These techniques are not yet widely applied to DEP–HAR aeroservoelastic systems, which further motivates the development of a robust multi-fidelity pipeline.

Finally, validation across the fidelity hierarchy is often missing in the literature. Many studies rely on CFD alone or low-fidelity tools alone; very few combine CFD, FSI, reduced-order models and experiments in a fully traceable manner. The absence of experimental data for DEP-equipped flexible wings exacerbates this problem. The framework proposed in this project aims to fill this gap by integrating wind-tunnel measurements into the calibration loop, thereby improving the credibility of the entire fidelity hierarchy. To illustrate how the proposed fidelity hierarchy supports the analysis and optimization of load alleviation strategies, Table 1 summarizes the relationship between key methods, the modeling levels applied and the advantages gained.

Table 1 - Summary of Modeling Fidelity Requirements and Advantages for Different Load Alleviation Approaches

Method / Design Element	Low Fidelity Use (ZAERO, ROM, DLM)	High Fidelity Use (CFD, FSI, OpenFOAM–MBDyn–PreCICE)	Benefit of Multi Fidelity Use
Composite tailoring (bend twist, tow steering)	Use equivalent stiffness and mode shapes to study flutter speed, mode coupling and root bending moments over many laminate variants.	Resolve local stress, strain and nonlinear deflections under realistic pressure and DEP slipstreams.	Fast laminate screening at low cost, with high fidelity checks for structural realism and aeroelastic behavior.
Folding wingtip	Represent folding as a control surface or extra degree of freedom to assess gust response and flutter margins for many fold angles and schedules.	Capture detailed 3D flow, separation, hinge loads and unsteady effects during motion.	Rapid design and control law tuning at low fidelity, with safety and load verification at high fidelity.
Twisting wingtip or distributed flaps	Model twist or flap deflection as modal or control inputs to evaluate spanwise load redistribution and closed loop response.	Resolve local flow, pressure and slipstream interaction around twisted or deflected segments.	Efficient exploration of actuation patterns, validated by realistic local aerodynamics and structural loads.
DEP thrust and differential thrust	Treat thrust and differential thrust as explicit inputs in MIMO state space models to study GLA, vibration and flutter control.	Model actuator disks or propellers in CFD to capture true slipstream deformation and non linear lift and moment response.	Controllers can be designed and tuned on ROMs, then checked against physically realistic DEP aerodynamics.
DEP thrust vectoring (TVC)	Add vectoring angles as control inputs to analyze their effect on stability and interaction with other actuators.	Simulate oblique slipstreams and resulting changes in local angle of attack, separation and unsteady loading.	Systematic TVC strategy design at low cost, with high fidelity verification of local aerodynamic side effects.
Integrated passive, semi active and active strategies	Combine tailoring, morphing and DEP control in one ZAERO or ROM environment for multi objective optimization.	Verify a small set of candidate integrated designs with CFD FSI and aeroservoelastic simulations.	Makes high dimensional, system level design feasible while retaining credibility for selected solutions.
Baseline wing and DEP layout (span, AR, placement)	Run parametric studies on planform and propeller placement to identify promising configurations.	Analyze selected layouts in CFD and FSI for detailed slipstream wing interaction and possible adverse phenomena.	Quickly map the design space, then refine only the best candidates with expensive simulations, reducing risk and cost.

2. Scientific and Technological Originality

A narrow, single method study would not be scientifically adequate for DEP equipped high aspect ratio wings because the underlying aeroservoelastic behavior is inherently coupled across structural, aerodynamic and propulsive domains. Composite tailoring, morphing wingtips, thrust based actuation and control laws do not operate independently; their effects interact through load redistribution, nonlinear deformations and slipstream variations. Studying these mechanisms in isolation, as done in most prior work, limits scientific insight and produces models that fail when evaluated under realistic DEP inflow conditions. The objective of this project is therefore not to explore each strategy separately but to establish an integrated multi fidelity framework capable of capturing these interactions, identifying effective combinations and providing validated tools that reflect true DEP induced aeroelastic behavior.

The proposed project introduces a unique aeroservoelastic framework that addresses each of the above limitations in a unified manner.

