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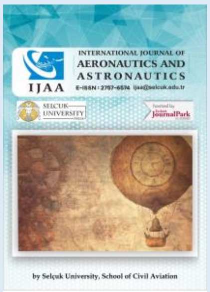

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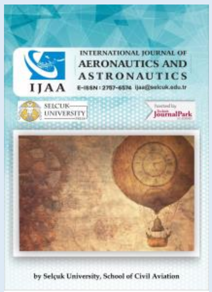

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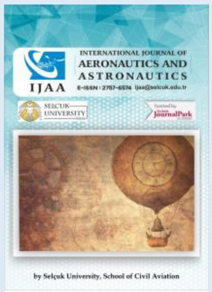

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International Journal of Aeronautics and Astronautics (IJAA) is refereed and interdisciplinary journal focused on publication of the original article, essay / review and scientific the translation aimed at contributing to the field of aviation management and technology in Turkey and the world. Our journal aims to contribute to science by taking place in national and international indexes. Journal publication languages are English and Turkish. Our journal, which adopts an open access policy, can be accessed free of charge.

International Journal of Aeronautics and Astronautics is a refereed academic journal published two times a year in June and December months in order to increase the quality of the articles published in the journal, to organize the publication and review process according to the expectations of the reviewers and authors, and to manage the processes with the right publication policy, the journal publication period has been arranged as 2 times a year as of 2023.

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The International Journal of Aeronautics and Astronautics is a double-blind peer-reviewed (reviewed by at least two reviewer), open access and online journal, covering all areas of aviation management and technology. It is an interdisciplinary journal focused on original articles, essays/reviews, letters to the editor, case reports, book reviews and scientific translations, aiming to contribute to the field of aviation management and technology in Türkiye and in the world. Journal publication languages are English and Turkish. The journal accepts manuscript in every publication period.

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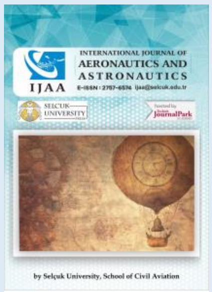

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Sorumlu yazar, makalesini Türk DergiPark Sistemi üzerinden dergiye gönderir. Gönderilen makale, daha önce hiçbir yerde yayımlanmamış veya değerlendirme aşamasında olmamalıdır. Gönderilen eser ile birlikte, telif hakkı formu ve etik kurul izin belgesi de gönderilmelidir.

Ücret Politikası

Journal of Aeronautics and Astronautics dergisinin tüm giderleri Selçuk Üniversitesi tarafından karşılanmaktadır. Dergide makale yayını ve makale süreçlerinin yürütülmesi ücrete tabi değildir. Dergiye gönderilen ya da yayın için kabul edilen makaleler için hiçbir ad altında işleme ücreti ya da gönderim ücreti alınmaz. Journal of Aeronautics and Astronautics yayın politikaları gereği sponsorluk ve reklam da kabul etmemektedir.

Akran değerlendirmesi

Gönderilen tüm yazılar, Yayın Kurulu'nun yayın kararlarını vermesi için hakem değerlendirme sürecine tabi tutulur. Böylece yazar, makale kalitesini geliştirebilir ve artırabilir. Ayrıca, yazarın makaleyi geliştirmesine yardımcı olur.

İncelemeler çift kör prosedürdür. Makalenin kabulü için en az iki olumlu yorum alınmalıdır. Gözden geçirenler ayrıca küçük veya büyük revizyon önerebilir. Hakemler tarafından büyük revizyona karar verilirse, revize edilen makale nihai kararları için hakemlere tekrar gönderilebilir. İnceleyenler için herhangi bir ücret yoktur.

Hakemler editör tarafından belirlenir. Editör ayrıca hakemin yazar önerileri arasından tercihini de yapabilir. Hakemler makale konusunda uzman olmalıdır. Yazarlar ve hakemler arasında herhangi bir çıkar çatışması olmamalıdır. Yazarlar kesinlikle hakemlerin adını bilmeyeceklerdir. Yayın kurulu bunu sağlayacaktır. Ayrıca hakemler birbirlerinin kimliklerini de bilmeyeceklerdir. Hakemler birbirlerinden bağımsız olarak değerlendireceklerdir. Hakemlerin farklı kararlar alması (kabul/reddetme) durumunda, Editör makaleyi değerlendirilmek üzere başka bir hakeme gönderebilir.

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Yayın Etiği
International Journal of Aeronautics and Astronautics, araştırma ve yayın etiği konusunda aşağıdaki ulusal ve uluslararası standartları benimsemektedir:
1. Basın Kanunu,
2. Fikir ve Sanat Eserleri Kanunu,
3. Yükseköğretim Kurumları Bilimsel Araştırma ve Yayın Etiği Yönergesi,
4. Committee on Publication Ethics (COPE),
5. Council of Science Editors (CSE),
6. World Association of Medical Editors (WAME),
7. International Committee of Medical Journal Editors (ICMJE)
8. Directory of Open Access Journals (DOAJ)
9. Open Access Scholarly Publishers Association (OASPA)

İntihali Önleme Kontrolü
Yayınlanmak üzere gönderilen tüm makaleler, "iThenticate" intihal programı ile incelenir. İnceleme sonucunda intihal/benzerlik oranı en fazla %25 olabilir. İntihal/benzerlik oranı %25'in üzerinde olan makaleler, editör kurulu tarafından direkt olarak reddedilir.

Geri Çekme, Retraksiyon ve Yayın Kötüye Kullanım Politikası
Makalenin değerlendirilmesi öncesinde veya sırasında; Yazarlar, yayın kurulu veya hakemler tarafından tespit edilen önemli değiştirilebilir hatalar nedeniyle makale yazar tarafından geri çekilmelidir. Örneğin; makalenin yanlışlıkla iki kez yayınlanması, yazım hataları, eksik veri girişi vb.
Aşağıdaki sebepler, makale yayına hazır olsa bile makalenin retraksiyon sebepleridir.
- Çoklu gönderimler
- Sahte yazarlık iddiaları
- İntihal
- Verilerin hileli kullanımı vb.

Makale yayınlanmışsa, okuyucu orijinal makaleye ulaşmadan önce makalenin retraksiyon notunu bir bağlantı aracılığıyla elektronik olarak görecektir. Ardından, her sayfada "RETRAKSİYON" yazan bir filigranla orijinal makaleye ulaşır.
Makale yayınlandıktan sonra, makalenin retraksiyonunu gerektiren sebepler dışındaki nedenlerle makalenin değiştirilmesi gerekebilir. Bu durumda makalenin yeni hali derginin son sayısında yayımlanır. Değişiklik için gerekli açıklamalar bu yeni sürümde belirtilmiş ve önceki sürüme bağlantı yapılmıştır.

Arşivleme ve Veri Dağıtım Politikası
Editör, yayınlanan materyalin güvenli bir şekilde arşivlenmesini sağlar. International Journal of Aeronautics and Astronautics yayınladığı makaleleri açık erişim esasına göre yazar(lar)ın herhangi bir işlem yapmasına gerek olmaksızın elektronik arşivlere gönderir ve tam erişime açık hale getirir. Yazar veya fon sağlayan kuruluş, yazarın kabul edilen makalesinin bir kopyasını arşiv sitelerine yükleyebilir. International Journal of Aeronautics and Astronautics

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yazar lisansı, yalnızca ticari olmayan kullanım için makalenin kaynağına atıfta bulunarak (tam bir alıntıyla) yeniden kullanıma izin verir. Ticari kullanım için yazarlardan izin alınması gerekmektedir. International Journal of Aeronautics and Astronautics, tüm makalelerini CC-BY-NC Creative Commons lisansı kapsamında açık erişimli tutmayı ve tam metin içeriğini arşiv platformlarında ve https://dergipark.org.tr/tr/pub/ijaa web sitesinde depolamayı taahhüt eder.

Arşiv Politikası: LOCKSS
Depo Politikası: Yayıncının Kendi Sitesi

Journal of Aeronautics and Astronautics dergisinde yayınlanan makaleler LOCKSS'da dijital olarak arşivlenir. Ayrıca yayımlanan makaleler, yazarı tarafından çalıştığı üniversitenin kurumsal arşivinde (DSpace, AVESİS vb.), konulu arşivlerde veya diğer her türlü arşivde ambargo süresi olmaksızın erişime açılabilir. Böylece bu yayına herkes ücretsiz olarak hemen ulaşabilir.
Journal of Aeronautics and Astronautics (e-ISSN: 2757-6574) dergisinin yayımcısı, araştırma sonuçlarının yayılmasını destekleme politikasına uygun olarak arşiv politikasını duyurmaktan memnuniyet duyar:

- Journal of Aeronautics and Astronautics yazarlara, bir makalenin kendi kendine arşivleme (yazarın kişisel web sitesi) ve/veya yayınlandıktan sonra kurumsal bir havuzda arşivleme için bir makalenin (yayıncı pdf) nihai yayınlanmış sürümünün kullanılmasına izin verir.
- Yazarlar, makalelerini halka açık ve/veya ticari konu tabanlı arşivlerde kendi kendilerine arşivleyebilirler. Ambargo süresi yoktur ancak yayınlanan kaynak belirtilmeli ve dergi ana sayfasına veya makalelerin DOI'sine bir bağlantı ayarlanmalıdır.
- Yazarlar makalenin çıktısını PDF belgesi olarak indirebilirler. Yazarlar makalenin kopyalarını meslektaşlarına herhangi bir ambargo olmaksızın gönderebilir.
- Selçuk Üniversitesi Yayınları, makalelerin tüm sürümlerine izin verir (Gönderilen sürüm, kabul edilmiş versiyon, yayınlanmış versiyon) ambargo olmaksızın yazarın tercih ettiği bir kurumsal veya başka bir arşivde saklanacaktır.
- Journal of Aeronautics and Astronautics, kalıcı arşivler oluşturulmasına izin vermek için LOCKSS sistemi kullanmaktadır. Stanford Üniversite Kütüphanelerine dayanan LOCKSS Programı, kütüphanelere ve yayıncılara kalıcı ve yetkili sayısal içeriğe erişimi sağlamak için ödüllü, düşük maliyetli, açık kaynak dijital koruma araçları sunar. LOCKSS Programı, "çok sayıda kopyanın güvenliğini sağlama" ilkesi üzerine kurulmuş, kütüphanenin liderliğindeki bir dijital koruma sistemidir. LOCKSS Programı, açık kaynaklı uç uca dijital koruma yazılımı kullanarak kütüphaneleri geliştirir ve destekler.

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LOCKSS: https://dergipark.org.tr/tr/pub/ijaa/lockss-manifest
RSS: https://dergipark.org.tr/tr/pub/ijaa/rss-feeds
Ambargo Süresi: Ambargo süresi yoktur.
Açık Erişim Lisansı: CC BY-NC 4.0
Telif Hakkı Sahibi: Yazar(lar) telif hakkını korur.
Arşiv Yeri: Kurumsal Arşiv, Crossref, Dergi Web Sitesi, Kurumsal Site, Yazarın Kişisel Web Sitesi, Halka Açık ve/veya Ticari Konu Tabanlı Arşivler.
Politika Koşulları: Atıf ve alıntı standartlarına uyularak dergiye atıf yapılmalıdır. DOI ile yayıncı sürümüne bağlanmalıdır.

Hakem Süreci Sonunda Kabul Edilen Versiyon
Ambargo Süresi: Yok
Arşiv Yeri: Dergi Web Sitesi, Kurumsal Site, Yazarın Kişisel Web Sitesi, Halka Açık ve/veya Ticari Konu Tabanlı Arşivler.
Telif Hakkı Sahibi: Yazar(lar) telif hakkını korur.
Dergiye Gönderilen İlk Metin
Ambargo Süresi: Yok
Arşiv Yeri: Dergi Web Sitesi, Kurumsal Site, Yazarın Kişisel Web Sitesi, Halka Açık ve/veya Ticari Konu Tabanlı Arşivler.

Kalıcı Makale Tanımlayıcı: DOI
Journal of Aeronautics and Astronautics dergisi her makalesine doi atamaktadır

Yazar Katkı Oranı Beyanı
Makalede, araştırmacıların katkı oranı beyanı, varsa destek ve teşekkür beyanı, çıkar çatışması beyanı belirtilmelidir.

ETİK İLKELER VE YAYIN POLİTİKASI

Editoryal Sorumluluklar
International Journal of Aeronautics and Astronautics'e gönderilen makalelerin hangilerinin yayımlanacağına karar vermekten Genel Yayın Yönetmeni, Sorumlu Editör ve Uluslararası Yayın Kurulu sorumludur.
Baş Editör, derginin içerik ve kalite açısından yetersiz gördüğü yazıları yayımlamamaya karar verme hakkını saklı tutar.
Derginin tüm editör ekibi, yayınlanmasını düşündüğü makalelerle ilgili olarak herhangi bir çıkar çatışması içinde olmamalıdır.
Baş Editör ve diğer editoryal üyeler, makaleleri herhangi bir ırk, cinsiyet, cinsellik, din, etnik veya politik önyargı içermeyen entelektüel içerik açısından değerlendirecektir. Editörler, gönderilen tüm yazıları gizli belgeler olarak ele alır; bu, yazarların izni olmadan bir yazı

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hakkındaki bilgileri kimseye ifşa etmeyecekleri anlamına gelir. Makale inceleme sürecinde şu kişiler makalelere erişebilir: Editörler, Hakemler, Yayın Kurulu Üyeleri. Bir yazıyla ilgili ayrıntıların yazarların izni olmadan üçüncü bir şahsa iletilebileceği tek durum, editörün ciddi araştırma suistimalinden şüphelenmesidir. Editör, etik ihlalden şüphelenirse veya bir ihlal iddiası olursa harekete geçmekle yükümlüdürler. Bu görev hem yayınlanmış hem de yayınlanmamış makaleleri kapsar.

Yazarın Sorumlulukları

Yazarlar, makalenin orijinal çalışma olduğunu ve başka bir dergide yayınlanmadığını ve aynı makalenin başka bir dergiye paralel olarak gönderilmediğini garanti eder.

Yazarlar ayrıca, yazının Yayın Kurulu'nun izni olmadan başka bir yerde (International Journal of Aeronautics and Astronautics'te yayınlandıktan sonra) hiçbir dilde yayınlanmadığını ve yayınlanmayacağını da taahhüt ederler.

Gönderilen makale bir araştırma projesi sonucuysa veya daha önce bir konferansta sunulmuşsa veya makaleyi destekleyen kurum veya kuruluş varsa, yazarlar bu bilgiyi Teşekkür bölümünde belirtmelidir.

Gönderilen makalenin etik standartlara uygun olmasını sağlamak yazarların sorumluluğundadır. Makalede yer alan bilgilerin asılsız veya hukuka aykırı olmadığını ve üçüncü şahısların haklarını ihlal etmediğini teyit eder, bu durumdan doğan her türlü tazminat talebini karşılar ve yayıncı hukuken sorumlu tutulamaz.

Katılımcıların Kişisel Verilerinin Korunması

International Journal of Aeronautics and Astronautics, Türk Dergipark tarafından kabul edilen Kişisel Verileri Koruma İlkerlerini kabul ederek uygulamaktadır.

İntihal

Bir başkasının fikirlerini, sözlerini, cümlelerini veya yaratıcı ifadelerini kendisininmiş gibi sunmak bilimsel etik açısından açık bir intihaldir.

Başka bir yazarın çalışmasından belirli bir ifadeyi, açıkça kaynak göstermeden, kaynağı doğru göstermeden veya kaynağı izinsiz olarak kendi çalışmasında kullanmak intihal olarak kabul edilir. İntihal olduğu tespit edilen yazarın makalesi doğrudan reddedilecektir.

Tekrar Yayın

Tekrar yayın, aynı makalenin veya büyük ölçüde benzer makalelerin birden fazla dergide yayınlanmasıdır. Editör bu tür makaleyi incelemeden geri gönderir. Bundan sonra editör, tekrar yayına teşebbüs eden yazara belli bir süre ambargo uygulayabilir, yazarın daha önce yayın yaptığı dergide (belki de önceki makaleyi yayınlayan derginin editörü ile eşzamanlı duyuru olarak) kamuoyuna bu durumu açıklayabilir veya bu tedbirlerin hepsini birlikte uygulayabilir.

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Aynı makalenin birden fazla dergiye eşzamanlı olarak gönderilmesi
Yazarlar aynı makaleyi aynı anda birden fazla dergiye gönderemezler. Editör, olası eşzamanlı gönderimi öğrenirse, makaleyi alan diğer editör(ler)e danışma hakkını saklı tutar. Ayrıca editör, makaleyi incelemeden iade edebilir veya incelemeleri dikkate almadan reddedebilir veya bu kararı ilgili diğer editör(ler)le tartışarak alabilir ve yazarlardan belli bir süre makale başvurusu kabul etmemeye karar verebilir. Ayrıca yazarların işverenlerine yazabilir veya bu tedbirlerin hepsini birlikte hayata geçirebilir.

Etik İhlal Bildirimleri
Okurlar, International Journal of Aeronautics and Astronautics de yayınlanan bir makalede önemli bir hata ya da yanlışlık fark ettiklerinde ya da editoryal içerik ile ilgili (intihal, yinelenen makaleler vb.) herhangi bir şikâyetleri olduğunda ijaa@selcuk.edu.tr adresine e-posta göndererek bildirimde bulunabilir.

Çıkar çatışması
Yazarlar çıkar çatışması olabilecek kişi, kurum ve kuruluşları açıklamalıdır.

Hakemlerin sorumlulukları
Hakemler, makalenin bilimsel değeri ve orijinalliği hakkındaki tarafsız görüşlerini zamanında yazılı olarak sunmalıdır.
Hakemler, gönderilen makaleyi derginin kapsamına, konunun özgünlüğüne, makalenin sunumuna, bilimsel nitelik ve özelliğine göre değerlendirir.
Hakemler etik ihlal, başka bir yerde yayınlanmış bir makale ile önemli benzerlik ve benzeri durumlar tespit ettiklerinde editörü uyarmalıdır.
Hakemler, yazarlar veya makaleyi destekleyen kurum veya kuruluşlar ile çıkar çatışması içinde olmamalıdır. Böyle bir durum editöre bildirilmelidir.
Hakemler makaleyi değerlendirirken tarafsız olmalıdır. Görüş, düşünce ve eleştirilerini destekleyici argümanlarla açıkça ifade etmelidir.
İncelenmek üzere gözden geçirenlere gönderilen tüm belgeler gizli olarak değerlendirilmelidir. Makalelerde belirtilen konu ve materyaller yazarların izni olmadan kullanılamaz. Bu bilgilerin kişisel kazanç amacıyla kullanılması durumunda tüm sorumluluk kullanıcıya aittir.

Feragatname
Yayınlanan eserlerdeki görüşler yazarlara aittir. Editörler ve Yayın Kurulu sorumlu tutulamaz. Yazılarda ifade edilen fikirlerin hukuki ve manevi sorumluluğu yazarlara aittir. Herhangi bir tazminat talebi olması durumunda yazarlar yasal olarak sorumlu tutulacaktır. Yayıncının herhangi bir sorumluluğu yoktur.

Etik Kurul İzni
Etik kuralları kapsamında şunlara dikkat edilmelidir.

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Sosyal bilimler dahil tüm disiplinlerde yapılan araştırmalar ile insan ve hayvanlar üzerinde etik kurul kararı gerektiren klinik ve deneysel araştırmalar için etik kurul onayı alınmalı ve bu onay makalede belirtilmeli ve belgelenmelidir.
Dergide ve/veya web sayfasında ulusal ve uluslararası standartlara atıfta bulunarak ayrı bir başlık altında belirtilmelidir.
Bu başlık altında hakemler, yazarlar ve editörler için ayrı başlıklar altında etik kurallar hakkında bilgi verilmelidir.
Makalelerin Araştırma ve Yayın Etiğine uygun olduğu belirtilmelidir.
Uluslararası standartlara ve kurumlara atıfta bulunulmalıdır. Örneğin, dergilere gönderilen bilimsel makaleler, International Journal of Aeronautics and Astronautics Editors (IJAAE) ve International Standards for Editors and Authors of COPE'nin (Committee on Publication Ethics) tavsiyelerini dikkate almalıdır.
Etik kurul izni gerektiren çalışmalarda, izne ilişkin bilgi (kurul adı, tarih ve sayı numarası) yöntem bölümünde ve makalenin ilk/son sayfasında yer almalıdır.
Veri toplamada kullanılan ölçekler için ölçek sahibinden izin alınmalı ve makalede belirtilmelidir.
Kullanılan fikir ve sanat eserleri için telif hakları düzenlemelerine uyulmalıdır.

Etik Kurul İzni Gerektiren Çalışmalar
1) Anket, görüşme, odak grup çalışması, gözlem, deney, görüşme teknikleri kullanılarak katılımcılardan veri toplanmasını gerektiren nitel veya nicel yaklaşımlarla yürütülen her türlü araştırma,
2) İnsan ve hayvanları (maddi/veri dahil) deneysel veya diğer bilimsel amaçlarla kullanmak,
3) İnsanlar üzerinde yapılan klinik araştırmalar,
4) Hayvanlar üzerinde yapılan klinik araştırmalar,
5) Kişisel verilerin korunması kanunu uyarınca geriye dönük çalışmalar.

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İLETİŞİM

Bize Ulaşın
Bizimle e-posta aracılığı ile iletişime geçebilirsiniz. Ayrıca, dergi yetkililerine ait bireysel iletişim bilgilerini de Editör kadrosu içerisinde bulabilirsiniz.

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ijaa@selcuk.edu.tr
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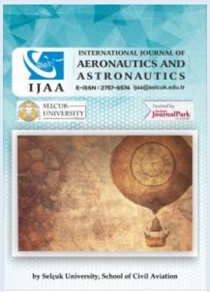

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Dear readers,

We present the 1st issue of the 6th volume of the International Journal of Aeronautics and Astronautics (IJAA) to your appreciation and evaluation publishing it on time. Besides, as an indicator of the increase in the scientific quality of our journal, our applications for registration in respected academic indexes continue rapidly and we are trying to make up for our deficiencies in this regard with great effort.

In this first issue of 2025, there are 5 important articles that we think you can benefit from. These articles cover social and engineering issues such as Aerodynamic insights from peregrine falcon flight using CFD: Applications in aircraft engineering, Aerodynamic performance comparison of circular and rectangular S-ducts for aircraft intakes: A CFD study, Analysis of a UAV propeller produced by various materials, Supersonic blowdown wind tunnel control using ABC optimized PID controller, The impacts of the great depression on the safety development in civil aviation: Business cycles approach. We hope that these articles published in our journal will be of interest to you and will guide your studies.

We have published high-quality scientific studies for you in this issue and previous issues. Our biggest goal is to increase our scientific quality in our future issues and to inform our valuable readers about social and technological issues in the field of aviation and space sciences. In order to achieve success in this goal, your contributions, both as writers and as reviewer, are very important to us. I look forward to your valuable stakeholders' contributions to us and our magazine, and on behalf of my entire magazine team, I wish you well and see you in our next issue.

June 30, 2025
Prof. Dr. Nilüfer CANÖZ

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Değerli okurlarımız,

International Journal of Aeronautics and Astronautics (IJAA)'ının 5. cildinin 2. sayısını, zamanında yayımlayarak siz değerli okurlarımızın beğenisine ve değerlendirmesine sunuyoruz. Ayrıca, dergimizin bilimsel kalitesinin arttığının göstergesi olarak saygın akademik dizinlere kayıt başvurularımız hızla devam etmekte ve bu konudaki eksiklerimizi büyük bir gayretle giderme çabası içerisindeyiz.

2025 yılına ait bu birinci sayımızda, sizlerin önemli ölçüde faydalanabileceğinizi düşündüğümüz 5 önemli makale yer almaktadır. Bu makaleler, alaca doğanının uçuş dinamiklerinden CFD ile elde edilen aerodinamik bulgular: Havacılık mühendisliğinde uygulamalar, uçak hava alığı için dairesel ve dikdörtgen S-kanallarının CFD ile aerodinamik performans karşılaştırması, çeşitli malzemelerle üretilen bir İHA pervanesinin analizi, ABC ile optimize edilmiş PID kontrolcü kullanarak sesüstü üflemeli rüzgar tünelinin kontrolü, büyük buhranın sivil havacılıkta emniyet gelişimine etkilerinin iş döngüleri yaklaşımı ile incelenmesi gibi sosyal ve mühendislik konuları içermektedir. Dergimizde yayınlanan bu makalelerin ilginizi çekeceğini ve sizlerin de çalışmalarınıza yön vereceğini ümit ederiz.

Bu sayımızda ve önceki sayılarımızda sizler için yüksek kaliteli bilimsel çalışmaları yayınladık. Gelecekteki sayılarımızda da bilimsel kalitemizi artırarak siz değerli okurlarımızı, havacılık ve uzay bilimleri alanında sosyal ve teknolojik konular ile bilgilendirmek en büyük hedefimizdir. Bu hedefimizde başarıya ulaşmak için sizlerin de gerek yazar gerekse hakem olarak sağlayacağınız katkılar bizim için çok önemlidir. Siz değerli paydaşlarımızın bizlere ve dergimize yapacağınız bu katkıları bekliyor, tüm dergi ekibim adına sonraki sayımızda görüşmek üzere esenlikler diliyorum.

30 Haziran 2025
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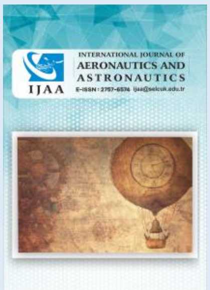

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Research Article / Araştırma Makalesi

Aerodynamic insights from peregrine falcon flight using CFD: Applications in aircraft engineering / Alaca doğanının uçuş dinamiklerinden CFD ile elde edilen aerodinamik bulgular: Havacılık mühendisliğinde uygulamalar

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Aerodinamik,
Uçak,
CAD tasarımı,
CD katsayısı,
Sürükleme kuvveti,
Alaca doğan

ABSTRACT

In this study, the aerodynamic characteristics of the peregrine falcon were analyzed using the Computational Fluid Dynamics (CFD) method. The falcon model scaled 1:1, was designed in SolidWorks® for both gliding and diving scenarios. Ansys Fluent® was employed to determine the drag and lift coefficients of the bird model. Numerical analyses were conducted at four different flow rates with Reynolds numbers ranging from 753205 to 3012821. The average drag coefficient (C_D) during diving was 0.00933, while the lift coefficient (C_L) was 0.00428, resulting in a C_D/C_L ratio 2.18. The average drag coefficient was for gliding 0.0227, and the lift coefficient was 0.0165, with a reduced C_D/C_L ratio of 1.38. Additionally, the flow structure around the bird model was examined to identify regions where pressure-induced drag forces were significant. The study discusses potential applications for aircraft and passive flow control components inspired by the peregrine falcon's superior aerodynamic features.

ÖZET

Bu çalışmada, alaca doğanın aerodinamik özellikleri Hesaplamalı Akışkanlar Dinamiği (HAD) yöntemi kullanılarak analiz edilmiştir. 1:1 ölçeklendirilmiş doğan modeli, hem süzülme hem de dalış senaryoları için SolidWorks®'te tasarlanmıştır. Kuş modelinin sürükleme ve kaldırma katsayılarını belirlemek için Ansys Fluent® program kullanılmıştır. Sayısal analizler, 753205 ile 3012821 arasında değişen Reynolds sayılarına sahip dört farklı akış hızında gerçekleştirilmiştir. Dalış sırasında ortalama sürüklenme katsayısı (C_D) 0,00933 olurken, kaldırma katsayısı (C_L) 0,00428 olarak belirlenmiş ve bunun sonucunda C_D/C_L oranı 2,18 olmuştur. Süzülme sırasında ortalama sürüklenme katsayısı 0,0227 ve kaldırma katsayısı 0,0165 olarak bulunmuş, C_D/C_L oranı ise 1,38'e düşmüştür. Ayrıca, basınç kaynaklı sürüklenme kuvvetlerinin önemli olduğu bölgeleri belirlemek için kuş modeli etrafındaki akış yapısı incelenmiştir. Çalışma, doğan kuşun üstün aerodinamik özelliklerinden esinlenerek uçak ve pasif akış kontrol bileşenleri için potansiyel uygulamaları tartışmaktadır.

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Nomenclature

F_D	Drag force, N	ν	Kinematic viscosity, m^2/s
C_D	Drag coefficient	ρ	Density, kg/m^3
C_L	Lift coefficient	**CFD**	Computational fluid dynamics
©	Trademark	**CAD**	Computer-aided design
Re	Reynolds number		

1. Introduction

The flying speed of birds varies depending on their species and anatomical structure. Factors that affect flying speeds include wing shape, muscle strength, and aerodynamic design. Some bird species can reach extremely high speeds while hunting or escaping from predators. For example, falcons and falcons can chase prey at speeds of up to 300-320 kilometers per hour. This speed is accompanied by their sharp eyes and fast maneuvering abilities. The peregrine falcon (Falco peregrinus) is one of the fastest birds in the world. It reaches speeds of up to 150 km/h during horizontal flight [1] and even reaches speeds of over 320 km/h when nose-diving to attack bird prey [2]. Almost all bird species can change the shape of their wings and thus their aerodynamic properties a concept known as the “transforming wing” [3-5]. While diving, peregrines also change the shape of their wings; as they accelerate and move them increasingly closer to their bodies. Their various body shapes can be described as the classic diamond shape of the wings followed by the tight vertical fold with the dimple-like profile of the forewing parts [6-7]. Peregrines are not only extremely fast flyers, but they also have remarkable maneuverability at high speeds. For example, during courtship behavior, they often change flight paths at the end of the dive, i.e. from a vertical dive to a steep climb. This suggests that peregrines are exposed to high mechanical loads [8]. Among biological systems, the superior aerodynamic structures of birds in particular have inspired researchers in this field. In one of these studies, Bayındırlı, et al. (2020) positioned the spoiler models they developed, inspired by biological systems, in the rear section of a bus model and provided passive flow control. In this way, they achieved an improvement of up to 19% in the C_D coefficient of the bus [14]. Yanqing et al. (2023) applied grooves and protrusions on the protective helmet and examined the effects of these methods on the C_D coefficient numerically and experimentally. By protruding from the surface, the features make the laminar flow turbulent, allowing the flow to adhere to the surface more, and this delays the separation of the flow and improves the pressure-induced drag force [15].
In this study, the aerodynamic properties of a peregrine falcon bird during diving and gliding and the flow structure around the bird were examined by using CFD. Inspired by the superior aerodynamic properties of the peregrine falcon bird, passive flow control parts will be developed for aircraft and land vehicles in future studies.

2. Material and Methods

2.1. CAD design of peregrine falcon

In this study, the aerodynamic properties of the peregrine falcon were determined numerically. In the study, a 1/1 scale bird model was drawn separately for gliding and diving situations in the SolidWorks program. Bird feathers are important elements that increase their aerodynamic performance. Feathers direct airflow, reduce drag and aerodynamically optimize the bird's body. In this study, the precise structure of the feathers was drawn in a simplified manner, as it would cause mesh errors in CFD analyses. Analysis errors due to the structure of the feathers are ignored. The bird picture in nature and drawing data of the bird model in the SolidWorks® program are given in Figure 1a-b and 2a-b.

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Figure 1a. Actual drawing data of peregrine falcon at the moment of diving [9]

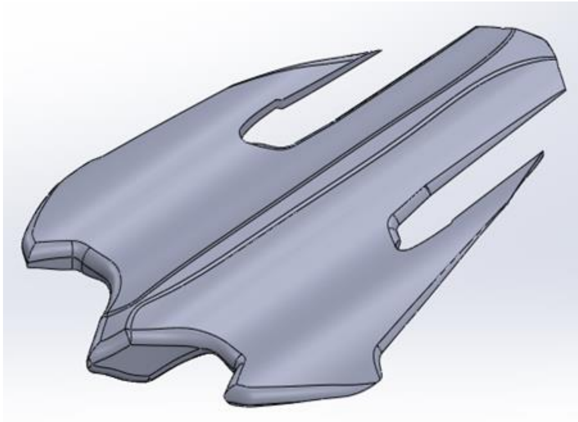

Figure 1b. CAD drawing data of peregrine falcon at the moment of diving

Figure 2a. Actual drawing data of peregrine falcon at the moment of gliding [9]

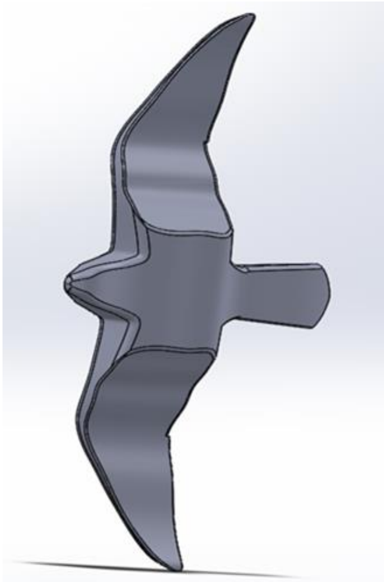

Figure 2b. CAD drawing data of peregrine falcon at the moment of gliding [9]

2.2. Providing of similarity conditions

In aerodynamic studies, three similarity conditions (geometric, kinematic, and dynamic) must be provided. The geometric similarity condition disregards minor surface irregularities. In order to ensure kinematic similarity in aerodynamic studies, the blockage rate must be lower than 7.5% [10-11]. Blockage ratio is a parameter in fluid mechanics that represents the ratio of the cross-sectional area of a model within a channel or wind tunnel to the total cross-sectional area of the channel or wind tunnel. In this study, blockage rate was lower than 10% to provide kinematic similarity. To ensure dynamic similarity Reynolds number independence was used in CFD analysis. Reynolds number is a dimensionless number in fluid mechanics that indicates whether a flow is laminar or turbulent. Reynolds number independence refers to the fact that in solving a particular flow problem, the results do not depend on the Reynolds number at sufficiently high Reynolds number values. In this case, the behavior of the flow does not change after a certain Reynolds number and therefore there is no need to increase the Reynolds

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number further when performing calculations or experiments. In short, the point is reached where the fundamental characteristics of the flow become independent of the Reynolds number.

2.3. Computational Fluid Dynamics (CFD) method

The Fluent© program used in this study solves general integral equations for continuity, momentum, energy and turbulence based on the finite volume method. During the analysis, continuity, amount of turbulence, and aerodynamic drag coefficient change graphs were monitored. The convergence of the solution was monitored from the error curves convergence graph. CFD analyses were carried out in solution domain conditions where the blocking rate was low, and the models to be analyzed were prepared in Ansys® Design Modeler, as seen in Figure 3a-b.

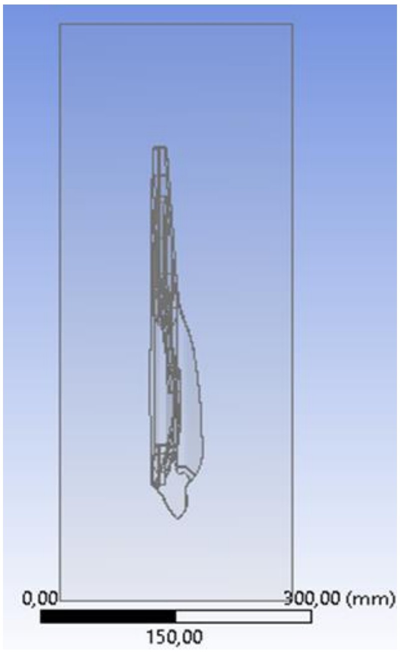

Figure 3a. Models in design modeler at the moment of diving

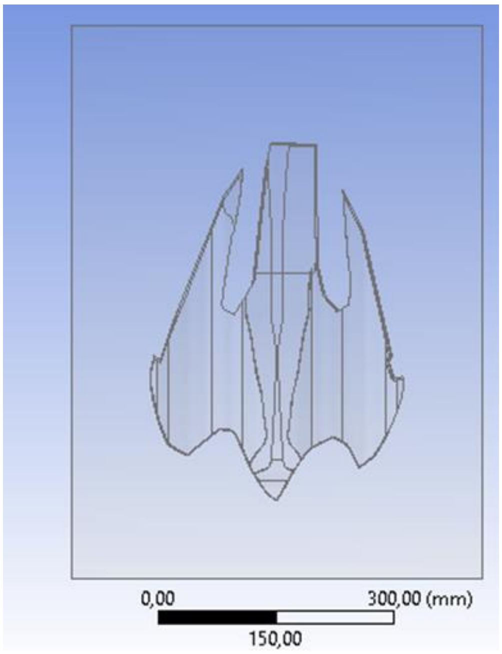

Figure 3b. Models in design modeler at the moment of gliding

Pressure and friction-induced drag forces acting on the peregrine falcon defined in the Fluent© program can be calculated separately. The total aerodynamic drag coefficient (C_D) is obtained from the sum of these two forces. Figure 4 shows the mesh structure created on the model. On the model, 2397102 triangular networks were created for gliding and 1572108 for diving moments.

The boundaries in the solution space are defined as follows. As given in Figure 5, analysis results and convergence chart were followed.

- ✓ Inlet: It is the surface where the fluid enters and is defined as the constant velocity boundary condition.
- ✓ Outlet: It is the surface from which the fluid exits and is defined as the constant pressure boundary condition.
- ✓ Wall and road (Wall): Walls are the edge surfaces of the rectangular volume that form the experimental area, and the wall boundary condition is used.
- ✓ Mold cavity (Wall) belongs to the drawing data of the model vehicle. It is the vehicle whose aerodynamic properties are determined. The wall is defined as the boundary condition.

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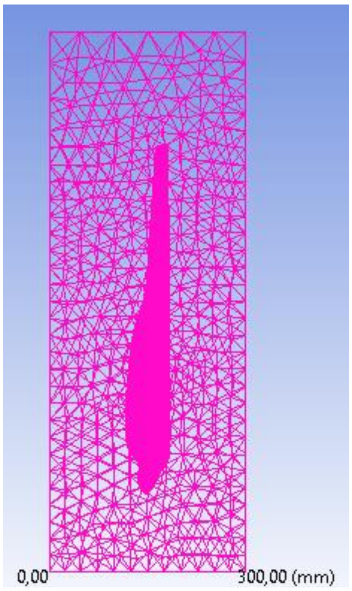

Figure 4a. Mesh distribution in CFD analysis for diving model

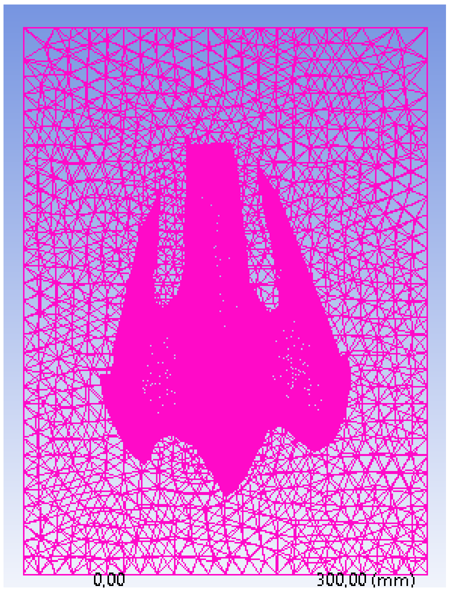

Figure 4b. Mesh distribution in CFD analysis for gliding model

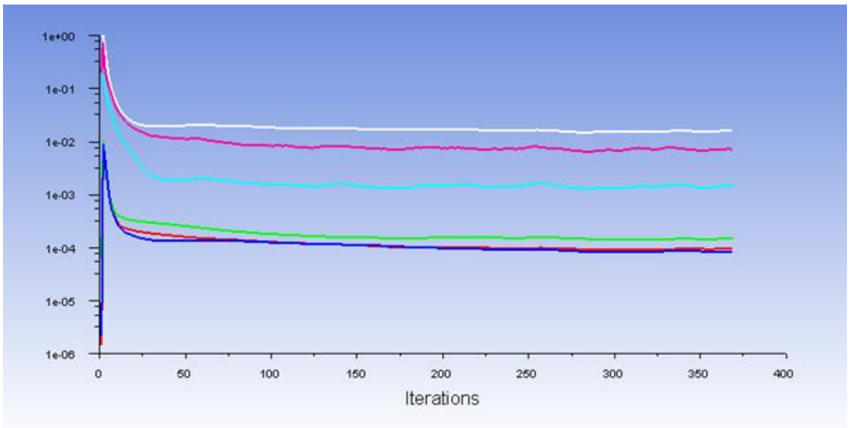

Figure 5. Convergence graph in CFD analysis

In computational fluid dynamics (CFD) analyses, air is designated as the fluid, and its properties, along with other parameters used in the analysis, are detailed in Tables 1 and 2.

Table 1. Features used in the analysis

Description	Value
Time	Constant
Velocity	Absolute
Exchange option	Node-based
Fluid	Incompressible air
Pressure – Speed connection	Simple

Table 2. Properties of the air used in the analysis

	Description	Value
ρ	Density	1 kg/m^3
μ	Dynamic viscosity	1.560×10^{-5} kg/m.s

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The aerodynamic drag coefficient (CD) is a function of the aerodynamic force (F_D), fluid density (ρ), velocity (V), and vehicle front projection area of geometry (A) as seen in Equation 1.

$$C_D = \frac{F_D}{{}^{1}/_{2}\, \rho\, V^2\, A} \tag{1}$$

Fluent© program, which is used in numerical flow analysis, solves general integral equations for continuity, momentum, energy and turbulence using the finite volume method. Continuity equation is expressed as the mass balance in the control volume in a flow, as in Equation 2.

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{2}$$

The rate of change of momentum of a piece of fluid is equal to the sum of the forces acting on this piece of fluid. The momentum increase rate of the unit volume of a piece of fluid in the x, y, and z directions is expressed by the terms, respectively. The most useful version of the Navier–Stokes equations in the finite volume method is given in Equation 3-5;

$$\rho \frac{Du}{Dt} = -\frac{\partial p}{\partial x} + div(\mu grad u) + S_{M_x} \tag{3}$$

$$\rho \frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + div(\mu grad v) + S_{My} \tag{4}$$

$$\rho \frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + div(\mu grad w) + S_{Mz} \tag{5}$$

3. Results and Discussion

3.1. Aerodynamic characteristics of the peregrine falcon during diving

Flow analyses were carried out at 4 different free-flow speeds. Dynamic similarity conditions were provided in all analyses. According to the analysis results, the average C_D coefficient at the time of the average dive was determined as 0.00933, and the C_L coefficient was 0.00428. The distribution of the total C_D coefficient due to pressure-friction is given in Figure 6 and Table 3. The pressure and friction distribution that creates the total drag and lift coefficients are given in Table 4.

Table 3. C_D and C_L values of results peregrine falcon while diving

Velocity (m/s)	Diving C_D	Diving C_L	Ratio of C_D/C_L
25	0.01014	0.00417	2.431
50	0.00937	0.00405	2.313
75	0.00904	0.00433	2.087
100	0.00879	0.00458	1.919
Average	**0.00934**	**0.00428**	**2.179**

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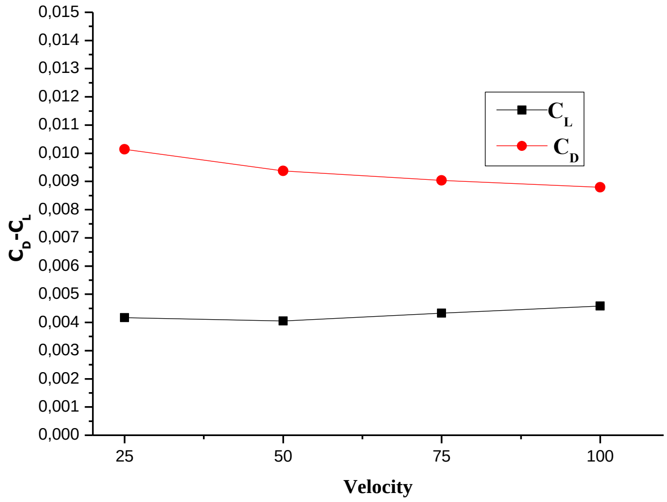

Figure 6. The graph of C_D and C_L values of peregrine falcon at the moment diving

Table 4. Pressure-friction distribution of total C_D and C_L

Drag Force Distribution					Lift Force Distribution			
			Total C_D				Total C_L	
25 m/s	Pressure	0.0058	0.0101	57.20%	Pressure	0.0042	0.0041	99.68%
	Friction	0.00434		42.80%	Friction	~ 0		0.32%
50 m/s	Pressure	0.00572	0.0094	61.05%	Pressure	0.00404	0.004	99.75%
	Friction	0.00365		38.95%	Friction	~ 0		0.25%
75 m/s	Pressure	0.0057	0.009	63.16%	Pressure	0.0043	0.0043	99.82%
	Friction	0.0033		36.84%	Friction	~ 0		0.18%
100 m/s	Pressure	0.0057	0.0088	64.53%	Pressure	0.0046	0.0045	99.83%
	Friction	0.0031		35.47%	Friction	~ 0		0.17%

As given in Figure 7a-c, the flow structure around birds is explained by aerodynamic principles and is one of the fundamental elements enabling their ability to fly. The wings of birds have an aerodynamic profile (similar to airplane wings). The upper part is generally curved, while the lower part is flatter. The angle of the wings affects the airflow. An optimal angle of attack increases lift while minimizing drag.

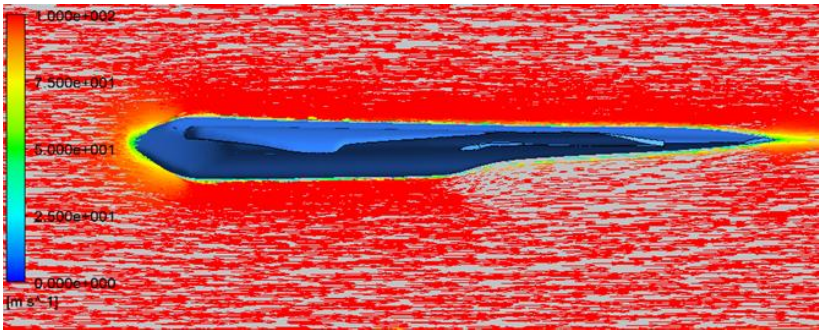

Figure 7a. Velocity vector image of the falcon bird during diving

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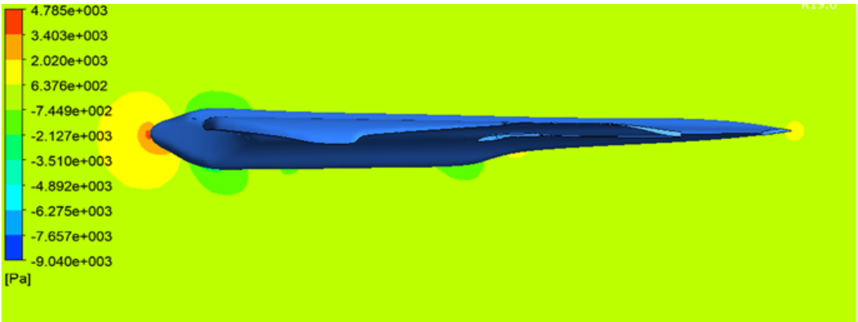

Figure 7b. Pressure contour image of the falcon bird during diving

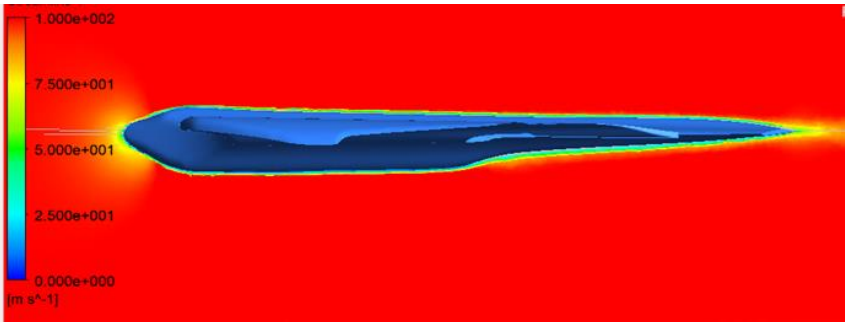

Figure 7c. Velocity streamline image of the falcon bird during diving

During a dive, the falcon folds its wings close to its body. This reduces drag, creating an aerodynamic structure and allowing it to reach high speeds. The wings form a narrow and thin profile, minimizing air resistance. This position also enhances the bird's stability. The wing and tail feathers make fine adjustments to provide steering and balance during the dive. The airflow around the bird during the dive generally remains laminar (smooth). This reduces air resistance and enables higher speeds. At high speeds or during sudden maneuvers, turbulence may occur, especially around the wing tips and tail. The falcon dynamically adjusts its body and wing position to keep turbulence under control.