1. The multi fidelity structure of the modeling chain is original: reduced order ZAERO models, mid fidelity aerodynamic databases incorporating slipstream corrections and high fidelity CFD and FSI simulations collectively create a consistency across fidelities that does not currently exist in the literature.
2. The project incorporates DEP forces directly into MIMO aeroservoelastic state space formulations, enabling control strategies based on thrust, differential thrust and thrust vectoring to be analyzed within a dynamically consistent model. Third, it systematically examines the combined influence of composite tailoring, morphing devices and DEP actuation on stability, load distribution and gust response, addressing interactions that have not been characterized before.
3. The framework integrates wind tunnel experiments into the validation loop, producing rare, traceable data for DEP aeroelastic interactions and strengthening the credibility of the entire modeling chain.

These contributions collectively create the first fully integrated, validated, multi fidelity aeroservoelastic modeling and control framework tailored to DEP equipped high aspect ratio wings. A summary linking the major scientific limitations to the objectives of the proposed project is presented in Table 2.

Table 2 - Overview of Current Challenges and Proposed Project Objectives

State of the Art and Remaining Challenges	High aspect ratio wings are key for future civil and military aircraft but exhibit strong nonlinear aeroelasticity, large deflections and reduced stability margins.
	Distributed electric propulsion alters loads through complex slipstreams and propulsion structure coupling that current tools cannot predict reliably.
	Composite tailoring, morphing and DEP based control are mostly studied in isolation, with no framework capturing their combined aeroelastic behavior.
	Existing aeroservoelastic models rely on oversimplified aerodynamics that fail under DEP inflow, causing gaps in gust and flutter prediction.
	A validated multi fidelity chain linking CFD FSI, ZAERO based aeroservoelastic analysis and reduced order control models does not yet exist.
	Experimental data for flexible wings with distributed propulsion are scarce, preventing robust validation of numerical methods and limiting practical readiness.
Present Work	Develop an integrated multi fidelity aeroservoelastic framework that connects CFD derived slipstream fields, ZAERO unsteady aerodynamic models and nonlinear FEM structural representations, providing a consistent and predictive environment for studying DEP induced aeroelastic behavior in flexible high aspect ratio wings.
	Formulate control ready aeroservoelastic state space models where thrust, differential thrust and morphing inputs are embedded directly as dynamic actuators, enabling realistic closed loop simulations of gust load alleviation, vibration reduction and flutter suppression.
	Establish a unified analysis and optimization platform that allows composite tailoring, morphing wingtips and DEP based actuation to be evaluated under identical aerodynamic and structural conditions, enabling systematic comparison and coordinated design of passive, semi active and active load alleviation strategies.
	Construct a calibrated multi fidelity workflow in which reduced order and ZAERO based models are systematically updated using high fidelity CFD FSI results, ensuring accuracy across the full operating envelope required for controller synthesis and design optimization.
	Design and test a flexible wing demonstrator in the wind tunnel, generating high quality experimental data to refine aerodynamic and structural models, validate aeroservoelastic predictions and deliver a practical methodology for future DEP equipped high aspect ratio wing designs.

2.1. Araştırma Sorusu veya Hipotezi: Projenin ele aldığı problem(ler), araştırma sorusu ve/veya hipotezi açık bir şekilde ortaya konulur.

The scientific problem addressed by this project arises from the fact that current aeroelastic and aeroservoelastic analysis tools are not capable of reliably capturing the coupled effects of unsteady aerodynamics, structural flexibility, distributed electric propulsion slipstreams and morphing devices on high-aspect-ratio wings. Conventional models for gust loads, flutter prediction and aeroservoelastic stability were developed for configurations with uniform inflow, rigid propulsion systems and limited structural deformation. These assumptions break down in modern DEP-equipped flexible wings, where slipstream-induced load redistribution, nonlinear structural deflections and strong actuator–aerodynamic coupling fundamentally reshape the aeroelastic behavior.

The project therefore focuses on understanding how these tightly coupled physical mechanisms can be represented within a unified aeroservoelastic framework that remains accurate, computationally tractable and suitable for control design. This effort raises several interconnected research questions. One concerns how unsteady aerodynamic loads, structural modal characteristics and DEP slipstream effects can be formulated together in a state-space representation that captures the essential dynamics without losing the critical nonlinear trends observed in high-fidelity simulations and experiments. Another question involves the flow of information across fidelity levels. The project seeks to determine how reduced-order ZAERO models, panel-method aerodynamics and CFD or FSI solvers can be combined so that each level remains consistent with the others across a range of flight conditions. A further area of inquiry examines how composite tailoring and morphing wingtips behave when coupled with DEP-based thrust or thrust vectoring, and whether their combined actions lead to favorable interactions, adverse coupling or entirely new load paths. Finally, the project must determine whether experimentally obtained wind-tunnel data can be used to calibrate and validate reduced-order and mid-fidelity models so that they reliably reproduce trends such as modal shifts, unsteady load patterns and stability boundaries.

These research questions lead to several scientific hypotheses that guide the project's development. One hypothesis is that a deliberately structured multi-fidelity modeling pipeline, when calibrated with high-fidelity CFD and FSI results, can predict the aeroelastic and aeroservoelastic response of DEP-equipped high-aspect-ratio wings within acceptable accuracy for engineering design. A second hypothesis is that DEP slipstreams introduce modifications to aeroelastic mode shapes, gust responses and flutter margins that cannot be captured unless aerodynamic, structural and propulsive effects are modeled simultaneously. A third hypothesis is that composite tailoring, morphing devices and DEP actuation have nonlinear and interdependent effects that may offer enhanced load alleviation and stability improvement when used together. A fourth hypothesis is that including DEP inputs as control effectors in a MIMO aeroservoelastic model will lead to measurable improvements in gust load alleviation and flutter suppression compared to strategies relying solely on aerodynamic surfaces. A final hypothesis is that reduced-order models calibrated using high-fidelity and wind-tunnel data will reproduce experimentally observed behavior, demonstrating that the proposed multi-fidelity methodology provides reliable predictive capability.

An additional component of the project, rarely addressed in the existing literature, concerns practical usability. At present, building a full FSI or aeroservoelastic model in ANSYS Mechanical, ZAERO or an open-source chain such as OpenFOAM coupled with MBDyn and PreCICE requires significant expertise, manual setup and detailed configuration. This complexity limits the adoption of advanced modeling techniques in both academia and industry. Therefore, embedded within the scientific aims of the project is a complementary goal: the development of software tools and user interfaces that wrap these multi-fidelity models into a consistent, user-friendly environment. This involves automating pre-processing steps, model generation, parameter transfer, calibration routines and basic post-processing so that aeroservoelastic researchers and engineers can employ high-level analysis tools without navigating the underlying technical burdens of each solver. The hypothesis guiding this component is that a structured and integrated software environment will not only improve accessibility but also reduce model-building errors and support a wider adoption of advanced aeroservoelastic techniques.

Together, these research questions and hypotheses define the scientific foundations of the project, establishing a clear pathway from multi-physics understanding to validated models and finally to usable tools that can support the next generation of high-aspect-ratio DEP-equipped aircraft designs.

2.2. Amaç ve Hedefler: Projenin amacı ve hedefleri açık, ölçülebilir, gerçekçi ve proje süresince ulaşılabilir nitelikte olacak şekilde açıklanır.

The aim of this project is to establish a complete aeroservoelastic analysis and design framework for high-aspect-ratio composite wings equipped with distributed electric propulsion, and to integrate this framework into a software environment that simplifies the use of advanced multi-fidelity tools. The project seeks to provide both accurate predictive models and practical design capabilities, enabling systematic exploration of passive, semi-active and active load-management concepts for next-generation flexible wings.

The first part of the project focuses on developing the multi-fidelity numerical tools that form the core of the framework. This includes creating reduced-order aeroservoelastic models in ZAERO, extending them to include propeller slipstream effects and linking them with mid-fidelity aerodynamic representations that reflect DEP-induced load distributions. In parallel, the project will build high-fidelity aerodynamic and structural simulations to resolve nonlinear

behavior, capture the interaction of slipstreams with flexible structures and provide reference data for subsequent calibration.
The second part of the project concerns the validation of these tools. High-fidelity CFD and FSI simulations will be used to calibrate the reduced- and mid-fidelity models, ensuring consistency across different modelling levels. This step will determine the ranges where reduced-order formulations remain accurate and identify specific aerodynamic or structural conditions where supplemental corrections are required.
The third part of the project focuses on analytical applications that use the validated framework to conduct systematic design and optimization studies. Several different load-management strategies will be explored. For passive concepts, the project will examine composite tailoring layouts and DEP placement to identify structural and aerodynamic configurations that naturally reduce loading. For semi-active approaches, folding or twisting wingtips will be evaluated to determine deflection ranges and actuation patterns that improve gust response and delay instability. For active control, DEP-based thrust modulation and thrust vectoring will be incorporated into the aeroservoelastic model to develop control-oriented design solutions. These optimization studies will quantify how the different strategies influence gust load alleviation, vibration levels, flutter and whirl-flutter behavior, and how they interact when used together.
The final part of the project involves experimental validation. A representative wing configuration will be designed, manufactured and tested in a wind-tunnel environment. The results will be used to verify both the high-fidelity simulations and the reduced-order models, closing the loop between numerical development, optimization and physical testing.
In addition to these technical objectives, the project will integrate all modeling and analysis steps into a unified software environment. This will streamline the construction of aeroservoelastic models, automate data exchange between fidelity levels and simplify optimization and analysis workflows, allowing researchers and engineers to use the framework without dealing with the full technical complexity of each solver.
Together, these objectives ensure that the project advances the scientific understanding of DEP–aeroelastic interactions while also producing practical design tools for future high-aspect-ratio flexible wings.