3.2. Aerodynamic characteristics of the peregrine falcon during gliding

The speed of the bird when gliding is much lower than when diving. Therefore, for the aerodynamic properties of the bird to be realistic during gliding, the actual values of the bird at the moment of gliding were used as the free flow speed. CFD analyses were carried out for this model at Reynolds numbers corresponding to 10, 20, 30, and 40 m/s speeds. The C_D coefficient of the geometric shape taken by the peregrine falcon during gliding was determined as 0.02274. The average C_L coefficient was determined as 0.01653. As seen in Table 5 and Figure 8, pressure and viscous drag forces, which are among the forces that affect the drag force during gliding, progress inversely proportional to the increase in speed. As the speed increases, the pressure-induced friction force decreases and the viscous friction force also decreases.

Table 5. C_D and C_L values of results peregrine falcon while gliding

Velocity (m/s)	Gliding C_D	Gliding C_L	Ratio of C_D/C_L
10	0.02435	0.01431	1.701
20	0.02272	0.01544	1.471
30	0.0222	0.018	1.233
40	0.02169	0.01836	1.181
Average	0.02274	**0.01653**	**1.375**

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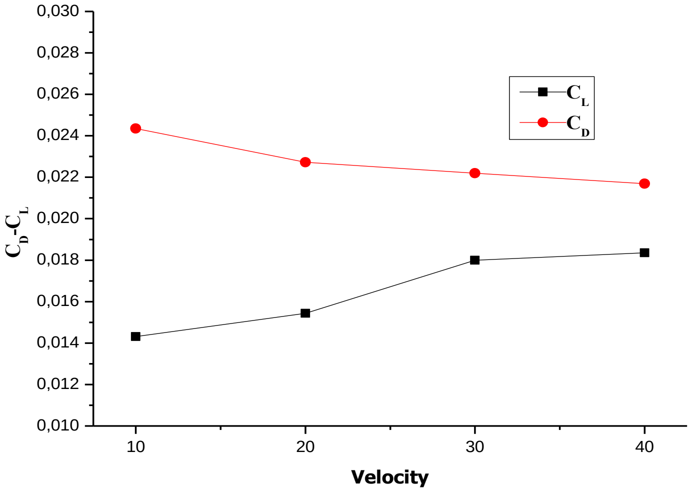

Figure 8. The graph of C_D and C_L values of a peregrine falcon at the moment gliding

Table 6. Pressure-friction distribution of total C_D and C_L

Drag Force Distribution					**Lift Force Distribution**			
			Total C_D				**Total C_L**	
10 m/s	Pressure	0.01993	0.02435	81.85%	Pressure	0.0143	0.014309	99.94%
	Friction	0.00442		18.15%	Friction	~ 0		0.06%
20 m/s	Pressure	0.0191	0.02272	84.07%	Pressure	0.01544	0.015441	99.99%
	Friction	0.00362		15.93%	Friction	~ 0		0.01%
30 m/s	Pressure	0.0190	0.0222	85.59%	Pressure	0.0180	0.018001	99.99%
	Friction	0.0032		14.41%	Friction	~ 0		0.01%
40 m/s	Pressure	0.0187	0.02169	86.17%	Pressure	0.0184	0.018359	99.95%
	Friction	0.0030		13.83%	Friction	~ 0		0.05%

As seen in Figure 9a-c, the aerodynamic structure of a falcon during gliding allows it to conserve energy, stay airborne for long periods, and carefully observe its prey. During gliding, the falcon spreads its wings wide. This increases its wingspan, maximizing lift. The 'primary feathers' at the wingtips spread separately to control the airflow. These feathers reduce turbulence at the wingtips, minimizing energy loss. The wings are positioned at an optimal angle of attack, which increases lift while keeping drag to a minimum. The aerodynamic shape of the wings and body during gliding ensures smooth (laminar) airflow. This reduces drag and conserves energy. While small turbulences may form around the wingtips and tail, these are managed effectively thanks to the wing design. Falcons utilize gravity and thermal air currents during gliding. This relates to their ability to travel long distances without expending much energy, a flight style known as gliding flight.

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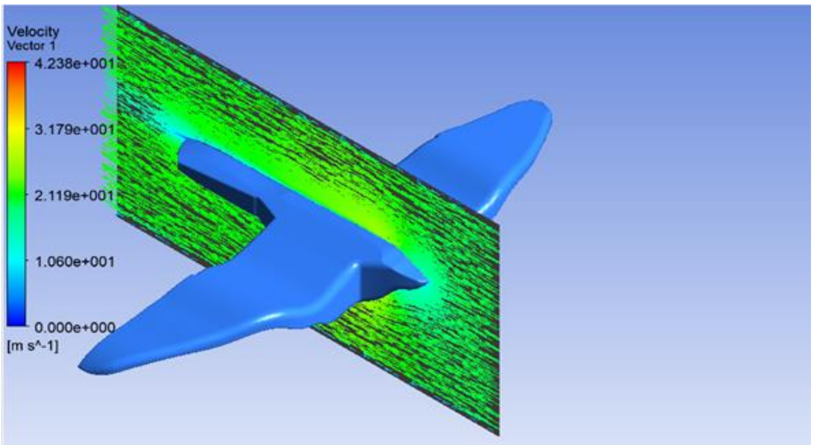

Figure 9a. Velocity vector image of the falcon bird during gliding

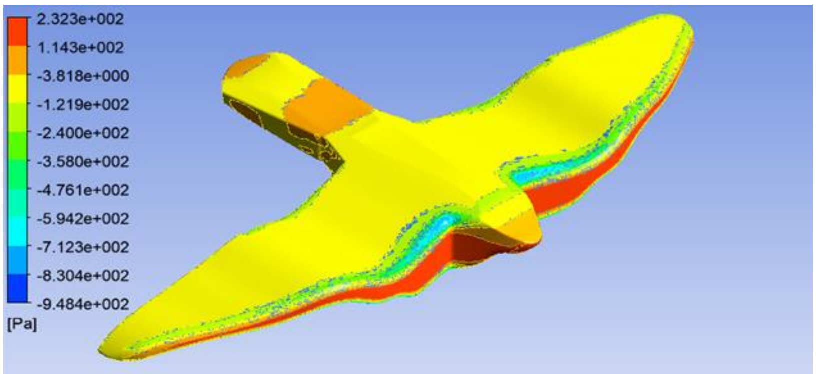

Figure 9b. Pressure contour image of the falcon bird during gliding

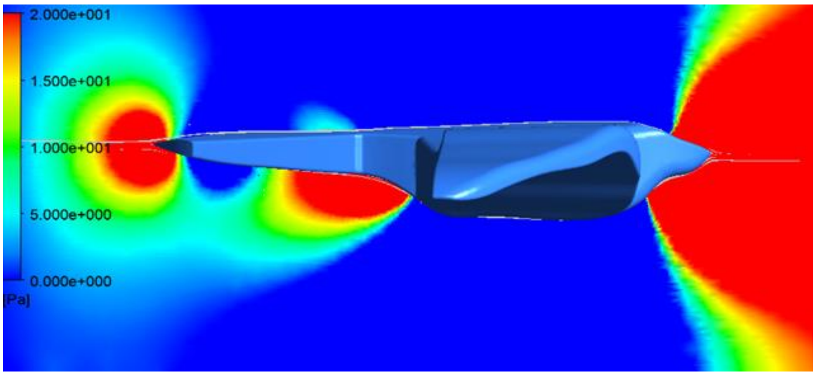

Figure 9c. Pressure streamline image of the falcon bird during gliding

The flying ability of birds is based on their perfect aerodynamic structure. This structure is important for generating lift, reducing drag, and being able to maneuver during flight. Bird wings are optimized to create lift. The upper surface of the wings is usually curved rather than flat; This increases the lift force by accelerating the airflow. The lower surface of the wings is flatter and generally more curved than the upper surface. Figure10a-b impressively explains how technology and aircraft are inspired by nature. Above is a majestic eagle in full flight, with its streamlined body and extended wings, perfectly designed for speed, agility, and efficiency in the air. Below is the famous camouflage bomber B-2 Spirit, whose design was inspired by the aerodynamics of the eagle.

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Figure 10a. Airplane models inspired by eagles [12]

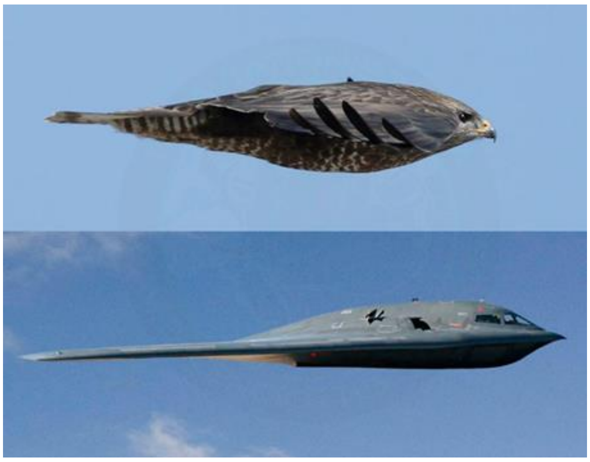

Figure 10b. Airplane models inspired by falcons [12]

Bird flight techniques have been an important source of inspiration for the aviation industry and technology development. By studying the aerodynamic principles of birds, people have developed new approaches to aircraft design and drone technologies. It has also contributed to important scientific research to understand the flight skills of birds, preserve biodiversity, and improve flight and aircraft technologies.

4. Conclusion

In this study, the aerodynamic properties of the peregrine falcon bird, the fastest animal species in nature, were examined. The geometric shape of the bird during gliding and diving was designed using CAD and flow analysis was carried out. The C_D coefficient at the moment of diving when the bird reached its highest speed was determined as 0.00934, the C_L coefficient was determined as 0.00428, and the average C_D / C_L ratio was calculated as 2.179. At the time of gliding, C_D was 0.02274, Cl was 0.01653, and the C_D / C_L ratio was determined as 1.375. While the C_D / C_L coefficient of the peregrine falcon increased by 143.6% during gliding, the C_L coefficient increased by 285.93% due to the geometric shape of the wings.

Authorship contribution statement
Cihan Bayındırlı, *Writing - original draft, Investigation, Visualization, Supervision, Conceptualization, Methodology, Software, Formal analysis.*
Conflicts of Interest: The author declares no conflict of interest.

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Research Article / Araştırma Makalesi

Aerodynamic performance comparison of circular and rectangular S-ducts for aircraft intakes: A CFD study/ Uçak hava alığı için dairesel ve dikdörtgen S-kanallarının aerodinamik performans karşılaştırması: Bir CFD çalışması

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Keywords

Aerodynamic performance, Computational fluid dynamics, Efficiency, S-ducts

Anahtar Kelimeler

Aerodinamik performans, Hesaplamalı akışkanlar dinamiği, S-kanal, Verimlilik

ABSTRACT

S-ducts are critical engine inlet components designed to optimize aerodynamics and flight performance, enhance efficiency, and ensure smooth airflow in both aerospace and automotive applications. These ducts are used to direct and deliver airflow to the engine, improving engine performance, increasing fuel efficiency, and minimizing effects such as turbulence. In military jets, S-ducts also serve as structures that enhance maneuverability and absorb incoming radar waves. Additionally, by smoothing the airflow, S-ducts play a significant role in noise reduction. However, secondary flows and flow separation can sometimes occur within S-ducts. These phenomena may negatively impact the performance of S-ducts, leading to a reduction in overall flight performance.

In this study, 3D models of circular and rectangular S-ducts were created using SOLIDWORKS to observe variations in velocity, pressure, flow distribution, and kinetic energy within ducts of different geometries. Flow analysis was carried out using the SST k-ω turbulence model in ANSYS Fluent. The analysis produced results for pressure, velocity, and kinetic energy. The findings indicated that although the pressure and velocity distributions were more uniform in the rectangular S-duct, the circular S-duct showed better performance in terms of pressure recovery and distortion coefficient.

ÖZET

S-kanallar, aerodinamik ve uçuş performansını optimize etmek, verimliliği artırmak ve hem havacılık hem de otomotiv uygulamalarında düzgün hava akışı sağlamak için tasarlanmış önemli motor giriş kanallarıdır. Bu kanallar, hava akışını motora yönlendirmek ve iletmek, motor performansını iyileştirmek, yakıt verimliliğini artırmak ve türbülans gibi etkileri en aza indirmek için kullanılır. Askeri jetlerde, S-kanallar manevra kabiliyetini artıran ve gelen radar dalgalarını emebilen yapılardır. Ek olarak, S-kanallar hava akışını yumuşatarak gürültüyü azaltma da önemli bir rol oynar. S-kanallarda bazen ikincil akışlar ve akış ayrımı meydana gelebilir. İkincil akışlar ve akış ayrımı, S-kanallardaki performans üzerinde olumsuz bir etkiye sahip olabilir ve bu da uçuş performansında düşüşe yol açabilir.

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Bu çalışmada, farklı geometriye sahip kanal içindeki hız, basınç, akış dağılımı ve kinetik enerji değişimlerini gözlemlemek için SOLIDWORKS kullanılarak dairesel ve dikdörtgen S-kanallar için 3B modeller oluşturuldu. Akış analizi, SST k-ω türbülans modeli uygulanarak ANSYS Fluent programıyla gerçekleştirildi. Analizlerde basınç, hız ve kinetik enerji için sonuçlar elde edildi. Bulgular, dikdörtgen S-kanalda basınç ve hız dağılımı daha düzgün olmasına rağmen, dairesel S-kanalının basınç geri kazanımı ve bozulma katsayısı açısından dikdörtgen S-kanaldan daha iyi sonuçlar verdiğini göstermiştir.

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1. Introduction

Multiple factors such as high pressure recovery, low drag value, low radar visibility and noise level, and minimum weight should be taken into consideration in aircraft intake design [1]. The main reason for using this component in combat aircrafts is to reduce the radar cross-section. However, designing and configuring it to achieve this reduction is a complex process [1]. Some aircraft feature an S-duct, an essential propulsion system component with an S-shaped curve to direct airflow to the engine, commonly used in military aircraft like the F-22 Raptor and certain civilian models [2]. It is important to ensure that the aircraft engine is properly supplied with air under all flight conditions [3]. Additionally, optimum design of S-ducts requires ensuring and controlling the flow pattern in the ducts [4]. S-ducts have also been used as a solution for positioning the central engine in tri-engine aircraft, and most tri-engine aircraft designs favor the use of S-ducts [5]. This structure, which has rectangular and circular inlet cross-sections, can have different turning angles and curvatures in the duct [5]. Due to the curvature in the S-duct design, issues such as pressure gradients, secondary flows and flow separation that can affect flight performance may occur [6]. As a key component in embedded propulsion systems, the S-duct presents particular challenges. Flow separation within the S-duct occurs due to the curvature of the centerline and the diffusion geometry, causing distortions and significant disruptions to the airflow [7]. As this crucial element has substantial impacts on aircraft's performance, there are many S-duct studies in the existing literature proposed by various researchers. To name a few;

Rk et al. [5] performed CFD (Computational Fluid Dynamics) analyses for 3 different S-duct designs with rectangular, circular and elliptical cross-sectional areas and proved that the duct with elliptical cross-sectional area yields better results in automobile and other vehicle applications.

Papadopoulos et al. [8] design a CAD (Computer Aided Design) model of a S-duct to specify optimal parameters for UAV (Unmanned Aerial Vehicle) application. In the study, the Gerlach shaped design was adopted to reduce the strength of secondary vortices and was proved that it was a good choice. The study also shows that the axial length should be changed to find the optimum length according to the total pressure losses. To carry out that a commercial flow solver program was used for flow field calculation. It was explained that the design should be tested experimentally to verify the findings of the analyses performed.

Thenambika et al. [3] performed CFD analysis for S-duct with submerged vortex generators and normal S-duct at 0.6 Mach and 1.0 Mach. It was found that the static pressure recovery would increase as the flow moved on along the duct, except at the beginning of the S-duct. As a result of the analysis of S-duct and S-duct with submerged vortex generators at 0.6 and 1 Mach numbers, it was concluded that the best result was obtained at 0.6 Mach number.

Saha et al. [9] studied the effects of ducts with different cross-sectional shapes for intake using the k-ε turbulence model and found that the elliptically shaped inlet had the best results, while the squared shaped inlet had the worst results in pressure recovery, loss coefficient, and flow distortion at the engine face.

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Migliorini et al. [10] represents an important step in characterizing the time-dependent disturbance under various inlet conditions, unlike previous studies. The research evaluated the effect of the thickness and orientation of the inlet vortices and the inlet total pressure profiles at different strengths and locations. As a result, it is suggested to evaluate the flow disturbance characteristics of S-ducts not only under uniform inlet conditions but also under different inlet conditions.

Xiao et al. [11] applied the lagged k-ω model to investigate the flow characteristics of the diffuser in a transonic flow. The study shows that the k-ω turbulence model with the addition of a lag model performs better in regions where flow separation occurs. The objectives of the study are to model turbulent flows with strong shock wave-boundary layer interactions more accurately and to demonstrate that a significant improvement is achieved when the lag model is used.

Zhang et al. [12] conducted a design study using the Shear Stress Transport (SST) k-ω turbulence model for analysis. In the paper, a modified SST turbulence model is proposed and validated. The study demonstrates the advantages of using a modified turbulence model and automatic optimization system to improve the S-duct design process. In addition, while aerodynamic performance is increased at low velocity, high velocity performance is decreased.

McLelland et al. [13] carried out a detailed experimental study to determine the effect of the intake flow profile on the intake flow disturbance at the outlet of the S-duct inlet. The thickness of the boundary layer and appropriate levels of asymmetry should be considered to ensure that the temporal and spatial characteristics of the inlet flow are accurately represented.

Aslan [15] investigated the pressure losses and distortions along the aerodynamic interface plane and obtained experimental results for three different mass flows in the thesis study. As the pressure loss increased with mass flow rate, it was concluded that lip separation had a detrimental effect on aerodynamic interface distortion. Additionally, different turbulence models were used in simulation results and compared with each other. The Reynolds Stress Model yielded the best results. It was concluded that simulation results supported the experimental data.

Nguyen [16] also concluded that flow separation and vortex formation occur inside the S-duct. Pressure loss increased with increasing Mach number, leading to pressure distortions at the engine inlet. The effects of vortices and secondary flows on flow distortion were investigated.

Chiang et al. [17] make the aerodynamic shape optimization of a boundary-layer-ingesting S-duct inlet for subsonic UAVs with embedded engines. By reshaping the duct walls, distortion was reduced and pressure recovery was increased.

To achieve better aerodynamic performance in S-ducts, this study investigated the effects of different jet intensities on flow separation. Additionally, the mechanism of pulsating jets in controlling separation was analyzed through flow separation characteristics within the S-duct. It has been observed that radial and axial pressure gradients in S-ducts play a critical role in the formation of secondary flows, and the pulse jet is an effective control method in weakening the flow separation. It has also been concluded that the pulse jet significantly reduces the vortex core loss and, accordingly, increases the dispersion effect in the flow [18].

Wang et al. [19] investigated the effects of co-rotating vortex generators on the flow field in a curved duct transitioning from elliptical to circular cross-section. Vortex generators placed on the lower surface of the first bend slightly reduced separation length and interacted more with the upper surface of the second bend, thereby modifying the internal pressure field and improving flow uniformity. Vortex generators placed only on the upper surface of the second bend did not significantly change flow uniformity. Installing vortex generators on both the lower surface of the first bend and the upper surface of the second bend improved overall flow uniformity, except

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at the upper region of the engine interface plane. Numerical simulations were performed to investigate the impact of vortex generator placement. The study considered a baseline configuration without vortex generators and four different layout scenarios. Placing vortex generators only on the second bend resulted in lower flow uniformity with a DC60 value of 24.12. Placing them only on the first bend yielded better flow uniformity with a DC60 value of 20.7. Installing vortex generators on both bends provided the best flow uniformity with a DC60 of 18.7. However, the configuration with vortex generators on both bends significantly increased the total pressure loss. Considering the trade-off between DC60 and total pressure recovery, placing vortex generators only on the first bend is more advantageous, as it provides a slightly better pressure recovery with a DC60 of 20.7 compared to the both-bends configuration.

Tanguy et al. [20] used two different S-duct configurations and experimentally measured the total pressure losses and distortion levels. Inlets with higher curvature angles exhibited more severe total pressure distortions.

Bae et al. [21] validated the Efficient Global Method with various test functions. When applied to S-duct shape design with two different design variables, a global minimum was searched across the design space after three samplings. The results showed that this method is effective in identifying globally optimal solutions for complex 3D internal flow design problems.

Tanguy et al. [22] presented the effects of flow controllers (especially vortex generators) on the time-dependent flow field at the inlet and outlet of S-ducts. It was found that total pressure loss was associated with two counter-rotating vortices, and adding a flow controller significantly reduced the DC60 parameter with reductions up to 50% observed in some configurations. Pressure recovery increased in all cases. Moreover, increasing the angular placement of circumferential flow controllers stabilized the flow.

D’ambros et al. [23] investigated a numerical method to reduce flow distortions and pressure losses inside an S-duct. Vortices and pressure losses were identified as the main causes, and the aim was to reduce them. The optimization yielded approximately a 14% reduction in pressure loss and about a 71% reduction in vortex strength. A rectangular cross-section yielded the best result in terms of pressure loss, while a triangular section was optimal for vortex reduction.

Furlan et al. [24] optimized the upper and lower surface curvatures of a rectangular S-duct to minimize pressure loss and outlet distortion after selecting the appropriate turbulence model and mesh configuration. Fixed duct length and offset constraints were used in the optimization. The findings demonstrated that the method could be used for air intake design of engines with distributed propulsion systems.

Bhat et al. [25] compared different turbulence models available in Fluent 13.0. The performance of offset and expanding ducts was evaluated, and the behavior of turbulence models in flow control situations using the Zero Net Mass Flux technique was examined. It was observed that the SST k-ω turbulence model yielded the best results.

Lee et al. [26] performed CFD analysis of RAE M 2129 S-duct and investigated the effect of inlet geometry aspect ratio. The SST k-ω turbulence model was used, and the performance of the S-duct was evaluated using the distortion coefficient. The computational results were compared with experimental data. It was found that the semi-circular cross-section yielded the best results in all tested scenarios.

Zeng et al. [27] developed a fast and multi-objective optimization method for S-duct designs with bucket-type inlets and outlets. The SST k-ω turbulence model was used, and a simplified and efficient method was developed to reduce computational costs in the optimization system. Compared to the original inlet, the optimized inlet achieved an increase in pressure recovery from 97% to 97.4%, and the DC60 parameter decreased by 21.7% at the design Mach number. The optimization objectives in this study were DC60 and total pressure recovery.

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Rider et al. [28] selected an S-duct operating at Mach 0.8. The SST k-ω turbulence model was used and proved more successful in predicting separation points compared to previous attempts. The tubercle geometry in the flow control duct was successful in reducing or eliminating separation in the representative S-duct under transonic flow conditions.

The aim of this study is to investigate the aerodynamic performance of S-duct geometries and to evaluate critical performance parameters such as pressure recovery and flow distortion. In this context, a baseline S-duct design was developed and CFD simulations were conducted to analyze the flow behavior in detail. The results obtained provide valuable insights for designing more efficient and low-distortion inlet systems. In this context, this study includes the flow analyses of the S-duct, which is primarily used in combat aircrafts and also designed for UAVs. It examines two different geometric shapes under varying flight conditions, differing from previous studies and existing S-duct designs. The analyses are conducted based on the flight conditions in which UAVs can operate. Since it is known that values such as static pressure, turbulence and kinetic energy directly affect flight performance, the analysis and calculation of such values are of critical importance for flight performance. Therefore, this study will provide insight into the performance assessment of the S-duct geometry for use in aircrafts.

2. Material and Methods

The methodology for aerodynamic evaluation of the S-duct can be divided into five main components including geometry parameterization, mesh deformation, flow solver, gradient computation, and the Mach number. The Mach number is the parameter that needs to be determined to start the design and calculate the inlet area, which was taken as 0.3 M for the analysis. The Mach number considered in this study is a value at which UAVs can fly. With this consideration, the required velocity calculation was performed for 6000 meters, where the analysis was conducted, and it was found to be 94.93 m/s. Subsequently, considering previous studies, the mass flow rate was determined to be 0.281 kg/s using the interpolation method. As a result of these calculations, the inlet cross-sectional area was determined to be 4490 mm2 using the continuity equation and the necessary parameters for the design were obtained. CFD parameters are given in Table 1.

Table 1. CFD parameters

Parameter	Value
Velocity (m/s)	94.93
Altitude (m)	6000
Density (kg/m^3)	0.66011
Mass flow rate (kg/s)	0.281
Area (m^2)	0.004490
Turbulence model	SST k-ω

In the design procedure, S-ducts with rectangular and circular cross sectional areas were modelled using SOLIDWORKS. All designs created for CFD analysis were then transferred to the ANSYS Fluent. To ensure a valid performance analysis for all geometries, the inlet and outlet sectional areas were kept the same. The turbulence model was chosen as the SST k-ω turbulence model based on literature. The model can make more accurate separation predictions compared to standard models [12].

Since a narrowing structure in the throat section of the duct, relative to the capture area (Ac), increases the flow rate and reduces static pressure, it is an important design consideration. The contraction ratio (CR = At/Ac), which defines the relationship between the throat area (At) and the capture area (Ac), was set to 0.75 based on previous studies. The design was carried out accordingly [8].

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Figure 1 and Figure 2 show the rectangular and circular S-duct designs where the inlet and outlet areas are kept the same and the duct has a narrowing structure. The bends in the duct have a radius of 80 mm, and the dimension that the flow will follow until it turns and exits the turn is 300 mm. The rectangular S-duct has a width of 89.5 mm and a length of 50.167 mm. The width and length of the S-duct are very important. These dimensions directly affect the character of the air flow passing through it. Width and length play a decisive role in factors such as pressure losses, flow separation, turbulence formation and smoothness of flow at the engine inlet. An improperly designed duct can lead to loss of efficiency, reduced engine performance and even aerodynamic imbalances. Therefore, both width and length should be optimized for aerodynamic performance.

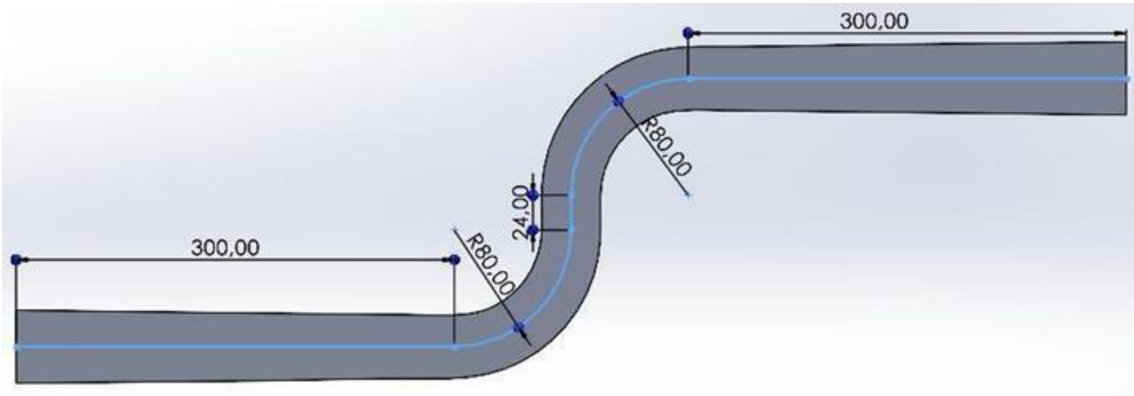

Figure 1. Rectangular S-duct design

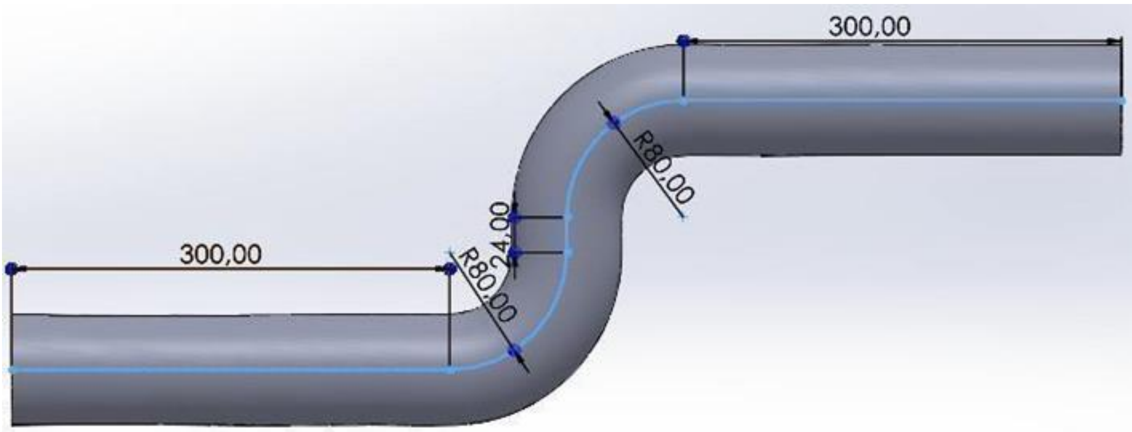

Figure 2. Circular S-duct design

Figures 3, 4, 5, 6, 7 and 8 show the mesh network applied to the considered S-duct geometries. After the design was completed, the analyses were performed. For circular and rectangular sections, the mesh size was 5 mm, edge sizing was given to the inlet and outlet parts of the geometries, and then the mesh network was created using the inflation command.

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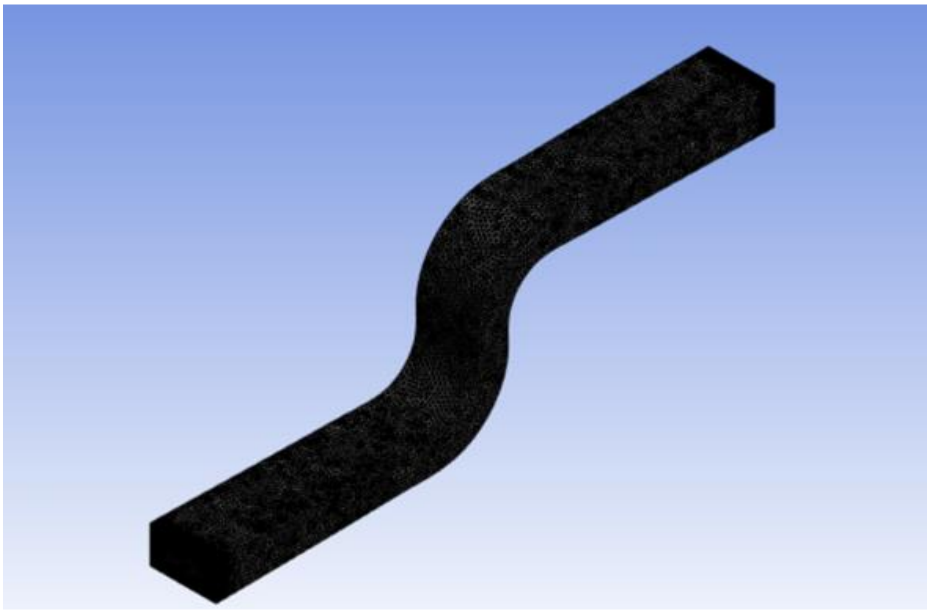

Figure 3. Rectangular S-duct meshing

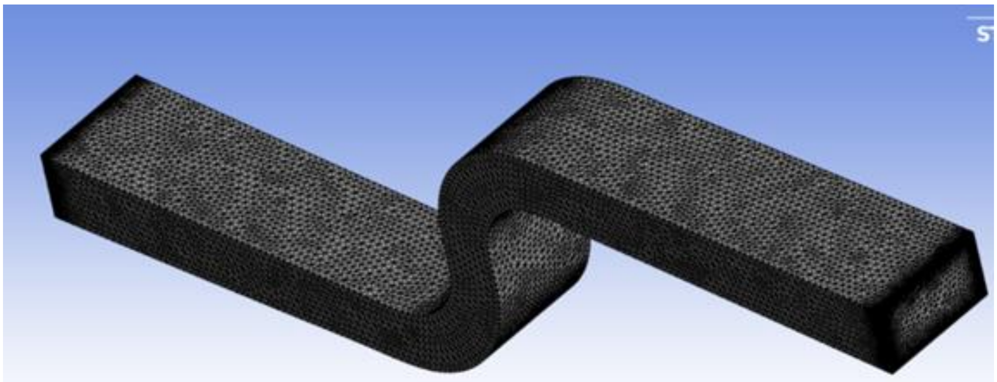

Figure 4. Rectangular S-duct meshing

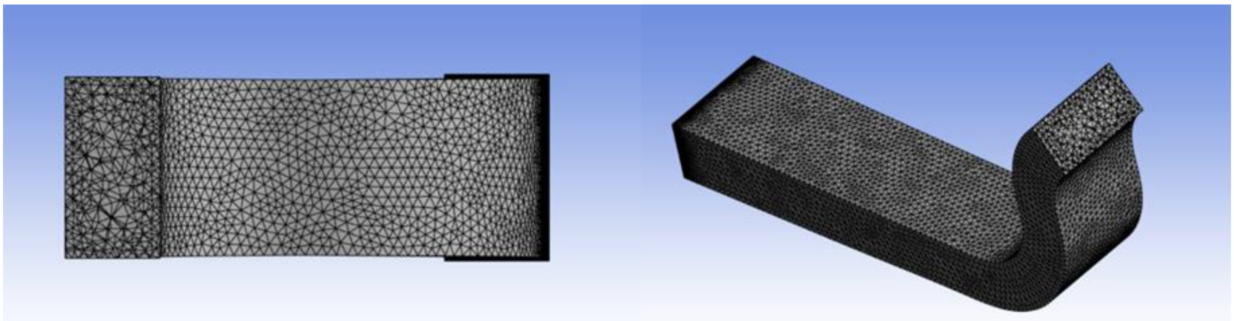

Figure 5. Rectangular S-duct meshing section views

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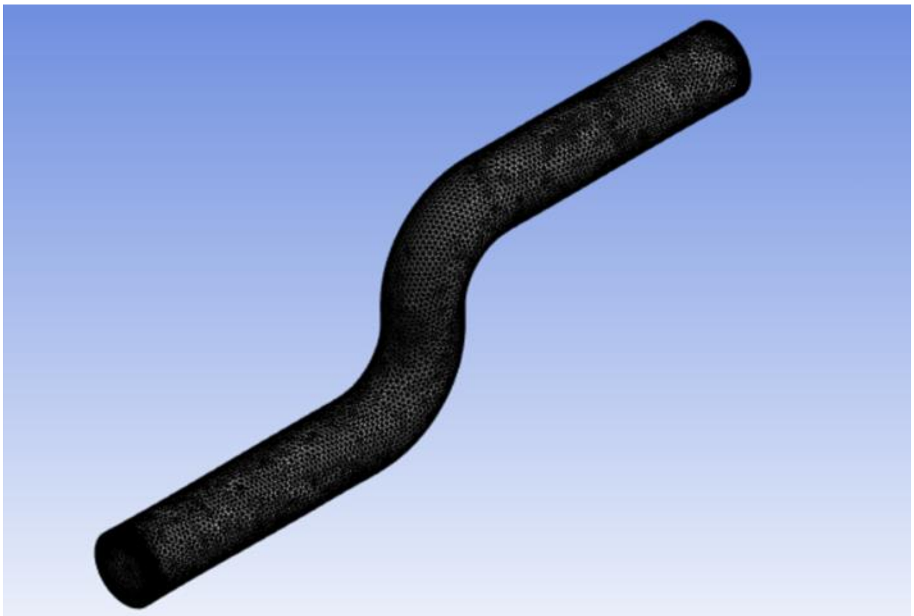

Figure 6. Circular S-duct meshing

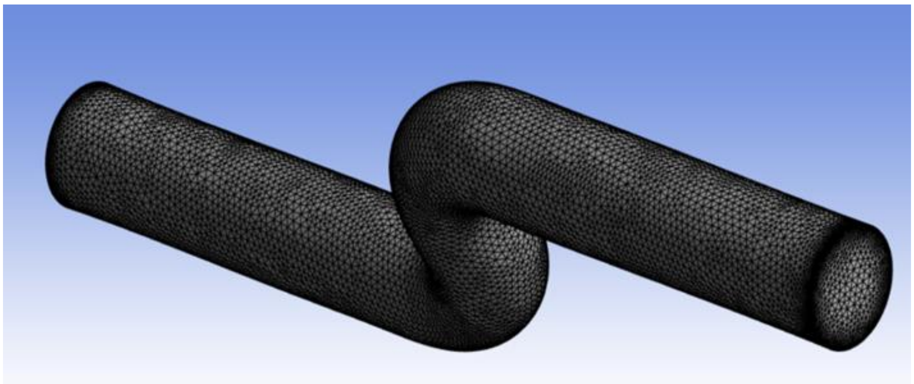

Figure 7. Circular S-duct meshing

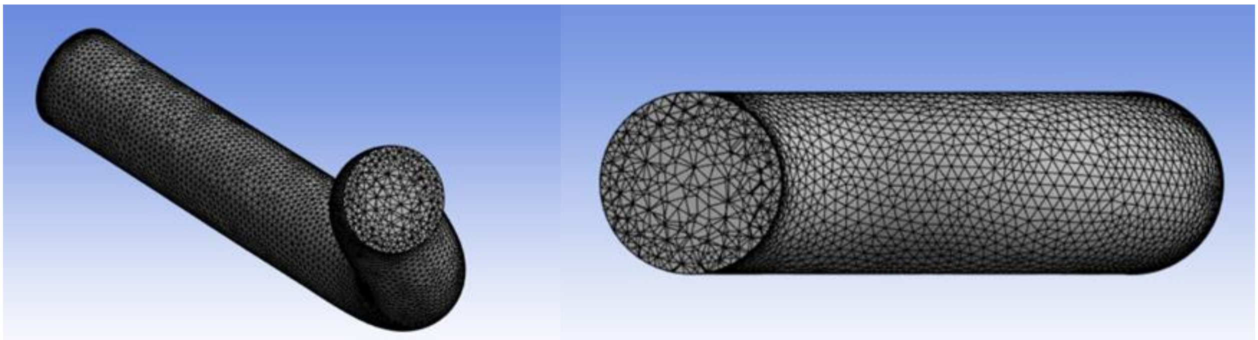

Figure 8. Circular S-duct meshing section views

The critical parameters obtained for the rectangular and circular S-ducts as a result of the mesh convergence examination are presented in Table 2 and 3, respectively.

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Table 2. Mesh convergence for rectangular S-duct

Mesh size (mm)	Distortion Coefficient (DC60)	Pressure Recovery (PR)
7	0.06946	0.6931
6	0.06893	0.6983
5	0.06875	0.6986

Table 3. Mesh convergence for circular S-duct

Mesh size (mm)	Distortion Coefficient (DC60)	Pressure Recovery (PR)
7	0.06299	0.7559
6	0.06297	0.7565
5	0.06286	0.7589

The number of elements, skewness ratio and orthogonal quality for each geometry are provided in Table 4. Mesh quality is assessed by orthogonal quality and skewness values. When the results obtained above are compared with the mesh metric visual provided in Figure 9, which shows that the mesh quality is within the appropriate intervals.

Table 4. Mesh metrics

Duct Geometry/Mesh Parameter	Rectangular Duct	Circular Duct
Number of Elements	261367	197413
	Max: 0.79823	Max: 0.7954
Skewness	Min: 8.8669e-005	Min: 5.9588e-004
	Average: 0.22668	Average: 0.22583
	Max: 0.99685	Max: 0.2046
Orthogonal Quality	Min: 0.20177	Min: 0.11662
	Average: 0.77204	Average: 0.77287

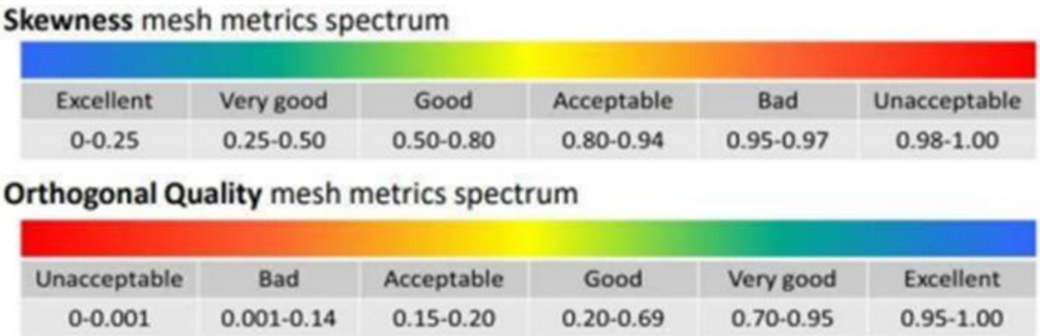

Figure 9. Mesh metrics spectrum [14]

3. Results

In this section, static pressure, velocity and turbulence kinetic energy contours are given for circular and rectangular ducts, respectively, and are interpreted separately.

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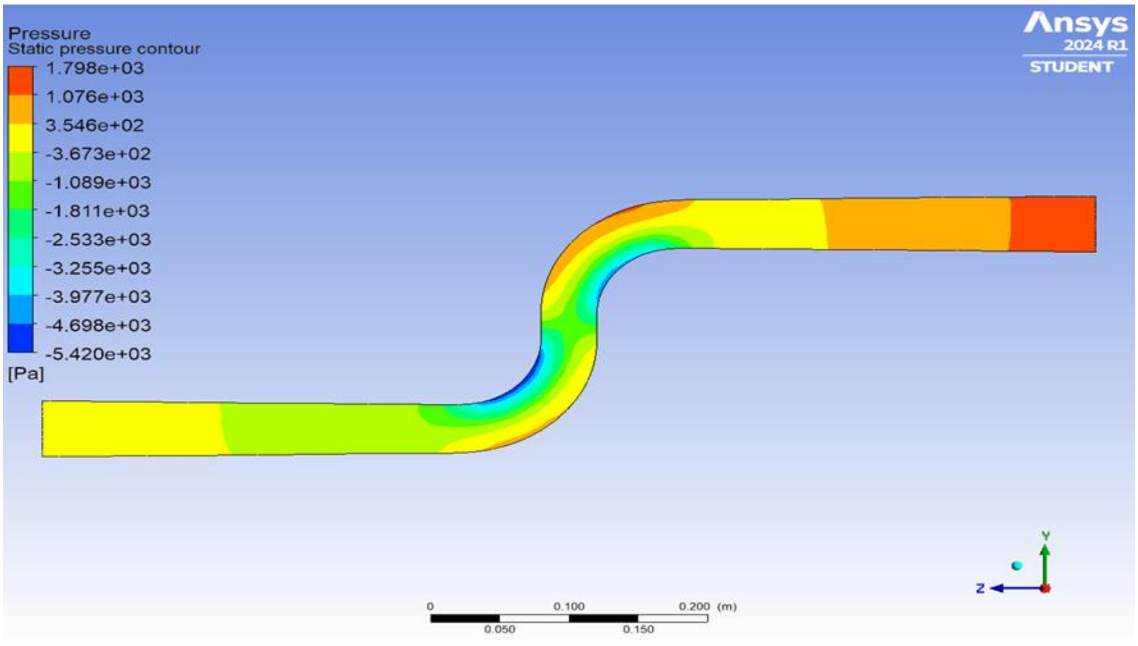

Figure 10. Rectangular S-duct static pressure contour

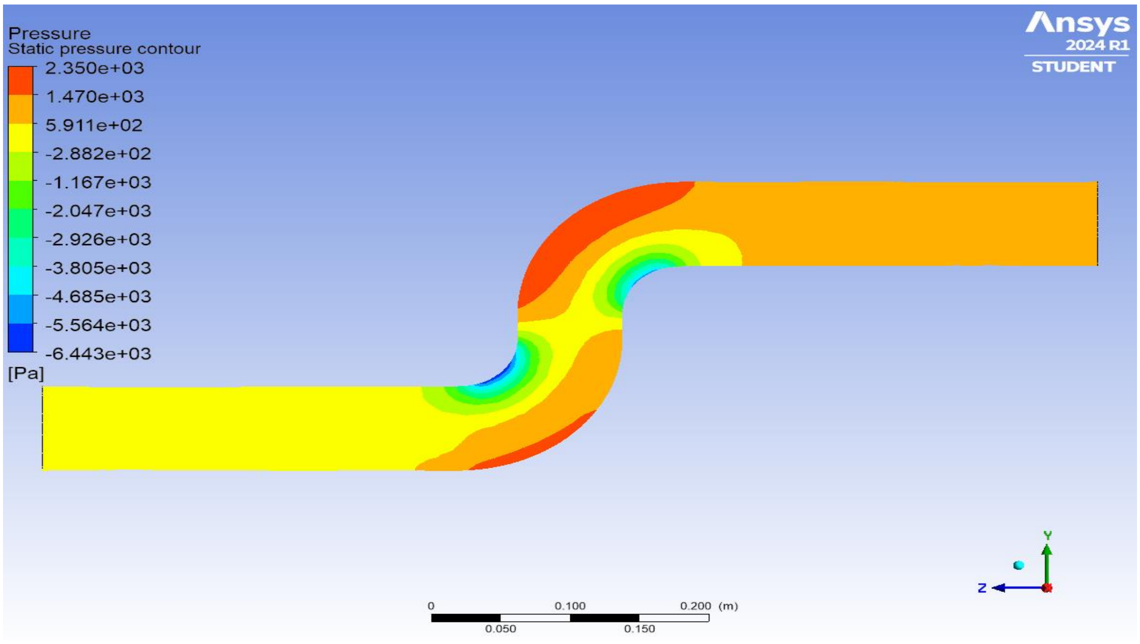

Figure 11. Circular S-duct static pressure contour

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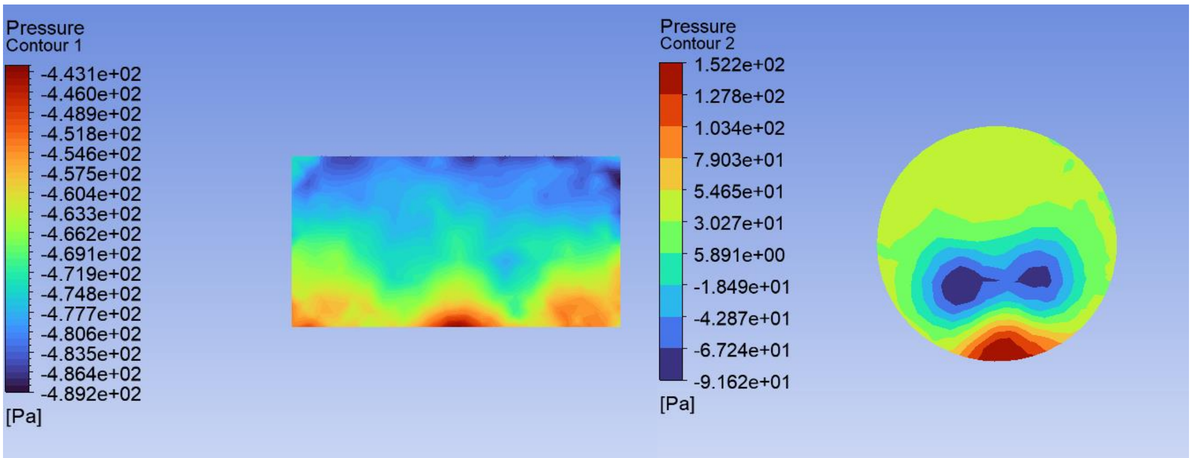

Figure 12. The pressure distribution for both S-ducts at a distance of 160 millimeters downstream of the duct exit

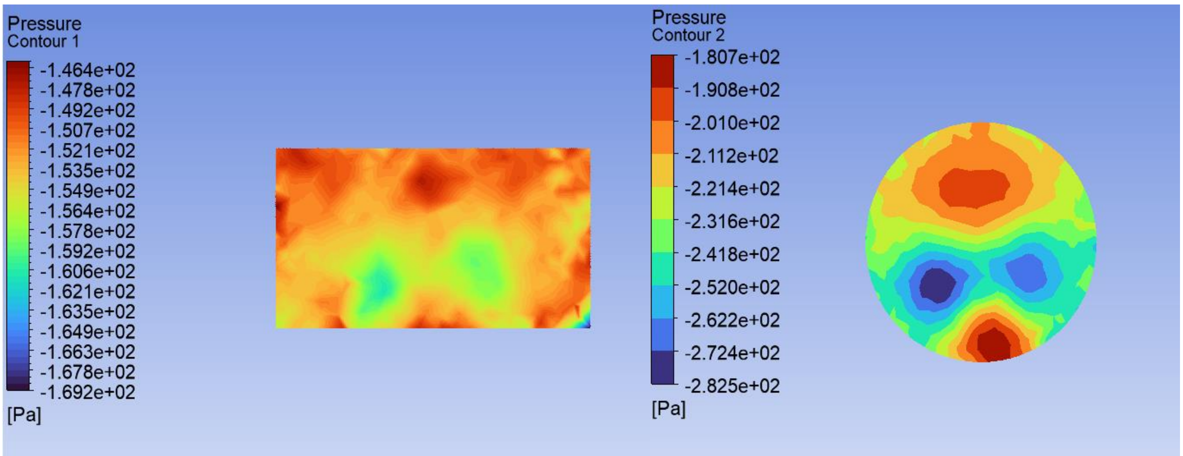

Figure 13. The pressure distribution for both S-ducts at a distance of 60 millimeters downstream of the duct exit

Energy consumption and stress on the system increase with high static pressure. Increased stress can damage the duct and the structures connected to the duct. At the same time, it is possible to say that the irregularities and turbulence in the flow increase at high stress values according to the distribution on the duct geometry. These irregularities and turbulence in the flow create a negative effect aerodynamically during the flight time. It is shown in Figure 10 and 11 that the maximum static pressure on the circular S-duct was found to be 2.350e+03 Pa, while the maximum static pressure on the rectangular S-duct was 1.798e+03 Pa. The pressure distributions for both S-ducts at distances of 60 millimeters and 160 millimeters downstream of the duct exit are shown in Figure 12 and 13. As a result of this analysis, the static pressure distribution of the rectangular duct is more efficient than the circular duct and the maximum static pressure value is much lower which is preferable.