3. YÖNTEM

Projede uygulanacak yöntem ve araştırma teknikleri (veri toplama araçları ve analiz yöntemleri dâhil) ilgili literatüre atıf yapılarak tercih sebepleri ile birlikte ayrıntılı bir şekilde açıklanır. Yöntemin projenin amaç ve hedeflerine ulaşmaya ne ölçüde elverişli olduğu ortaya konulur. Yöntem bölümünün; araştırma tasarımı, bağımlı ve bağımsız değişkenler, istatistiksel yöntemler vb. unsurları içermesi gerekir. Proje konusu ile ilgili ön çalışma yapılmış olması halinde bilgi verilmesi beklenir. Yönteme ilişkin akış şeması araştırmanın tasarımı göz önünde bulundurularak sunulabilir.

4. PROJE YÖNETİMİ

4.1. Yönetim Düzeni: İş-Zaman Çizelgesi ve İş Paketleri

4.1.1. İş-Zaman Çizelgesi

Projenin iş paketlerinin (İP) hangi zaman aralıklarında gerçekleştirileceği "İş-Zaman Çizelgesi"nde sunulur. Literatür taraması, gelişme ve sonuç raporu hazırlama aşamaları, proje sonuçlarının paylaşımı, makale yazımı ve malzeme alımı iş paketi olarak sunulmamalıdır.

İŞ-ZAMAN ÇİZELGESİ (*)

İP No	İş Paketi Adı	Projenin Başarısındaki Önemi (%) (**)	Kim(ler) Tarafından Gerçekleştirileceği (***)	AYLAR																																			
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36

(*) Çizelgedeki satırlar gerektiği kadar genişletilebilir ve çoğaltılabilir.
(**) Bu bölüme 0-100 arası sayısal değerler verilerek sütun toplamının 100 olması gerekmektedir.
(***) İP'de görev alacak kişilerin isimleri ve görevleri (araştırmacı, danışman, bursiyer ve yardımcı personel) yazılır. Bu aşamada bursiyer(ler)in isimlerinin belirtilmesi zorunlu değildir. Proje ekibinde araştırmacı ve danışman olarak görev alacak kişiler çevrim içi başvuru sırasında başvuru ekranındaki "Proje Personeli" adımından Proje Başvuru Sistemi'ne (PBS) eklenmeli, yardımcı personel ve bursiyer olacak kişiler için ise başvuru formunun "Ek-2 Bütçe ve Gerekçesi" dokümanında bilgi verilmelidir.

TÜBİTAK

3.1.2. İş Paketleri

Aşağıdaki İş Paketi Tablosu her bir İP için hazırlanır. İP'nin başarılı bir şekilde tamamlanma durumunun izlenebilmesi için her bir İP'nin hedefi, kim(ler) tarafından gerçekleştirileceği, başarı ölçütü, ara çıktısı/çıktıları ve risk yönetimi sunulur.