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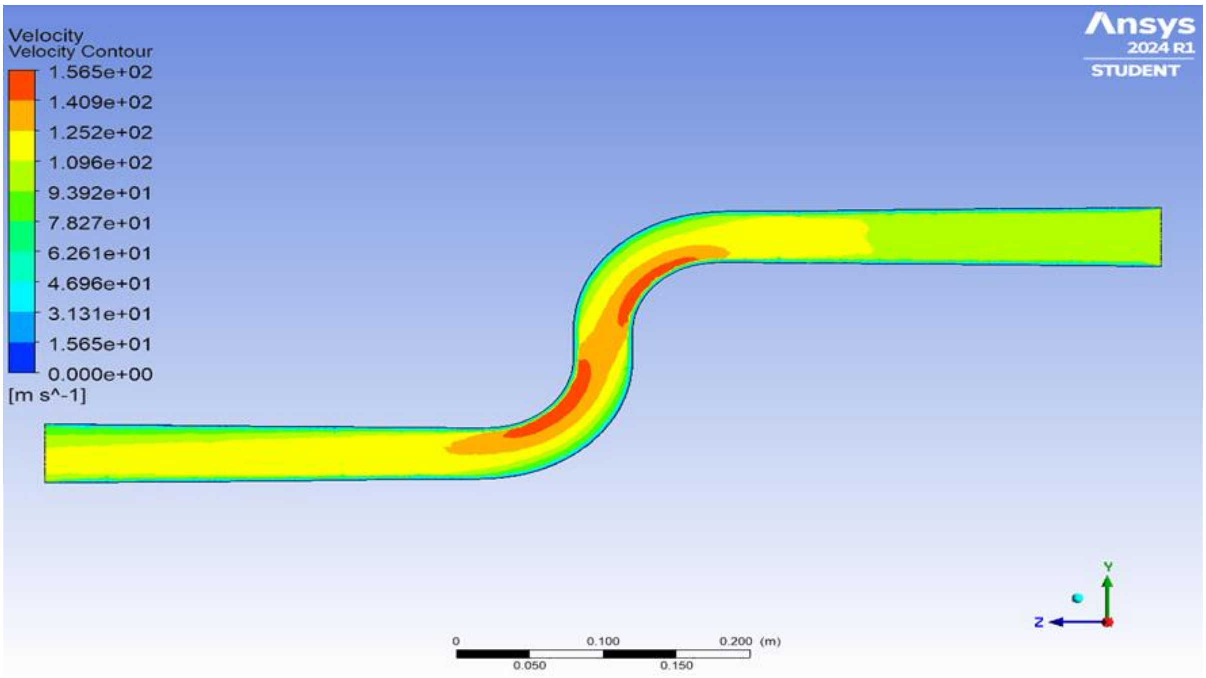

Figure 14. Rectangular S-duct velocity contour

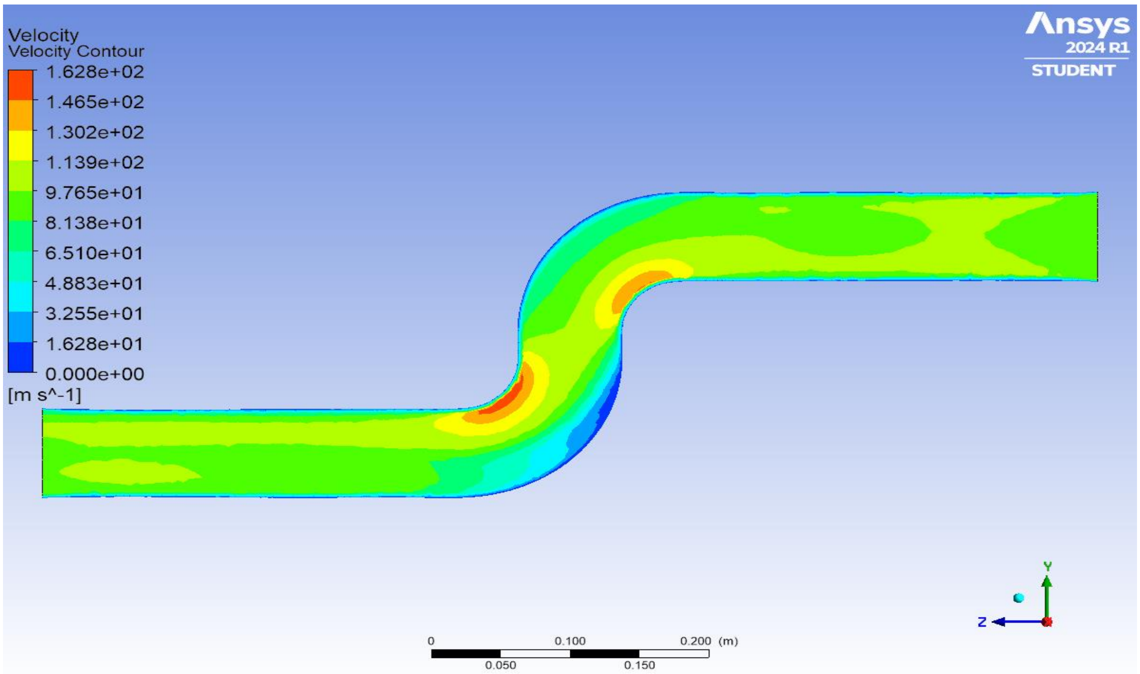

Figure 15. Circular S-duct velocity contour

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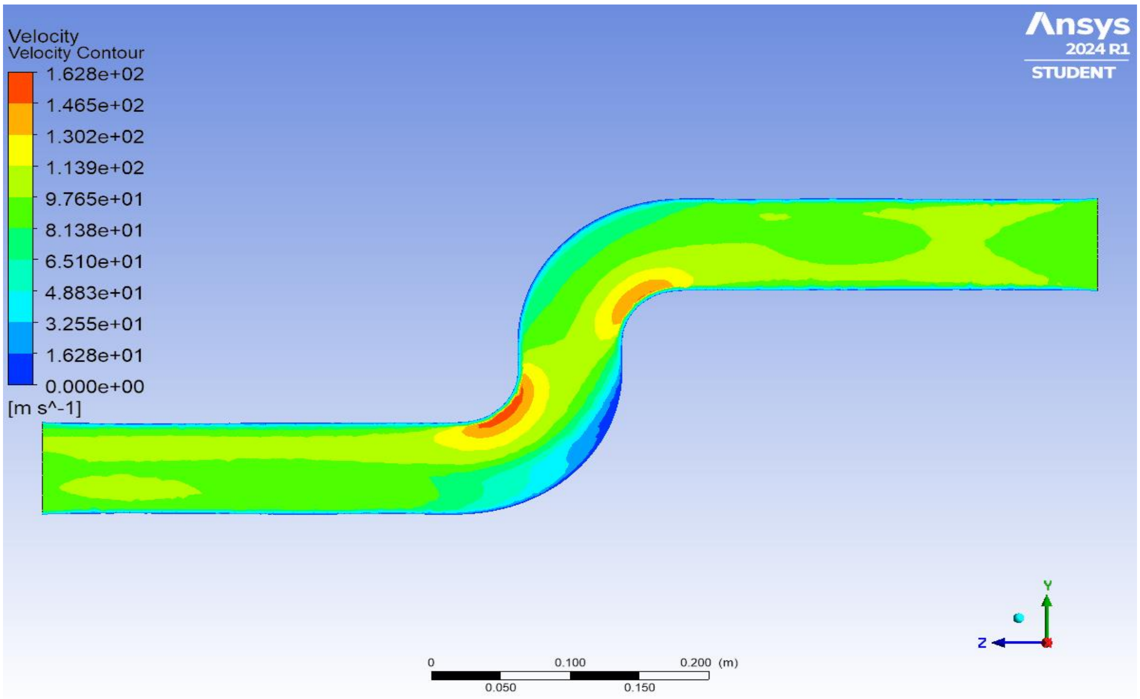

Figure 15. Circular S-duct velocity contour

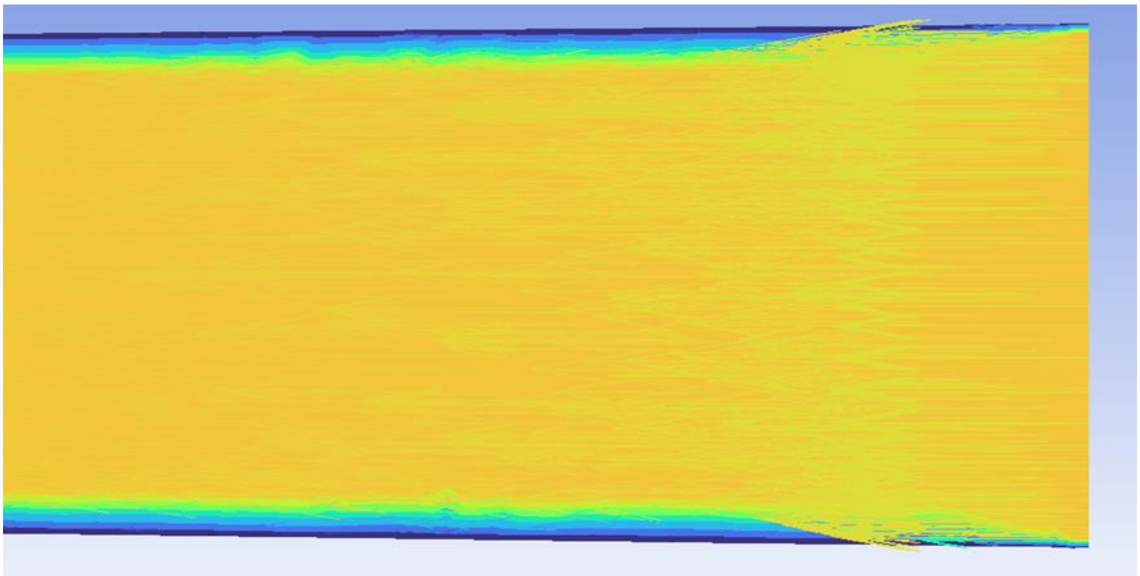

Figure 16. Detailed velocity contour and vector inlet view of the rectangular S-duct

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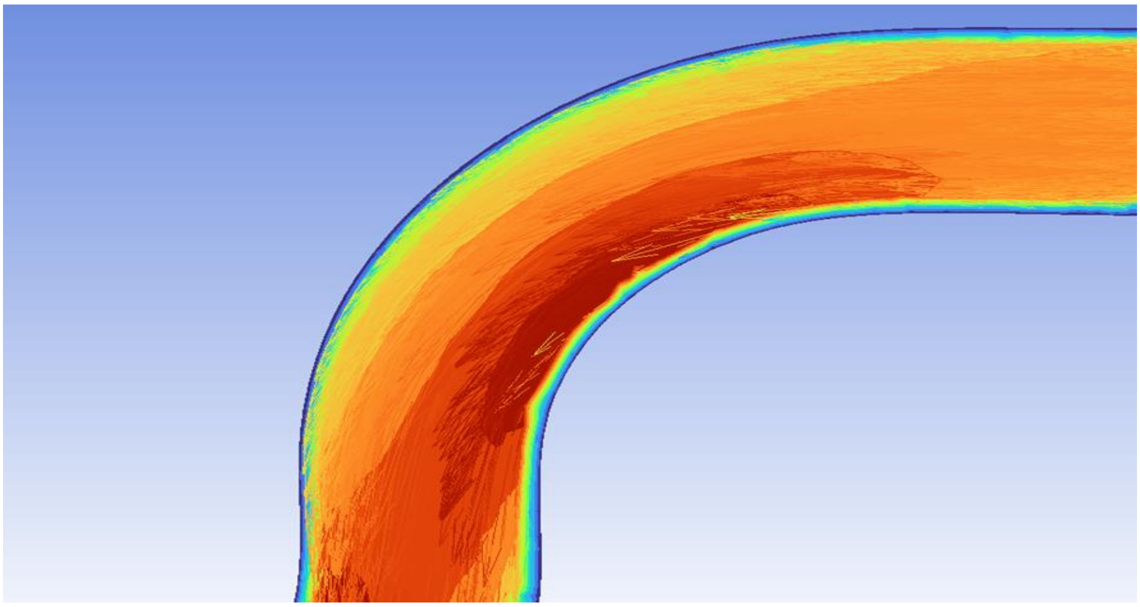

Figure 17. Detailed velocity contour and vector first curve view of the rectangular S-duct

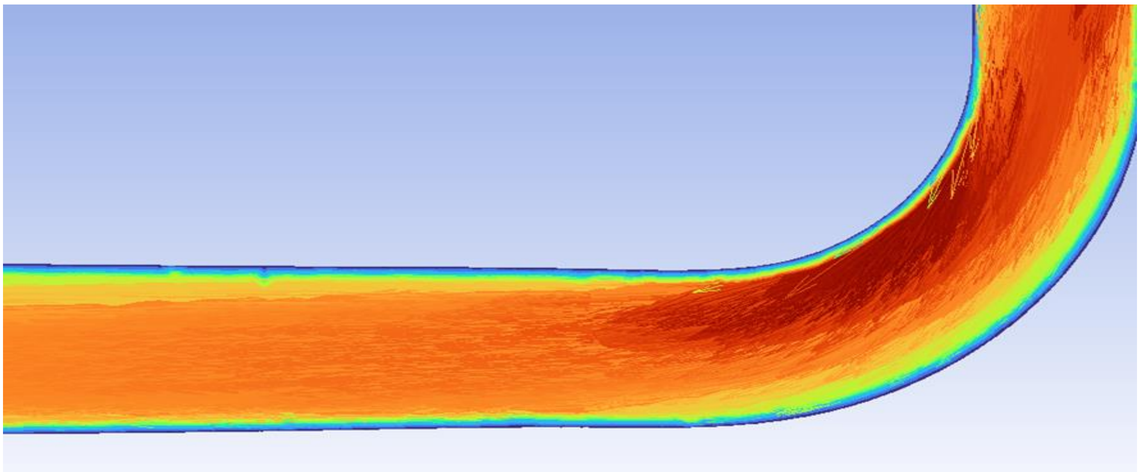

Figure 18. Detailed velocity contour and vector second curve view of the rectangular S-duct

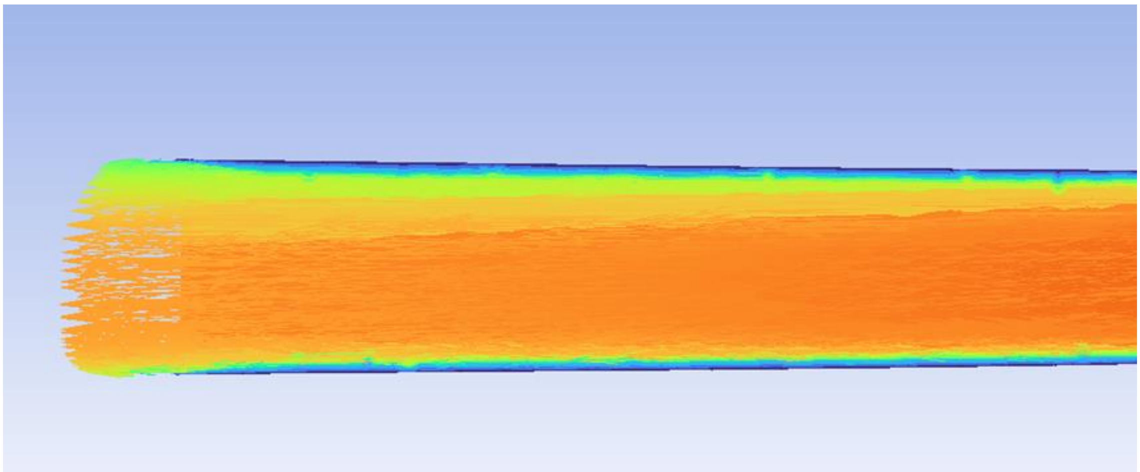

Figure 19. Detailed velocity contour and vector outlet view of the rectangular S-duct

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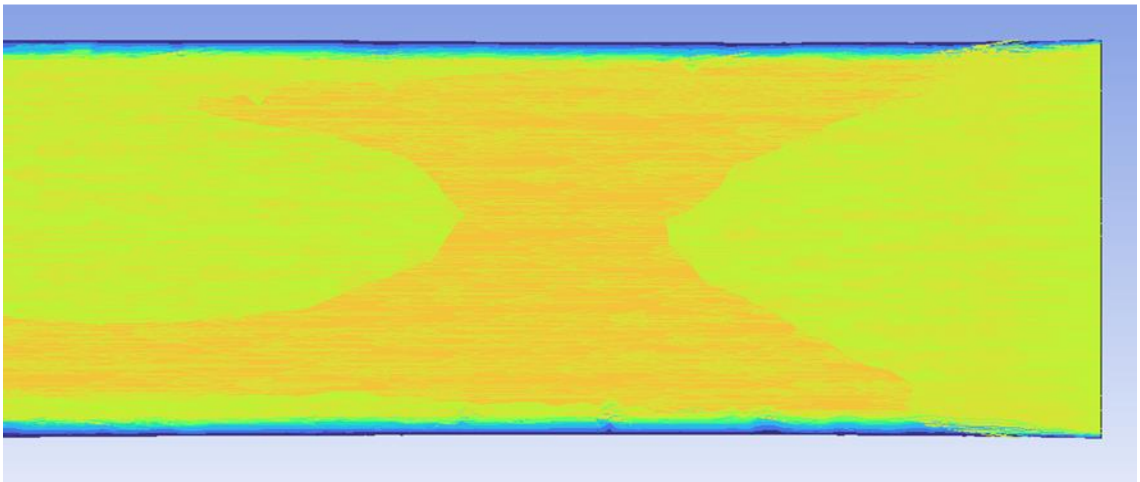

Figure 20. Detailed velocity contour and vector inlet view of the circular S-duct

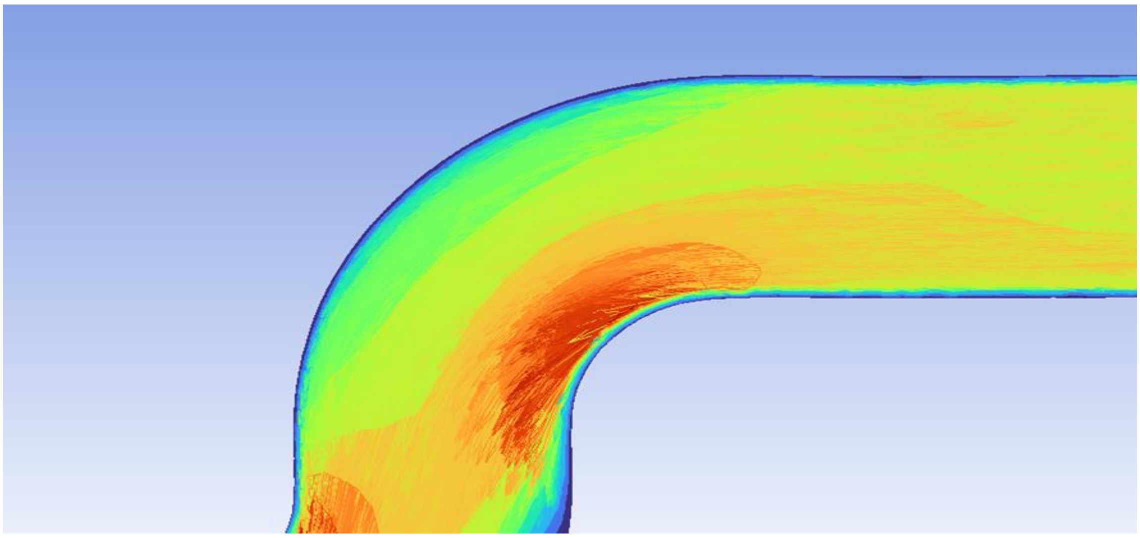

Figure 21. Detailed velocity contour and vector first curve view of the circular S-duct

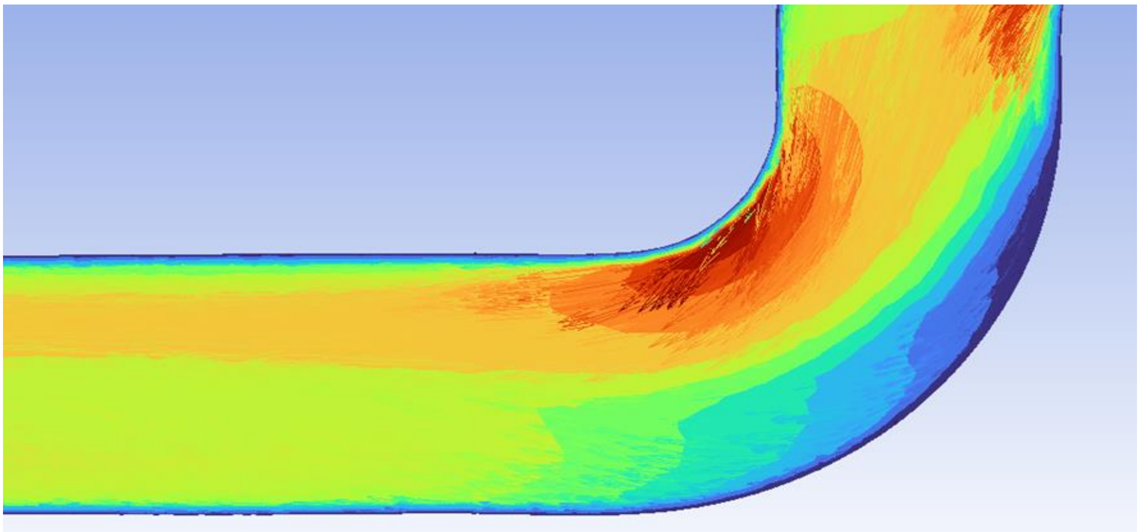

Figure 22. Detailed velocity contour and vector second curve view of the circular S-duct

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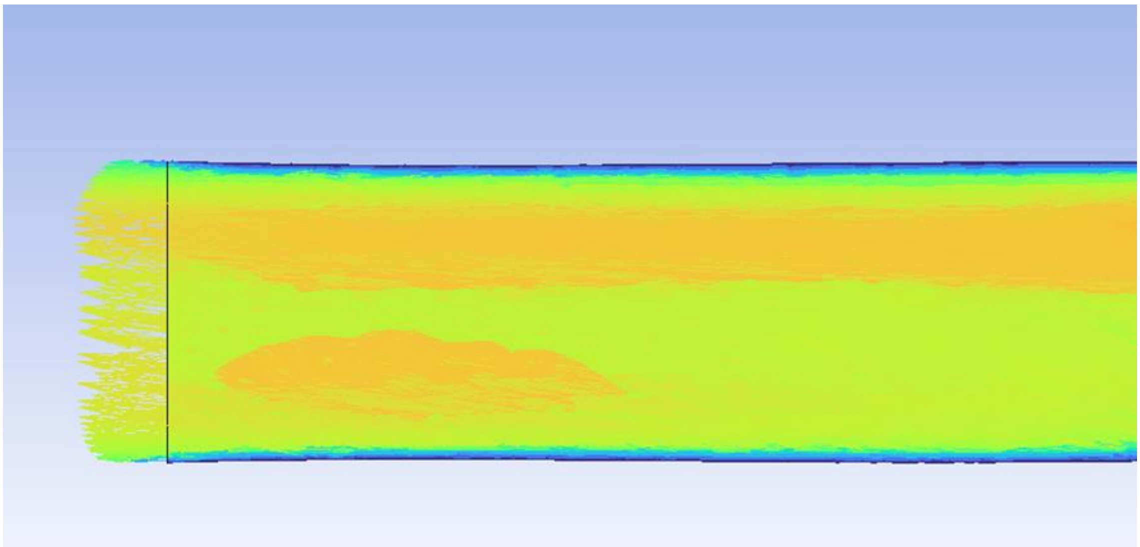

Figure 23. Detailed velocity contour and vector outlet view of the circular S-duct

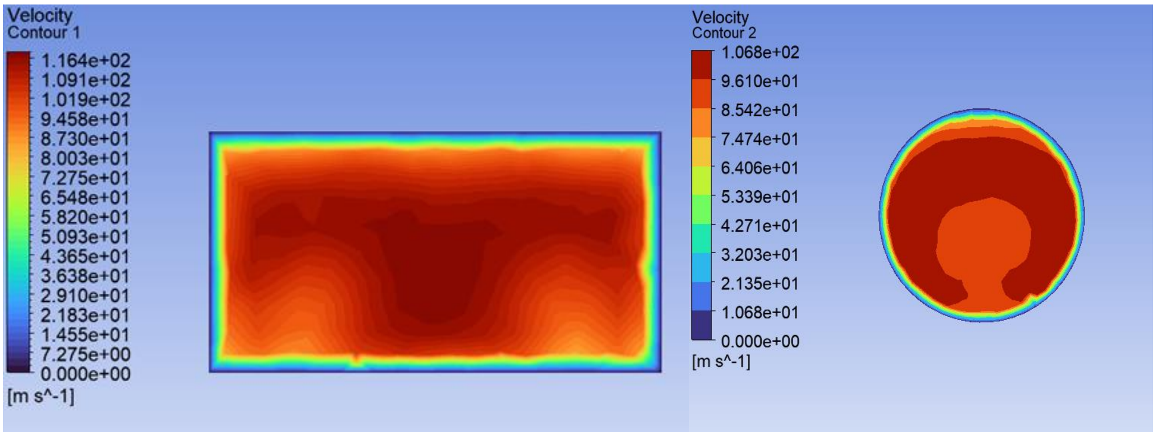

Figure 24. The velocity distribution for both S-ducts at a distance of 160 millimeters downstream of the duct exit

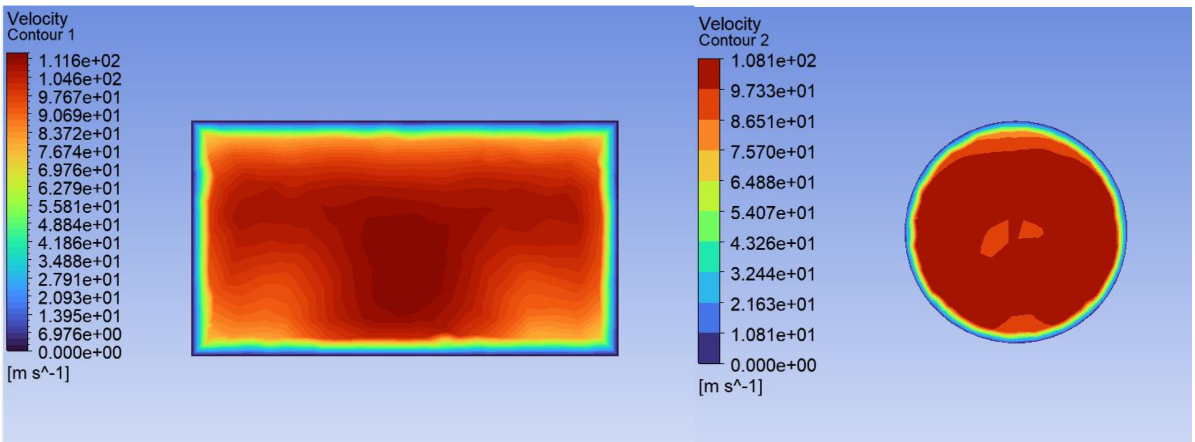

Figure 25. The velocity distribution for both S-ducts at a distance of 60 millimeters downstream of the duct exit

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Figure 14 and 15 show that the maximum airflow velocity inside the circular S-duct was 1.628e+02 m/s, while the maximum velocity value was obtained as 1.565e+02 m/s inside the rectangular S-duct. In the rectangular S-duct, the wall effect is high and the boundary layer thickness increases at the corners, which creates additional friction in the flow. This explains why the velocity in the rectangular S-duct is lower than that in the circular S-duct.

Comparing the corresponding pressure contours in Figure 10 and 11, and airflow velocity contours in Figure 14 and 15 reveal that pressure decreases in areas where velocity increases and velocity increases in areas where pressure decreases.

The detailed velocity contour and velocity vectors are shown in Figure 16 to 23. Also, velocity distributions for both S-ducts at a distance of 60 millimeters and 160 millimeters downstream of the duct exit are shown in Figure 24 and Figure 25. For both S-ducts, there was an increase in velocity in the concave regions. For circular S-ducts, in Figure 24 and Figure 25 the flow appears mostly homogeneous; although there are slightly lower velocities at the center, overall circular symmetry is maintained. The two small low-velocity regions at the center may indicate the presence of secondary flow effects. A distinct low-velocity region has formed at the center, which may indicate that the flow has shifted outward from the center. Such a profile is typically associated with flow separation and the intensification of secondary flows. S-ducts that have two non-planar bends may increase pressure gradients. Especially in the concave surfaces, the flow was directed toward the walls due to centrifugal effects. This results in lower velocities at the center and higher velocities near the outer edges. The vortex pairs developing within the duct may cause the flow to be directed toward specific regions. This becomes more pronounced toward the outlet and results in low-velocity regions at the center and high-velocity rings near the edges. The velocity profile observed for the rectangular S-duct is a conventional velocity profile (see Figure 24 and 25).

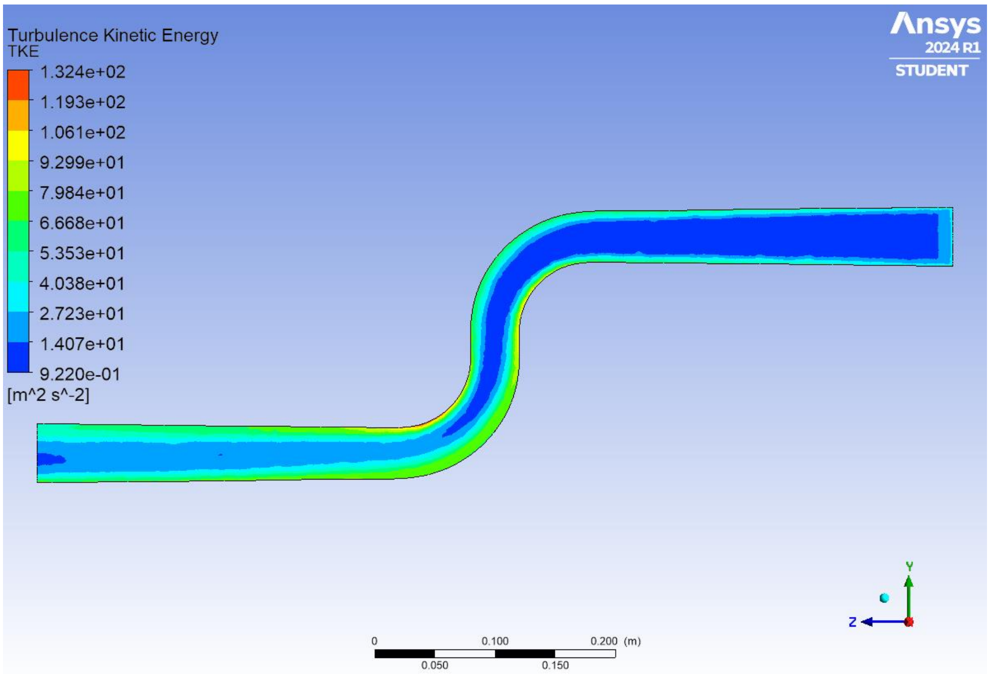

Figure 26. Rectangular S-duct turbulent kinetic energy contour

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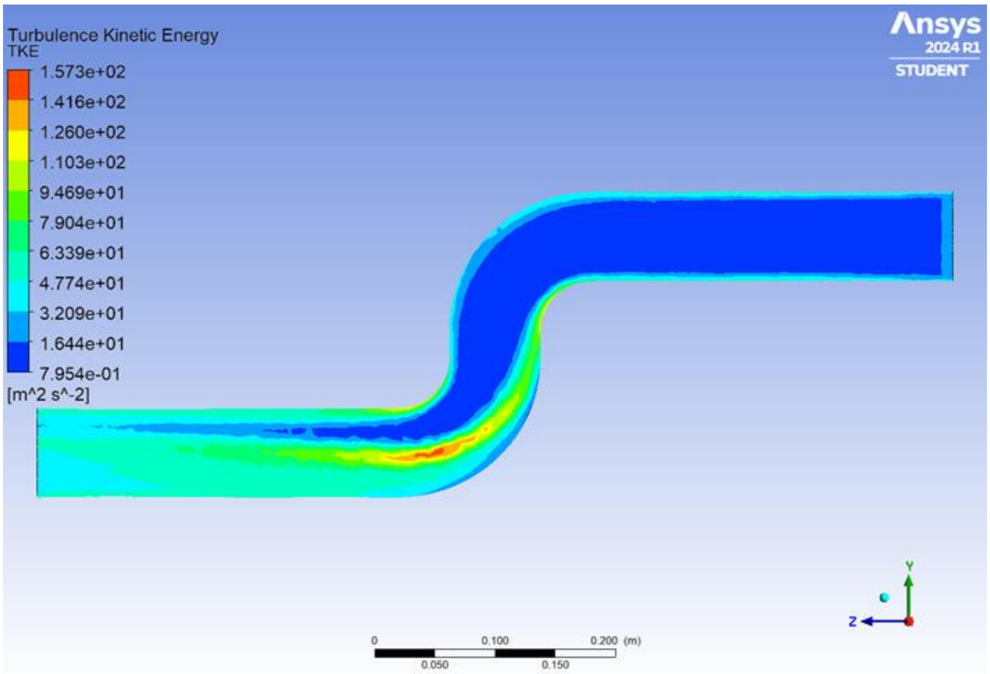

Figure 27. Circular S-duct turbulent kinetic energy contour

Relatively low turbulent kinetic energy reduces the energy loss and drag force in the system. As the drag force in the system decreases, flight becomes more efficient in terms of reduced fuel consumption. However, if relatively high turbulent kinetic energy is carried in turbulent flows, it is likely that the turbulent kinetic energy distribution becomes crucial in the components used for propulsion system applications such as S-duct. Figure 26 and 27 show that the maximum turbulent kinetic energy value in the circular S-duct was around 1.573e+02 m2/s2, while the maximum turbulent kinetic energy value in the rectangular S-duct was attained as 1.324e+02 m2/s2. This analysis proved that the turbulent kinetic energy distribution of the rectangular duct seems to be more efficient than the circular duct.

Table 5 briefly summarizes the overall CFD results. It can be stated that the maximum static pressure of the rectangular S-duct is lower and better distributed than the circular S-duct. The maximum value of the turbulent kinetic energy is lower in the rectangular S-duct than in the circular S-duct. It was also observed that the distribution of turbulent kinetic energy is uniform for the rectangular S-duct.

Table 5. CFD analysis results

Duct Geometry/Analysis Result	Rectangular Duct	Circular Duct
Static Pressure (Pa)	Max: 1.798e+03	Max: 2.350e+03
	Min: -5.420e+03	Min: -6.443e+03
Velocity (m/s)	Max: 1.585e+02	Max: 1.628e+02
	Min: 0	Min: 0
Turbulent Kinetic Energy (m^2/s^2)	Max: 1.324e+02	Max: 1.573e+02
	Min: 9.220e-01	Min: 7.954e-01

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4. Conclusion

In this study, the aerodynamic performance of circular and rectangular S-ducts is investigated under the specified flight conditions. Two different models were designed in SOLIDWORKS to analyze certain parameters, including static pressure, airflow velocity, and turbulent kinetic energy, using ANSYS Fluent.

As a result of the series of analyses, the concluding remarks can be outlined as follows;

● The rectangular S-duct performs better in terms of static pressure compared to the circular S-duct. A decrease in static pressure reduces energy consumption and system stress, thereby improving overall efficiency.

● On the other hand, increased, non-uniform static pressure and turbulent kinetic energy increase vibration and noise in the system.

● Although the pressure and velocity distribution is more uniform in the rectangular S-duct, the circular S-duct performs better compared to the rectangular S-duct in terms of pressure recovery and distortion coefficient.

● The velocity profile observed in the circular S-duct may be caused by factors such as geometric curvatures, pressure gradients and wall effects, vortex formation, and secondary flows.

Future Research

Within the scope of this study, basic geometries were considered and analyses were performed. In the continuation of the study, different optimized geometries used in practice will also be analyzed. Moreover, the numerical analysis results, in this article, could not be verified due to lack of experimental data. As the authors cannot validate it with experimental data, in order to ensure the reliability of the results, the numerical analysis results will be validated by experimental study results in future studies.

Acknowledgment

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Authorship contribution statement

Mehmet Turan Ekinci, *Conceptualization, Software, Data curation, Writing – original draft.* **Mahmut Sami Büker,** *Conceptualization, Writing – review & editing, Supervision.*

Conflicts of Interest: The author declares no conflict of interest.

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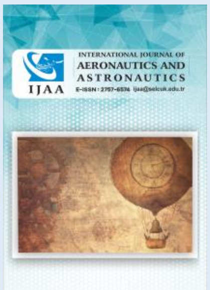

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Research Article / Araştırma Makalesi

Analysis of a UAV propeller produced by various materials / Çeşitli malzemelerle üretilen bir İHA pervanesinin analizi

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Anahtar Kelimeler
CFRP,
Deformasyon,
PLA,
Gerilme Analizi ,
İHA Pervanesi

ABSTRACT

Recently, Unmanned Aerial Vehicle (UAV) systems have started to attract great interest worldwide. With the orientation of the technology sector to this field, studies on UAV systems have gained momentum. Propellers, which are an important part of UAV systems, are of great importance to the propulsion system of the aircraft. Deformations that may occur, especially in propellers that are expected to have high strength, greatly affect flight safety. In this study, a two-bladed propeller model measuring 12 inches was created. The deformations caused by applying force to the created propeller model were examined. In this study, CFRP (Carbon Fiber Reinforced Polymer) and PLA (Polylactide Acid) materials were preferred. The mechanical properties of materials are defined in the ANSYS program. As a result of the force applied to the propeller model, the amounts of deformation occurring in CFRP and PLA materials have been obtained. At the end of the study, the difference between the properties of the two materials was discussed.

ÖZET

Son zamanlarda insansız Hava Aracı (İHA) sistemleri dünya çapında büyük ilgi görmeye başlamıştır. Teknoloji sektörünün bu alana yönelmesiyle İHA sistemleri üzerine çalışmalar hız kazanmıştır. İHA sistemlerinin önemli bir parçası olan pervaneler, uçağın tahrik sistemi için büyük önem taşımaktadır. Özellikle yüksek mukavemete sahip olması beklenen pervanelerde oluşabilecek deformasyonlar uçuş güvenliğini büyük ölçüde etkiler. Bu çalışmada 12 inç ölçülerinde iki kanatlı pervane modeli oluşturulmuştur. Oluşturulan pervane modeline kuvvet uygulanmasıyla oluşan deformasyonlar incelenmiştir. Bu çalışmada CFRP (Karbon Fiber Takviyeli Polimer) ve PLA (Polilaktik Asit) malzemeler tercih edilmiştir. Malzemelerin mekanik özellikleri ANSYS programında tanımlanmıştır. Pervane modeline uygulanan kuvvet sonucunda CFRP ve PLA malzemelerinde meydana gelen deformasyon miktarları belirlenmiştir. Çalışmanın sonunda iki malzemenin özellikleri arasındaki fark tartışılmıştır.

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1. Introduction

Propeller propulsion system in aircraft is of great importance as it affects parameters such as flight range, duration and power consumption [1]. These subsystems, which provide acceleration of aircraft, can be subjected to high stress instantaneously. Due to the shape of the propeller blades, accurate calculation of the stresses is very difficult [2]. Determining where and how much stress under a certain force at the propeller is important for propeller performance. In addition, propellers must be manufactured in such a way that they can withstand these loads to be used safely. Different materials are used to produce high-strength propellers depending on the area of use.

There are many studies in the literature on the strength of different materials. Yeh (2020) printed PLA and Carbon Fiber Composite materials with Fused Deposition Modeling (FDM) method. Standard tests were applied on the models created. As a result of the tests, Carbon Fiber Composite material was found to be six times more durable than PLA [3]. Ramesh et al. (2020) compared the strength of propellers modeled with Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) materials. In addition, material optimization was performed using two advanced numerical methodologies (Fluid-Structure Interaction (FSI) and Moving Reference Frame (MRF)). At the end of the study, it was found that the strength of GFRP material was higher [4]. Jayakumar et al. (2024) designed a drone with a coaxial propeller in their study. The propeller designed in the study was modeled with CFRP, GFRP and titanium materials. Numerical analysis of the modeled propellers was performed and material strengths were compared. As a result of the comparison, titanium material has lower total deformation, normal and equivalent stress. In the light of the data obtained, titanium material was found to have the best performance [5]. Uddin et al. (2021) compared Nickel Aluminum Bronze (NAB) and composite (CFRP and GFRP) materials on a ship propeller. Maximum principal stress, maximum principal strain, equivalent stress, equivalent strain values were calculated with structural analysis. As a result of the study, it was observed that the deformation amount of CFRP material was lower compared to other materials [6]. Siddarth et al. (2023) compared CFRP and GFRP materials. As a result of the study, it was observed that GFRP material deformed more than CFRP material. Considering the strength and thermal properties, it was concluded that CFRP material is more preferable than GFRP [7]. Arivalagan et al. (2023) performed structural analysis on turbine blades produced by 3D printing method. In the study, the structural properties of PLA and ABS (Acrylonitrile Butadiene Styrene) materials were compared. As a result of the study, PLA material was found to have better structural properties compared to ABS [8].

In this study, the stresses on a two-blade UAV propeller made from CFRP and PLA materials were investigated and the material strengths were compared. The new propeller model was designed and the materials were defined as anisotropic materials. By defining the materials as anisotropic, the results are aimed to be close to reality. During this investigation, SolidWorks software was used for propeller design and ANSYS software was preferred for mechanical analysis.

2. Material and Methods

2.1. Materials

Composite materials are lightweight and durable materials obtained by combining different materials and used in various sectors. These materials consist of matrices and fibers in matrices. Matrices are used to maintain geometric order and transfer the load acting on the material to the fibers [9]. Composites have many advantages which are high impact resistance, high thermal resistance and high wear resistance [10]. For these reasons, composite materials are widely used in many industries such as aerospace, automotive, construction and sporting goods. For the CFRP material properties given in Table 1, Ref. [11] was utilized.

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Table 1. Material properties of CFRP

Properties	Values
Density (ρ)(kg/m^3)	1600
Young's Modulus E_X (GPa)	120
Young's Modulus E_Y (GPa)	10
Young's Modulus E_Z (GPa)	10
Poisson's Ratio NU_{XY}	0.16
Poisson's Ratio NU_{YZ}	0.2
Poisson's Ratio NU_{ZX}	0.16
Rigidity Modulus G_{XY} (GPa)	5.2
Rigidity Modulus G_{YZ} (GPa)	3.8
Rigidity Modulus G_{ZX} (GPa)	6

PLA is a thermoplastic polymer derived from biodegradable and renewable resources. It is usually obtained by polymerization of lactic acid produced from plant sources such as corn starch or sugar cane [12]. This way, PLA is considered an environmentally friendly material and is seen as a potential alternative to replace traditional petroleum-derived plastics. PLA has the advantages of light weight, biocompatibility and good mechanical properties [13]. For the PLA material properties given in Table 2, Ref. [14] was utilized.

Table 2. Material properties of PLA

Properties	Values
Density (ρ)(km/m^3)	1.24
Please check Young's Modulus E_X (MPa)	2444
Young's Modulus E_Y (MPa)	2864
Young's Modulus E_Z (MPa)	2864
Poisson's Ratio NU_{XY}	0.35
Poisson's Ratio NU_{YZ}	0.35
Poisson's Ratio NU_{ZX}	0.35
Rigidity Modulus G_{XY} (MPa)	1040
Rigidity Modulus G_{YZ} (MPa)	1040
Rigidity Modulus G_{ZX} (MPa)	1040

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2.2. Methods

2.2.1. Propeller design

In this study, the behavior of a UAV propeller with different materials defined under a certain force is investigated. Within the scope of the study, an original design was used in the propeller model. NACA 2412 was used as the airfoil structure in the propeller. The airfoil structure is given in Figure 1. The propeller is modeled as a 12 inch long UAV propeller in SolidWorks program. The model consists of 5 stations. The airfoil angle at each station is 14, 37, 34, 20 and 5 degrees from root to tip, respectively. The propeller model is given in Figure 2.

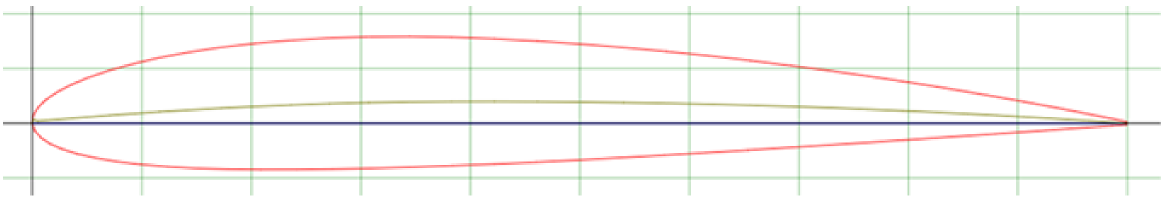

Figure 1. The appearance of the NACA 2412 airfoil used

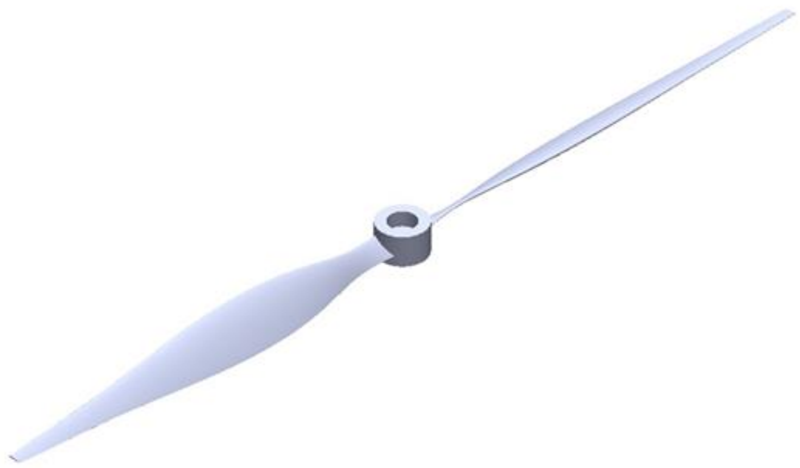

Figure 2. The designed propeller model

2.2.2. Structural analysis

ANSYS software was used for numerical analysis. The mechanical properties of CFRP and PLA materials were defined in the program. A 10 mm mesh was placed on the propeller model. In order to determine the optimum element size, analyses were performed with mesh models of 5 mm, 8 mm, 10 mm, 12 mm, 15 mm and 18 mm using CFRP material. The results obtained are given in Table 3. When the results were examined, it was seen that the values were close to each other and it was decided to use 10 mm mesh size for the analysis. The mesh model is shown in Figure 3.