<table>
<tr><th colspan="2">İŞ PAKETİ TABLOSU (*)</th></tr>
<tr><td>İP No: 1</td><td>İP Adı:</td></tr>
<tr><td colspan="2">İP Hedefi:</td></tr>
<tr><td>İP Kapsamında Yapılacak İşler/Görevler:
•
•</td><td>İP'yi Gerçekleştirecek Kişi(ler) ve İP'ye Katkıları (**)
•
•</td></tr>
<tr><td colspan="2">Başarı Ölçütü: İlgili iş paketinin hangi kriterleri sağladığında başarılı sayılacağı ölçülebilir ve izlenebilir şekilde nitel ve/veya nicel olarak belirtilir.
•
•</td></tr>
<tr><td colspan="2">Ara Çıktılar: İP için öngörülen ve başarı ölçütünün gerçekleşeceğini somut olarak gösteren (teknik rapor, liste, diyagram, analiz/ölçüm sonucu, algoritma, yazılım, anket formu, verim, ham veri vb.) ara çıktılara ilişkin bilgi verilir.
•
•</td></tr>
<tr><td colspan="2">Risk Yönetimi (***): İlgili iş paketi kapsamında projenin başarısını olumsuz yönde etkileyebilecek riskler ve bu risklerle karşılaşıldığında projenin başarıyla yürütülmesini sağlamak için alınacak tedbirler (B Planı) sunulur. B planının uygulanması projenin temel hedeflerinden ve özgün değerinden sapmaya yol açmamalıdır. B planına geçilmesi durumunda yöntem değişikliğine gidiliyor ise bu durum detaylandırılmalıdır. <u>Her bir iş paketi için risk öngörülmesi zorunlu değildir.</u></td></tr>
<tr><td>Risklerin Tanımı</td><td>Alınacak Tedbir(ler) (B planı)</td></tr>
<tr><td>•</td><td>•</td></tr>
<tr><td>•</td><td>•</td></tr>
</table>

(*) İP sayısına göre tablo, risk ve alınacak tedbir (B planı) sayısına göre ilgili satırlar çoğaltılabilir.
(**) İşler/Görevler'de görev alacak kişi(ler)in isimleri ve görevleri (araştırmacı, danışman, bursiyer ve yardımcı personel) yazılır. Bu aşamada, bursiyer(ler)in isimlerinin belirtilmesi zorunlu değildir. Proje yürütücüsü tüm iş paketlerinden sorumludur. Projede görevlendirilecek kişi(ler)in ilgili İP'ye sağlayacağı katkı, uzmanlık alan(lar)ına göre belirtilir.
(***) Risk ve alınacak tedbir (B planı) sayısına göre ilgili satırlar çoğaltılabilir.

4.2. Araştırma Olanakları

Projenin yürütüleceği ve/veya proje ekibinin görev aldığı kurum/kuruluşlarda yer alan altyapı/ekipman, kullanım amacı ile birlikte listelenir.

ARAŞTIRMA OLANAKLARI TABLOSU (*)

Altyapı/Ekipman Türü, Modeli (Laboratuvar, Makine-Teçhizat, vb.)	**Yer Aldığı Yürütücü/Katılımcı Kurum/Kuruluş**	**Projede Kullanım Amacı**

(*) Tablodaki satırlar gerektiği kadar çoğaltılabilir.

TÜBİTAK

5. KARİYER GELİŞTİRME POTANSİYELİ

Yürütücünün yüksek lisans, doktora veya tıpta uzmanlık çalışmalarının proje önerisi ile olan ilişkisi ve benzerlikleri/farklılıkları belirtilir. Yürütücünün lisansüstü çalışmalarına ek olarak; proje önerisinin yürütücünün kariyer gelişimine yapacağı katkılar, yeni yetenekler ve/veya disiplinlerarası çalışma yetkinliği kazandırma potansiyeli açıklanır.

5. YAYGIN ETKİ

Proje başarıyla gerçekleştirildiği takdirde projeden elde edilmesi öngörülen çıktılar ve projeden oluşması öngörülen etkiler ile bu çıktıların paylaşımı ve yayılımına yönelik etkinlikler kısa ve net olarak ilgili bölümde belirtilir.

5.1. Öngörülen Çıktılar

Projeden elde edilmesi öngörülen çıktılar amaçlarına göre belirlenen kategorilere ayrılarak belirtilir, ölçülebilir ve gerçekçi hedeflere dayandırılır. Bu çıktıları kullanacak kurum/kuruluş(lar)a (var ise) ilişkin bilgi verilmesi beklenir. Her bir çıktının elde edilmesinin öngörüldüğü zaman aralığı belirtilir.

Çıktı Türü	Öngörülen Çıktı(lar)	Öngörülen Zaman Aralığı (*)
Bilimsel/Akademik Çıktılar (Ulusal/Uluslararası Makale, Kitap, Kitap Bölümü, Bildiri vb.):		
Ekonomik/Ticari/Sosyal Çıktılar (Prototip, Ürün, Patent, Faydalı Model, Üretim İzni, Tescil, Görsel/İşitsel Arşiv, Envanter/Veri Tabanı/Belgeleme Üretimi, Spin-off/Start- up Şirket vb.):		
Araştırmacı Yetiştirilmesine ve Yeni Proje(ler) Oluşturulmasına Yönelik Çıktılar (Yüksek Lisans/Doktora/Tıpta Uzmanlık/Sanatta Yeterlik Tezleri ve Ulusal/Uluslararası Yeni Proje vb.):		

(*) 0-12 ay, 12-18 ay, proje sonrası vb. şeklinde belirtilir.