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Table 3. Analysis results according to mesh sizes

Properties	5 mm	8 mm	10 mm	12 mm	15 mm	18 mm
Total Deformation (mm)	160.54	160.55	**160.33**	160.52	160.49	160.49
Directional Deformation (mm)	83.811	83.763	**83.737**	83.806	83.803	83.803
Equivalent Elastic Strain (mm/mm)	0.040063	0.040068	**0.040076**	0.04005	0.04008	0.04008
Maximum Shear Elastic Strain (mm/mm)	0.043479	0.043484	**0.043498**	0.043502	0.04351	0.04351
Equivalent Stress (MPa)	362.13	362.23	**362.24**	361.91	32.29	362.29
Maximum Shear Stress (MPa)	182.06	182.06	**182.09**	182.03	182.1	182.1

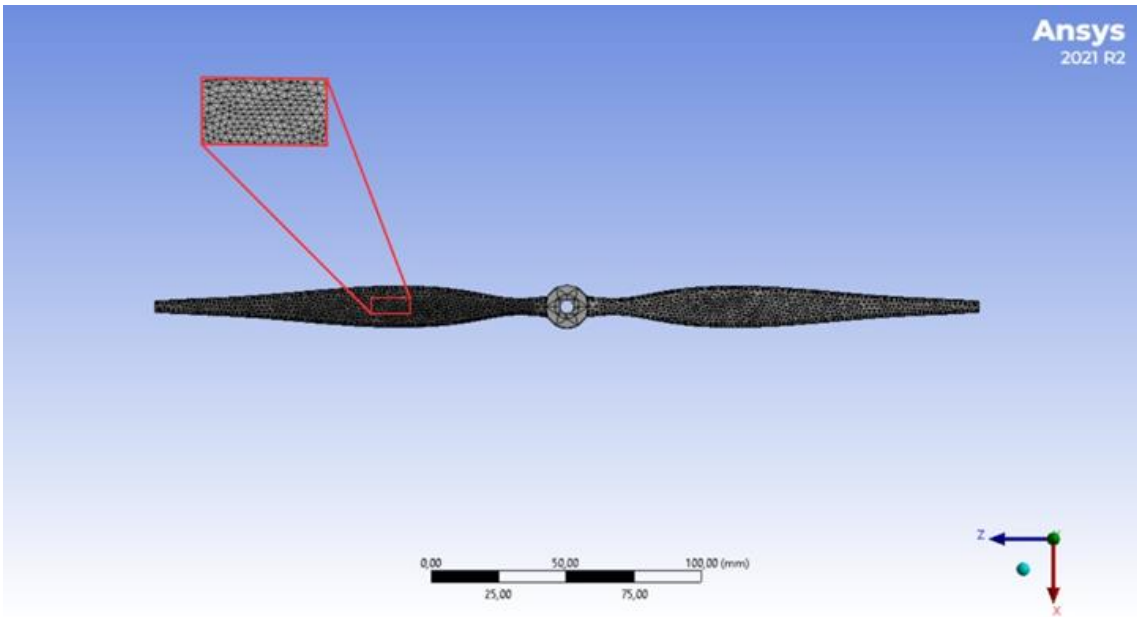

Figure 3. The mesh model on the propeller

On the model, the fixed part is defined as the propeller hub and the parts to be applied force are defined as the propeller blades. After the necessary definitions were made, force was applied on the blades. The forces are applied to the midpoints of the propeller blades. The fixed part on the propeller and the applied forces are shown in Figure 4 and Figure 5. The amount of force to be applied to the propeller blades was defined as appropriate for an airplane requiring 0.3 kgf (2.941995 N) thrust.

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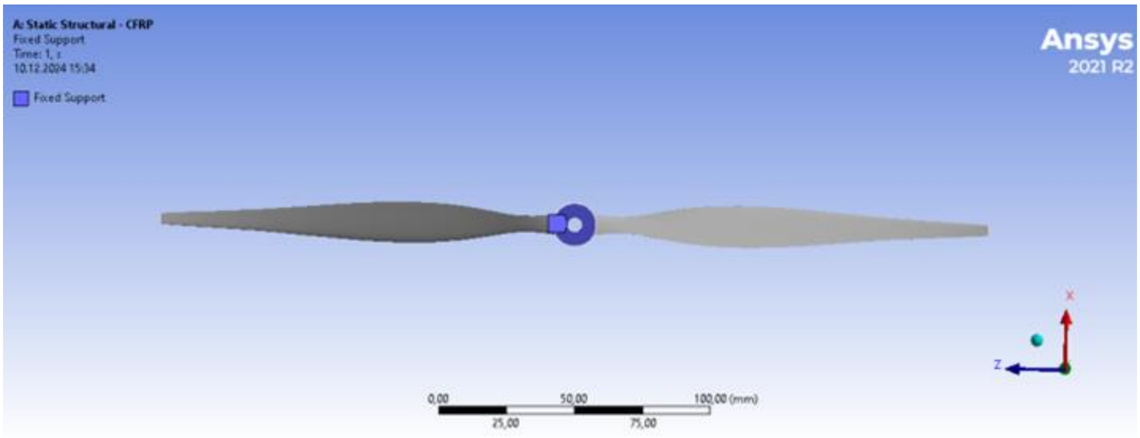

Figure 4. The part that is considered fixed on the propeller

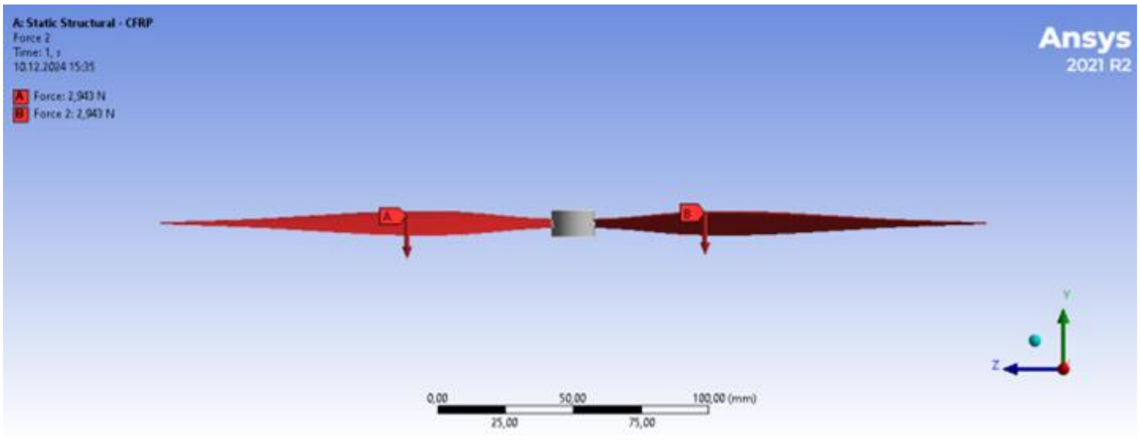

Figure 5. Forces applied to the propeller blades

3. Results

In this study, a propeller with NACA 2412 airfoil structure is designed. Structural analysis of the propeller with CFRP and PLA materials was performed with ANSYS program. The analysis results are given separately for CFRP and PLA materials.

3.1. Structural analysis – CFRP

The deformation of the propeller in the direction of the applied force is shown in Figure 6 and Figure 7. Figure 6 shows the total deformation of the CFRP material and Figure 7 shows the maximum shear stress. Total deformation, directional deformation, equivalent elastic strain, maximum shear elastic strain, equivalent stress and maximum shear stress values obtained from the analysis are given in Table 3.

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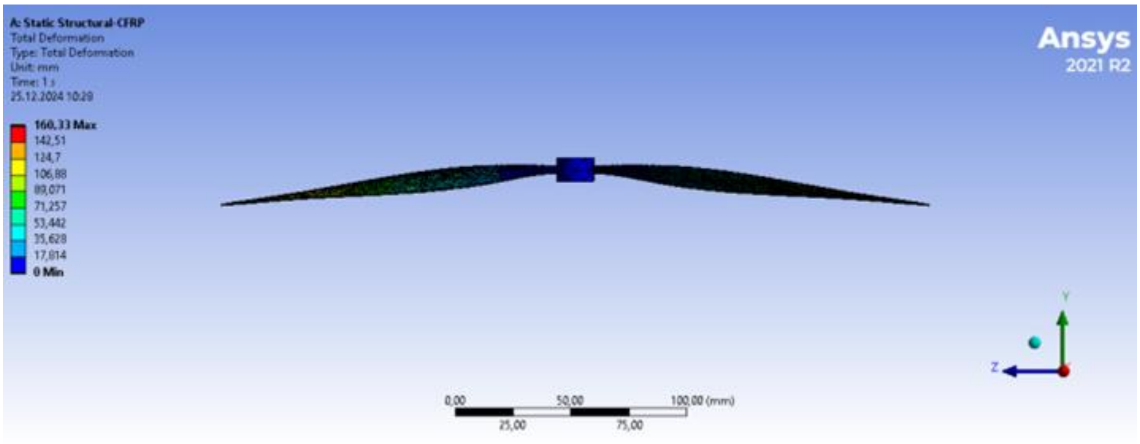

Figure 6. Total deformation of CFRP

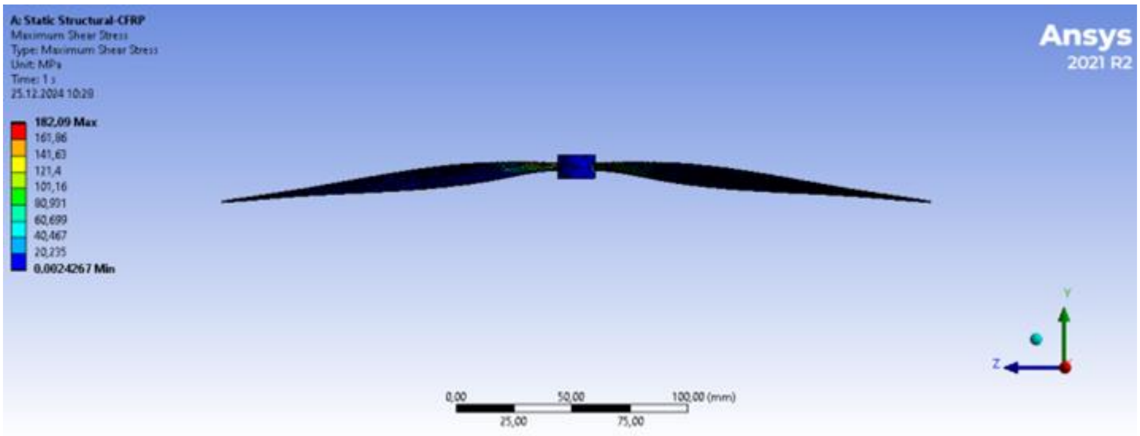

Figure 7. Maximum shear stress of CFRP

3.2. Structural analysis – PLA

The deformation of the propeller with PLA material is shown in Figure 8 and Figure 9. Figure 8 shows the total deformation of the PLA material and Figure 9 shows the maximum shear stress. Total deformation, directional deformation, equivalent elastic strain, maximum shear elastic strain, equivalent stress and maximum shear stress values obtained from the structural analysis are given in Table 4.

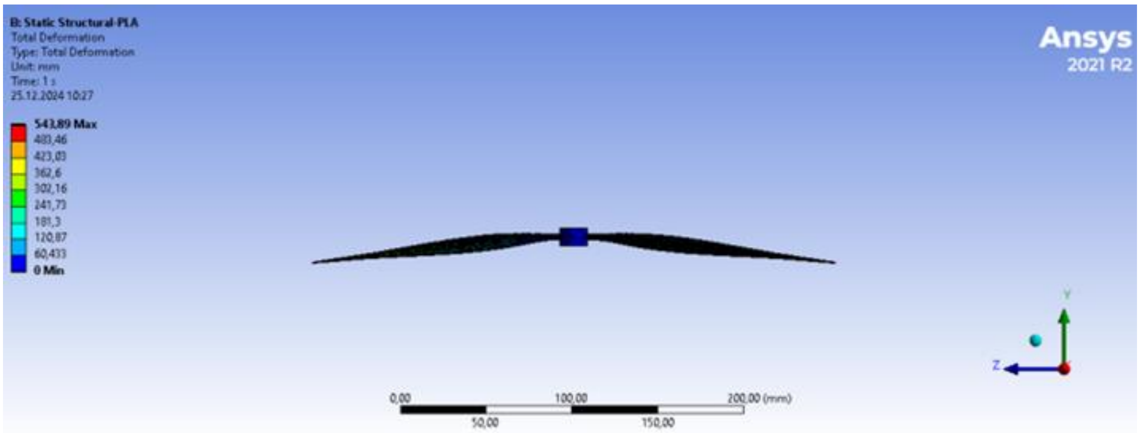

Figure 8. Total deformation of PLA

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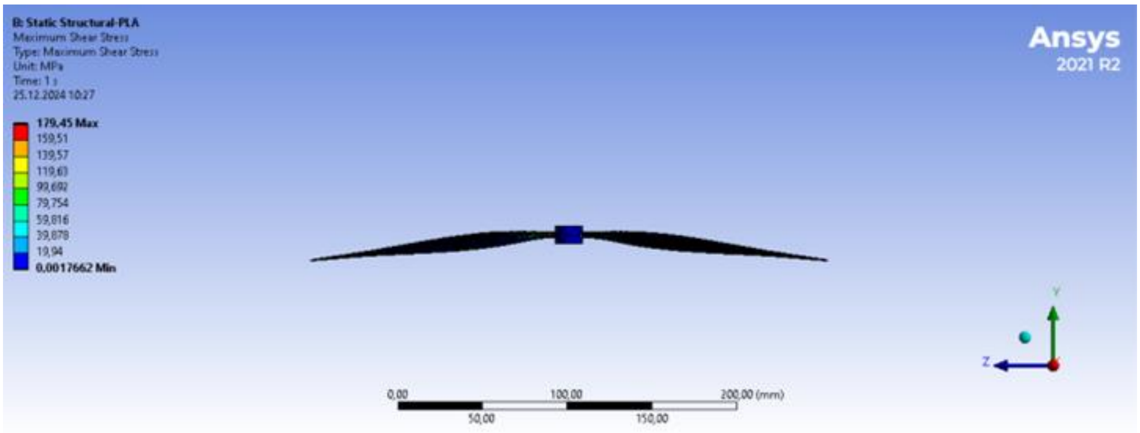

Figure 9. Maximum shear stress of PLA

Table 4. Analysis results for CFRP and PLA

Material	CFRP	PLA
Total Deformation (mm)	160.33	543.89
Directional Deformation (mm)	83.737	285.62
Equivalent Elastic Strain (mm/mm)	0.040076	0.1193
Maximum Shear Elastic Strain (mm/mm)	0.043498	0.17168
Equivalent Stress (MPa)	362.24	350.11
Maximum Shear Stress (MPa)	182.09	179.45

Table 4 shows that the total deformation of PLA is 3.39 times the total deformation of CFRP. PLA's directional deformation is 3.41 times, equivalent elastic strain is 2.98 times and maximum shear elastic strain is 3.95 times that of CFRP. For equivalent stress and maximum shear stress, the values are close to each other.

4. Conclusion

In this study, a 0.3 kgf (2.941995 N) thrust force was applied to a propeller model with different materials and the amount of deformation on the propeller was investigated. As a result of the structural analysis, Total Deformation, Directional Deformation, Equivalent Elastic Strain, Maximum Shear Elastic Strain, Equivalent Stress and Maximum Shear Stress values were obtained. When the values obtained were analyzed, it was seen that PLA material was deformed more than CFRP material. In addition, when the stress on both materials was compared, it was found that the CFRP material was subjected to more stress. As a result of the study, CFRP material was found to be approximately 3.4 times more durable than PLA material and this result was found to be compatible with the studies in literature. It is also concluded that the deformation amounts of the materials have large values compared to the applied force. The reason for this is thought to be that the propeller model design does not have sufficient thickness for the materials used. As a suggestion to this, an optimization study using a different airfoil structure is aimed to be carried out in future studies.

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Authorship contribution statement
Süreyya Sevinç Varol, *Research, Visualization, Conceptualization, Methodology, Software, Formal Analysis.* **Mehmet Emin Çetin,** *Investigation, Supervision, Examination.* **Mesut Uyaner,** *Examination, Visualization, Supervision, Editing.* **Bilge Albayrak Çeper,** *Investigation, Supervision, Examination.*

Conflicts of Interest: The authors declare no conflict of interest.

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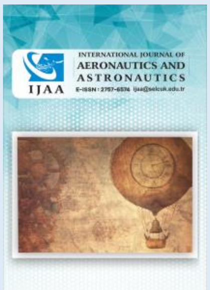

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Research Article / Araştırma Makalesi

Supersonic blowdown wind tunnel control using ABC optimized PID controller/ ABC ile optimize edilmiş PID kontrolcü kullanarak sesüstü üflemeli rüzgar tünelinin kontrolü

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Optimizasyon,
PID,
Sesüstü üflemeli rüzgar tüneli,
Yapay arı kolonisi

ABSTRACT

Supersonic blowdown wind tunnels enable the testing of aircraft prototypes in the Mach 1.2 to 5 range, but these tunnels allow very limited test times due to their structure. In addition, once the wind tunnel system starts operating, the pressure in the tank where the air is stored changes constantly. This means that the parameters of the already nonlinear system dynamics are continually changing. To utilize this time effectively, fast-responding, stable and highly efficient controllers are needed. These controllers should be able to provide the required pressure in the settling chamber as fast as possible for the desired flow conditions in the test section. In these types of testbeds, Proportional-Integral-Derivative (PID) controllers are widely used because of their reliability, simplicity and ease of implementation. PID controllers can also provide fast and stable responses, as they can reduce the error, eliminate the steady-state error, and minimize the overshoot and oscillations. PID controllers only require the measurement of the error and the tuning of the coefficients, which can be performed manually or automatically. For a PID controller it is essential to optimize its coefficients to achieve the best performance and stability. There are different methods to tune a PID controller, such as trial and error, Ziegler-Nichols method, Cohen-Coon method, and optimization algorithms. This study proposes the use of an artificial bee colony in the optimization of PID coefficients used in the control of a supersonic blowdown wind tunnel. Because of complexity, an artificial bee colony is used to optimize PID coefficients with three different objective functions. The optimized coefficients are compared to gradient optimization results, and the best approach is determined.

ÖZET

Sesüstü üflemeli rüzgar tünelleri, Mach 1,2 ila 5 aralığında uçak prototiplerinin test edilmesini sağlar, ancak bu tüneller yapıları nedeniyle çok sınırlı test sürelerine izin verir. Ayrıca rüzgar tüneli sisteminin çalışmaya başlamasıyla birlikte havanın depolandığı tankın basıncı sürekli olarak değişmektedir. Bu da zaten doğrusal olmayan sistem dinamiğinin

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parametrelerinin sürekli olarak değişmesi anlamına gelmektedir. Bu problemlerle etkin bir şekilde başa çıkabilmek için hızlı tepki veren, kararlı ve yüksek verimli kontrolcülere ihtiyaç vardır. Bu kontrolcüler, test bölümünde istenen akış koşulları için dinlenme odasında gerekli basıncı mümkün olan en hızlı şekilde sağlayabilmelidir. Bu tür test yataklarında güvenilirlikleri, basitlikleri ve uygulama kolaylıkları nedeniyle Orantısal-İntegral-Türevsel (PID) kontrolcüler yaygın olarak kullanılmaktadır. PID kontrolcüler kararlı durum hatasını ortadan kaldırabilmeleri, aşım ve salınımları en aza indirebilmeleri gibi özellikleri ile hızlı ve kararlı yanıtlar sağlayabilirler. PID kontrolcüleri yalnızca hatanın ölçülmesini ve katsayıların ayarlanmasını gerektirir, bu da manuel veya otomatik olarak yapılabilir. Bir PID kontrolünde en iyi performansı ve kararlılığı elde etmek için katsayılarını optimize etmek çok önemlidir. Katsayıları belirlemek için Ziegler-Nichols yöntemi, Cohen-Coon yöntemi ve optimizasyon algoritmaları gibi farklı yöntemler kullanılmaktadır. Bu çalışma, bir sesüstü üflemeli rüzgar tünelinin kontrolünde kullanılan PID katsayılarının optimizasyonu için yapay arı kolonisi yönteminin kullanılmasını önermektedir. 3 farklı amaç fonksiyonu kullanılarak farklı PID katsayıları elde edilmiştir. Optimize edilen katsayılar gradyan optimizasyon sonuçlarıyla karşılaştırılmış ve en iyi yaklaşım belirlenmiştir.

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1. Introduction

The wind tunnel is the system that enables the tests of aircraft to be carried out on the ground with desired similarity parameters such as Mach number and Reynolds number. Supersonic Blowdown Wind Tunnels (SBWT) enable these tests to be performed at supersonic speeds in a laboratory environment for limited periods of time. It is necessary to obtain required pressure gradient between the inlet and outlet of the nozzle so that air flow at supersonic Mach numbers can be achieved. For this purpose, the air pumped into a storage tank is allowed to reach the settling chamber by leaving a regulation valve in a controlled manner. The air in the settling chamber passes through a nozzle and reaches the test section. By keeping the air pressure in the settling chamber constant, the wind tunnel can be operated at the desired Mach number. This critical operation can be performed properly by controlling the opening of the pressure regulation valve by means of a well-designed PID controller. High performance controller promises to provide maximum test duration by minimizing the rising and settling times without overshoot, to minimize the steady-state error, to compensate for the decreasing storage pressure and to prevent oscillations during the test. In literature, P, PI, PD, and PID controllers are tested, and it is seen that the PI and PID are superior to others [1]. It is seen that PI and PID controllers are effective but determining the coefficients is an important challenge [2]. To overcome this challenge, Linear Quadratic Gaussian (LQG) controller is tested. It is observed that the LQG control structure has a bigger overshoot and settling time than the PI controller in SBWTs. Therefore, it is proposed to use LQG with a correction method [3]. Fuzzy logic is proposed to improve the performance of the PI controller. Fuzzy logic takes the error and its derivative as input and affects the signal to the PI controller. It is declared that overshoot and setting time are reduced significantly [4]. Another Fuzzy-assisted PI structure is tested, where the fuzzy logic has two inputs as error and error derivative. The fuzzy logic output is summed with the simultaneously generated PI control signal to produce a new control signal. It is shown that the proposed method has less settling time but more overshoot [5]. When the Adaptive Neural-Network optimized Fuzzy-PI structure is tested, the optimization depends on the previously obtained database, it is issued that the overshoot, settling time, and steady-state error outcomes are better compared to conventional PI controller [6]. In the same way, Fuzzy-PD is used to control pressure and temperature for SBWT. It is declared that the proposed controller gives valuable performance [7]. The feed-forward controllers are tested for stagnation pressure control of SBWTs, and good accuracies are obtained [8]. In a different proposition, a Neural Network (NN)

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structure that represents an SBWT is created and this NN model is used to gain PID coefficients by using Genetic Algorithms (GA) for different conditions. The gain scheduled PID coefficients are tested, and the results are better compared to conventional PID controllers [9]. However, all these methods used to produce better results against PID are more complicated than PID, and methods such as fuzzy logic and genetic algorithms have limited operating ranges.