5.2. Öngörülen Etkiler

Proje başarıyla gerçekleştirildiği takdirde öngörülen uygulama alanları ve projenin sosyo-ekonomik/kültürel alanlarda sağlayacağı katkılara ilişkin değerlendirmelere yer verilir.

- Öngörülen Uygulama Alanları: Projeden elde edilmesi planlanan araştırma çıktılarının mevcut ve/veya öngörülen potansiyel uygulama alanları belirtilir. Varsa proje sonuçlarından yararlanacak olası son kullanıcılarla (politika yapıcılar, sivil toplum/kullanıcılar, özel sektör vb.) ilişki kurulması ve bu ilişkinin açıklanması beklenir.
- Sosyo-ekonomik/Kültürel Katkı**:** Yaşam kalitesine katkı; kesintisiz ve güvenilir enerji arzı; temiz ve döngüsel ekonomi uygulamaları; sera gazı salınımının azaltılması; atık yönetiminin etkinleştirilmesi; iklim değişikliği ile uyum ve mücadeleye katkı; kaliteli ve güvenli temiz suya erişim; biyoçeşitliliğin korunması; sürdürülebilir, kaliteli ve güvenli gıdaya erişim; doğal afet yönetimi; sürdürülebilir ve akıllı ulaşım; kültür ve doğa varlıklarının korunması; dezavantajlı grupların toplumsal hayata katılımı; eğitim kalitesinin iyileştirilmesi; yaşam boyu öğrenme; sosyal politikalara katkı; sivil güvenlik vb. alanlarda değerlendirmeler yapılır.

Öngörülen katkıların On İkinci Kalkınma Planı başta olmak üzere üst politika belgelerindeki hedefler ve politikalar ile ilişkisinin kurulması ve bu ilişkinin ilgili belgelere atıf yapılarak açıklanmasında fayda görülmektedir.

5.3. Proje Sonuçlarının Yayılımı ve Bilim İletişimi Kapsamında Gerçekleştirilecek Faaliyet Planı

Hedef Kitle: *Proje sürecinde elde edilecek çıktı ve ulaşılacak sonuçlardan yararlanması öngörülen hedef kitlenin (akademisyenler, politika yapıcılar ve uygulayıcılar, özel sektör, bireyler, belirli yaş grupları vb.) kimler olduğu, ilgili hedef kitleye ulaşmak için nasıl bir yol izleneceği ve hedef kitlenin öngörülen yayılım faaliyetlerinden nasıl yararlanacağı belirtilir.*
Hedefler ve Beklenen Kazanımlar: *Gerçekleştirilecek yayılım faaliyetleri ile proje konusuna ilişkin farkındalığın, ilginin ve bu doğrultuda bilgi birikiminin artırılmasına yönelik nasıl bir hedef ortaya konulduğu açıklanır. Proje sonuçlarının hedef kitle ile paylaşılmasının neden önemli olduğu ve nasıl bir kazanım sağlanacağı açıklanır.*
Kullanılacak Araçlar: *Aktarılmak istenen içeriğin hangi kanallar/iletişim araçları (dijital platformlar, medya araçları, web sitesi, çalıştay, toplantı, podcast, infografik gibi görsel/işitsel araçlar, fuarlar, atölyeler, sergiler vb.) kullanılarak paylaşılacağı, neden bu araçların seçildiği ve etkileşimin nasıl sağlanacağı hedef kitlenin yapısı göz önünde bulundurularak açıklanır.*
Zamanlama: *Planlanan faaliyetlerin hangi zaman diliminde gerçekleştirileceği ve ne kadar süreceği açıklanır.*

BELİRTMEK İSTEDİĞİNİZ DİĞER KONULAR

Sadece proje önerisinin değerlendirilmesine katkı sağlayabilecek bilgi veya veri (grafik, tablo, vb.) eklenebilir.

BAŞVURU FORMU EKLERİ

EK-1: KAYNAKLAR
EK-2: BÜTÇE VE GEREKÇESİ
EK-3: PROJE EKİBİNİN DİĞER PROJELERİ VE GÜNCEL YAYINLARI (Proje Başvuru Sistemi (PBS)'ne girilen bilgiler doğrultusunda Sistem tarafından otomatik olarak oluşturulmaktadır.)