PID controllers are the most widely used control algorithm due to their simple implementation and usefulness [10]. Due to its high accuracy and stability, PID control systems have become an important component of engineering applications in various fields such as robotics, automotive, aerospace, industrial automation, and heating. In addition, there are many PID control applications for SBWTs in the literature. For this reason, the PID control approach is used in this study. However, while PID coefficients can be easily calculated for linear systems, it is difficult for highly nonlinear systems such as SBWTs. So, a meta-heuristic method is used to optimize PID coefficients.

Nowadays, meta-heuristic approaches are preferred as an alternative to classical methods to simplify optimization problems. Strategies derived from natural and biological phenomena, such as the foraging strategies of ants and other insects, are examples of strategies derived from nature. The strategy used was influenced by the clever behavior of insects, and swarms can be defined as any group of interacting agents or individuals [11, 12]. The group behaviors and cooperative actions displayed by insects when addressing complex challenges have inspired the concept of swarm intelligence, which has been instrumental in the development of contemporary metaheuristic methods. This concept relies on the understanding of how individuals can collaborate effectively by following simple rules. Particle Swarm Optimization [13], Ant Colony Algorithm [14], and Artificial Bee Colony (ABC) [15] are the most well-known algorithms in this field.

The Artificial Bee Colony (ABC) algorithm, a swarm intelligence-based algorithm, was proposed by Karaboğa in 2005 for multimodal and multidimensional numerical optimization problems [15]. It provides very remarkable results for continuous optimization problems [16, 17]. The Artificial Bee Colony (ABC) algorithm is used in this work to optimize the PID controller coefficients of a SBWT. During the optimization process, the controller's effectiveness is assessed using various performance criteria. In this context, regularly used objective functions such as Integral Absolute Error (IAE), Integral Squared Error (ISE) and Integral Time-weighted Absolute Error (ITAE) are examined. The impact of each objective function on controller performance is thoroughly investigated and compared to discovering the optimal PID coefficients that deliver the best system performance. As a result, this research not only focuses on the best PID controller design but also strives to give a comprehensive analysis of how different objective functions affect control system performance.

2. Supersonic Blowdown Wind Tunnel (SBWT)

The properties of supersonic vehicles can be mainly observed in two ways: Conducting a flight test using an actual vehicle prototype and conducting a wind tunnel test on a scaled vehicle model. There are different types of wind tunnels depending on their speed regime, geometry, working fluid, and the special purpose. In this study, blowdown type supersonic ($1.2 < \text{Mach} < 5.0$) wind tunnels are considered.

The SBWT system consists of the following main components: High pressure storage tank, control valve, settling chamber, nozzle, test section, and diffuser as shown in Figure 1.

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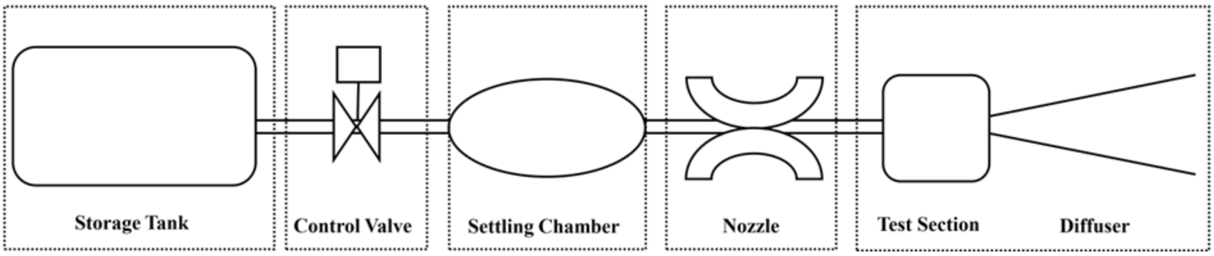

Figure 1. Diagram of supersonic blowdown wind tunnel

SBWTs operate intermittently using energy stored in high-pressure tanks. Firstly, at the beginning of the wind tunnel test, the control valve is opened and then the pressure difference creates a flow inside the wind tunnel, whereby air is drawn from the storage tank and exhausted into the atmosphere. The Convergent–Divergent (CD) nozzle plays a crucial role in accelerating the flow from near stagnation conditions to supersonic speeds. It is assumed that the stagnation flow parameters are obtained at the outlet of the settling chamber where the stagnation pressure and temperature are measured as the flow progresses through the nozzle, it is subjected to acceleration in order to ensure that the requisite flow parameters are attained for the desired conditions within the test section. [18]. In order to obtain different Mach numbers in the test section, the CD nozzle contour is changed and simultaneously the required stagnant flow parameters at the settling chamber are provided by the control valve. Therefore, the algorithm driving the control valve is extremely important for the efficient use of the limited experimental time of blowdown wind tunnels.

An SBWT is usually modelled using lumped parameters. In this method, the wind tunnel is divided into separate sections, each of which is then subjected to a separate analysis. This approach allows greater focus on specific accuracy criteria by treating each section in more detail [19]. Two control volumes are selected for its analysis: The storage tank and the settling chamber. The subsequent process involves utilising the fundamental principles of conservation - in particular those of mass, momentum and energy - and systematically applying them to the defined control volumes under consideration. Finally, the mathematical model of the SBWT is obtained by applying the conservation of mass and energy laws first to the reservoir and then to the settling chamber [20]. The equations used are listed below:

$$\frac{d\rho_{ST}}{dt} = -\frac{1}{V_{ST}}\dot{m}_{CV} \tag{1}$$

$$\frac{dP_{ST}}{dt} = -\frac{KR}{V_{ST}}T_{ST}\dot{m}_{CV} \tag{2}$$

$$\frac{d\rho_0}{dt} = \frac{1}{V_0}(\dot{m}_{CV} - \dot{m}_\star) \tag{3}$$

$$\frac{dP_0}{dt} = \frac{KR}{V_0}(T_{ST}\dot{m}_{CV} - T_0\dot{m}_\star) \tag{4}$$

$$\dot{m}_\star = \rho_\star A_\star V_\star = \sqrt{\frac{K}{R}\left(\frac{2}{\mathrm{K}+1}\right)^{\frac{K+1}{2(K-1)}}} A_\star \frac{P_0}{\sqrt{T_0}} \tag{5}$$

In this context, the term "ρ" refers to air density, "V" refers to volume, "m" refers to mass, "$\dot{m}$"refers to mass flow,"P"refers to pressure, "T" " refers to temperature, "M"refers to Mach (speed of sound) number and "A"refers to cross-sectional area.

The indexes; "ST" denotes the storage tank, "CV" denotes the control valve, "0" denotes the settling chamber, "TS" denotes the test section and " $*$ " denotes the nozzle throat. "K" is the ratio of air specific heat to pressure and is taken as 1.4, "R"is the air gas constant and is taken as 287 [8].

T_{ST} (storage tank temperature) and T_0 (settling chamber temperature) are accepted as $288\ K$.The V_{ST} (storage tank volume) is taken as $2600\ m^3$and V_0 (settling chamber volume) is taken as $360\ m^3$ [8].

The "A_*"nozzle throat area is defined as follows:

$$A_\star = A_{TS} M_{TS} \left(\frac{5 + M_{TS}^2}{6}\right)^{-3} \tag{6}$$

where A_{TS} (test section area) is given as 2.25 m^2 [8]. M_{TS}refers to the air speed at test section.

The mass flow that pass through the control valve can be calculated by the equation given below [21]:

$$\dot{m}_{cv} = \rho_{CV} A_{CV} v_{CV} = \sqrt{\frac{2K}{R(K-1)}} \frac{P_{ST}}{\sqrt{T_{ST}}} A_{CV} \left(\frac{P_{CV}}{P_{ST}}\right)^{\frac{1}{K}} \sqrt{1 - \left(\frac{P_{CV}}{P_{ST}}\right)^{\frac{K-1}{K}}} \tag{7}$$

The maximum mass flow that pass through the control valve is achieved when the ratio of P_{CV} (pressure at control valve) to P_{ST} (pressure at storage tank) is equal to or greater than 0.5283.

In the event of a blockage in the flow, the mass flow is calculated using the equation provided in equation (7) for $P_{CV}/P_{ST} = 0.5283$ [8]. Temperature, pressure and density are assumed at ideal conditions.

Although the model of the SBWT is simplified through these approaches, it remains highly nonlinear. This nonlinear behavior adds complexity to the wind tunnel's flow dynamics, requiring further investigation to accurately control and predict the flow.

3. PID Control

PID control system is an efficient and effective control system in literature [22]. PID systems provide control through 3 main factors called K_p,K_i and K_d. These systems are formed by multiplying error by proportional, integral and derivative coefficients [23]. By changing the control coefficients, the controller response specifications such as overshoot, steady state error, settling time and rise time can be observed. Also, the PID controllers are easy to carry out, that is why they are generally used. The coefficients must be optimized for getting better results in these systems.

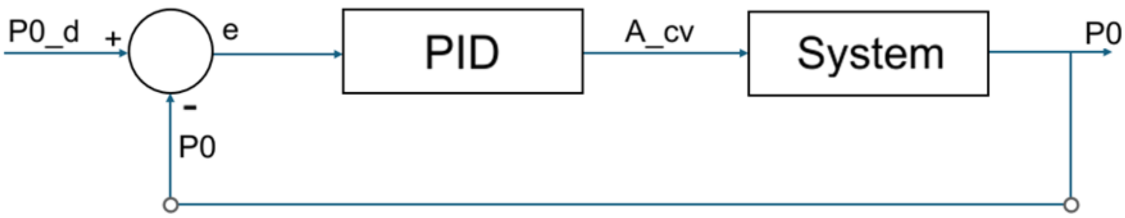

Figure 2. PID control of the stagnation pressure supersonic blowdown wind tunnel

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In the literature, there are mainly two controlled parameters as stagnation pressure and valve mass flow rate. In this study, the stagnation pressure is controlled as given in Figure 2.

4. Optimization

Optimization methods use mathematical algorithms to maximize system performance or minimize errors. There are many optimization methods in the literature, and they can be divided into two categories: classical and meta-heuristic. Gradient Descent (GD), a traditional optimization method, uses derivative (gradient) information to find the minimum point of cost function. The derivative of a function indicates the slope (direction) of the function at that point. If the slope is positive, the algorithm moves backwards (in the negative direction) to reach smaller values; if the slope is negative, it moves forward (in the positive direction). With this movement, it is tried to reach the minimum value [24].

4.1. Artificial bee colony algorithm

The form of knowledge that results from the actions of individuals without a centralized decision-making body is called swarm intelligence. Organisms such as ants, bees, swarms of birds, schools of fish, etc., act with swarm intelligence [14, 25]. These swarms are driven by a common goal (food selection, self-preservation, finding energy). Various artificial intelligence algorithms have been developed inspired by the behavior of swarms. Artificial intelligence bee colony, one of these artificial intelligence algorithms, was first discussed by Karaboğa in 2005 [25]. The artificial intelligence bee colony algorithm is modelled based on the food selection and dance movements of bees and the model consists of three main components: food source, employed foragers and unemployed foragers. The quality of a food source depends on many factors, such as the distance of the food from the nest, the diversity or density of the food, and the ease of access to the food. Employed foragers are associated with a specific resource and carry information about this resource (direction and distance from the nest) to the hive. There are two types of unemployed foragers, scouts and explorers. Unemployed foragers do not have specific resources like labor foragers, so they are constantly looking for food sources. Scout bees look for new food sources around the hive to increase food diversity. Onlooker bees stay in the nest and forage with information from worker foragers. The dance part is very important in the communication between bees. During the dance the bees learn about the quality of the food [26].

Each food around the hive is a possible solution. The ABC algorithm starts with a randomly assigned bee. One bee is assigned for each food source, so that as many bees work as there are food sources. The number of Honeybees (nHB) is the parameter that defines the size of the colony. The ABC algorithm starts with explorer bees finding food sources. The worker bees go to the food sources found by the explorer bees and the food quality is assessed by the scout bees. The worker bee whose food source is exhausted becomes a scout bee. This cycle continues until the best quality food source is found [26].

4.1.1. Employing bees and generating new solutions

Recruited bees randomly move towards other sources and try to find better food sources. The food source is expressed as a permutation and the mathematical model is constructed as follows. This ensures diversity and makes the algorithm's solution space more comprehensive.

$$stepsize = rand_{(i)(j)}.(HB - HB[permute(i)(j)])$$

$$newHB = HB + stepsize \tag{8}$$

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□□□□(□)(□) [-1 1] is a number randomly selected from the range. i is the number of honeybees, and j is the number of dimensions of the problem [26].

4.1.2. Onlooker bees and exploitation process

The solutions discovered by employed bees are shared with onlooker bees, who then evaluate them based on a selection probability. Onlooker bees focus on improving specific solutions by exploiting their neighborhood. The selection process is typically conducted, where higher-quality solutions are given priority for further improvement.

$$P_{(i)} = \frac{PFit_{(i)}}{\sum_{i=1}^{nHB} PFit_{(i)}} \tag{9}$$

$PFit_{(i)}$ is the penalised objective function value of the first food source [26].

$$stepsize = rand_{(i)(j)}.\,(HB_{rws} - HB[permute(i)(j)])$$

$$newHB = \begin{Bmatrix} HB_{rws} + stepsize, & if\ rand < mr \\ HB_{rws,} & otherwise \end{Bmatrix} \tag{10}$$

4.1.3. Scout bees and ensuring diversity

If a solution cannot be improved after a certain number of iterations, it is abandoned, and scout bees are activated. Scout bees generate entirely new random solutions in the search space. This phase introduces diversity and helps the algorithm escape from local optima. By replacing abandoned solutions, scout bees contribute to the overall performance of the algorithm [26].

4.2. Objective functions

Objective functions are used for the optimization of PID parameters. In this study, there are three types of objective functions. These are Integral Absolute Error (IAE), Integral Squared Error (ISE) and Integral Time-weighted Absolute Error (ITAE).

Table 1. Objective functions

Objective Function	Mathematical Formula
Integral of Absolute Error (IAE)	$\int_0^t \lvert e(t)\rvert dt$
Integral of Squared Error (ISE)	$\int_0^t e(t)^2 dt$
Integral of Time-weighted Absolute Error (ITAE)	$\int_0^t t\lvert e(t)\rvert dt$

In this paper, PID coefficients are obtained by using GD and ABC with objective functions those are ISE, IAE, ITAE. The graph of the control system was obtained with the PID coefficients. By comparing the graphs obtained, the optimum PID coefficients for the control system were determined. The objective function formulations used are given in Table 1.

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5. Results and Discussion

The gradient descent and ABC algorithms simulation results have been examined for a SBWT. The ABC algorithms are tested for three cost functions: ISE, IAE, and ITAE. In this study, 20 honeybees are used, the maximum number of objective function evaluations (maxNFEs) is chosen as 400, and the modification rate (mr) is chosen as 0.8. The optimizations are implemented several times to find the best results. The coefficients obtained as the result of optimizations are given in Table 2. Optimizations were performed for the case where the Mach value is 2 and the stagnation pressure is $0.25 * 10^6\ Pa$.

Table 2. PID coefficients

Optimization Methods	K_p	K_i	K_d
Gradient Descent	$1.6012 * 10^{-5}$	$1.2402 * 10^{-5}$	$-1.6832 * 10^{-7}$
ABC (ISE)	$8.8251 * 10^{-5}$	0	0
ABC (IAE)	$4.8067 * 10^{-4}$	$1.5718 * 10^{-5}$	$2.4207 * 10^{-7}$
ABC (ITAE)	$4.2337 * 10^{-4}$	$1 * 10^{-4}$	0

The optimized PID coefficients are implemented in the SBWT. The PID results are shown in Figure 3, and control signals in Figure 4. The results show that all the controllers run regularly for nearly 46.5-47.5 seconds. This small interval is important for controllers, as this system consumes the air stored in the tank. Therefore, there is a very short run time for each tunnel test.

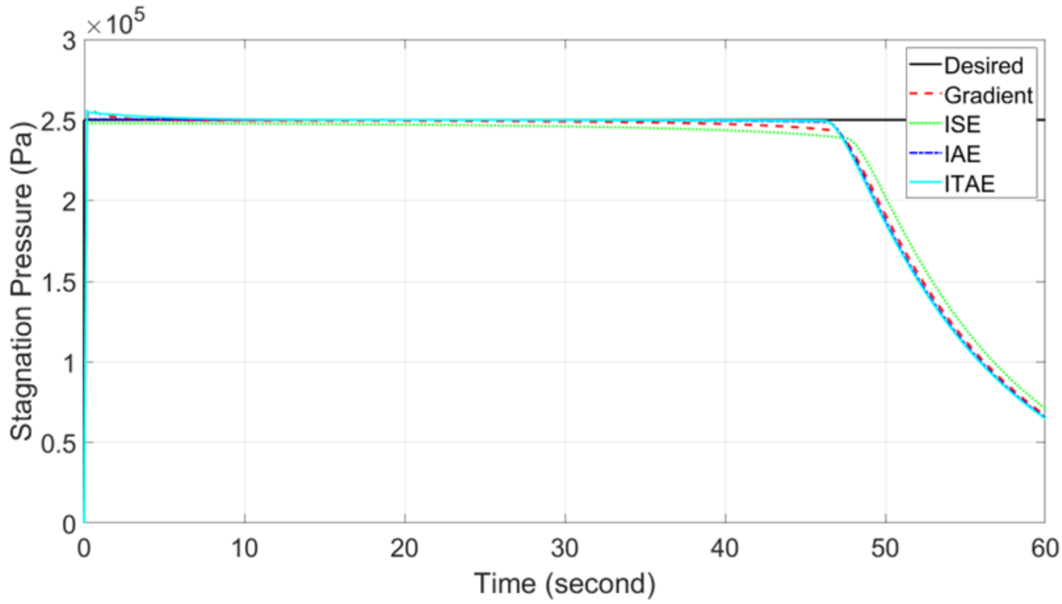

Figure 3. Optimized PID results

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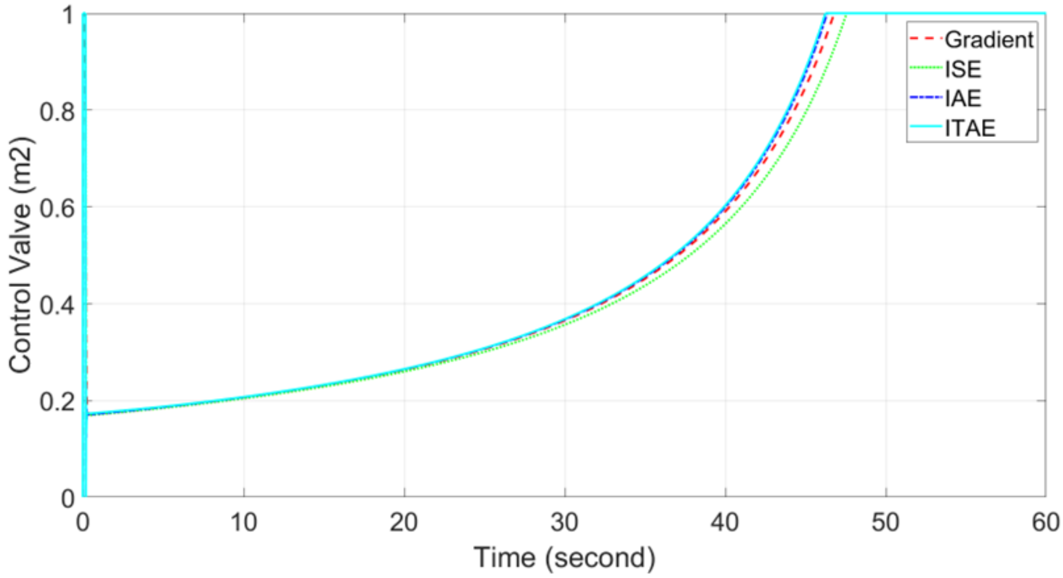

Figure 4. Optimized PID control signals

When the wind tunnel starts working, the control valve must be opened to its limit immediately as seen in Figure 4. Thus, the stagnation pressure reaches the desired values quickly. The PID control coefficients must provide this condition. As seen from the results, the four control signals provide a fast reaction but the ITAE cost function and GD methods have overshoots. The others (ISE and IAE) do not have overshoot values.

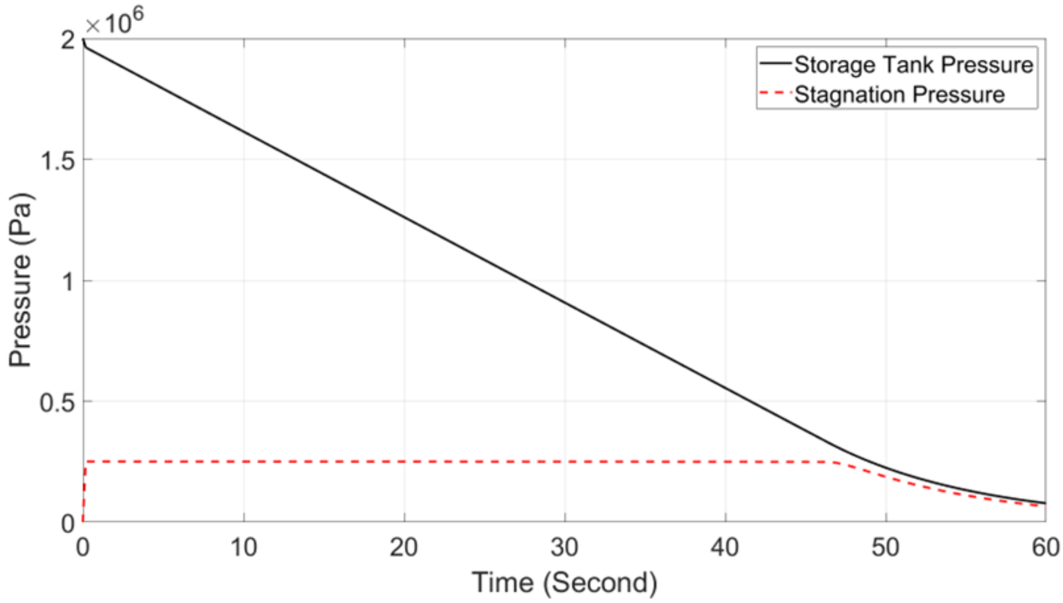

Figure 5. Storage tank and stagnation pressure relation for IAE optimized PID control

After the control valve is quickly opened to the end, it closes a little and opens slowly to keep the pressure at the desired level. Because in the meantime, the storage tank pressure declines with time. For this reason, as the storage tank pressure decreases, the control valve should be opened larger to ensure that the stagnation pressure is at the desired level. The relationship between the storage tank and stagnation pressure can be seen in Figure 5, which is the result of PID optimized with IAE cost function.

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When the results in Table 3 are examined, it is seen that the ISE and IAE optimized PID have better performance compared to the others in terms of overshoot and settling time. However, the ISE-optimized PID never reaches the desired pressure, and this causes a high Root Mean Squared Error (RMSE) value. This is an undesirable situation in tunnel tests.

The RMSE values are calculated for 46 seconds. Because after the 46th second, the storage tank pressure can no longer provide the flow required for the desired stagnation pressure.

Table 3. Comparison of control performances

Methods	Overshoot (%)	Settling Time (s)	RMSE (46s)
Gradient Descent	2.50	0.623	$9.2238 * 10^3$
ABC (ISE)	0	0.178	$9.9525 * 10^3$
ABC (IAE)	0	0.178	$8.9664 * 10^3$
ABC (ITAE)	2.51	0.2	$9.0202 * 10^3$

As seen from Table 3, the PID optimized by IAE is not only overshoot-free but also has the minimum settling time and the minimum RMSE. So, it has the best control performance compared to others.

6. Conclusion

A modeling of an SBWT was conducted that addresses the challenges of achieving stable and precise control of stagnation pressure during the short and critical operation times. Considering the highly nonlinear nature of the SBWT system, the determination of the PID coefficients poses a great challenge. To overcome this, a metaheuristic optimization approach based on the Artificial Bee Colony (ABC) algorithm is implemented to determine PID coefficients that minimize the steady state error on the desired pressure value and provide maximum test time.

The PID controller coefficients are optimized using three different objective functions: Integral of Absolute Error (IAE), Integral of Squared Error (ISE) and Integral of Time-weighted Absolute Error (ITAE). These methods are compared to the Gradient Descent method.

In conclusion, it was found that the optimization with the IAE (Integral Absolute Error) objective function gives the best performance. The IAE-optimized PID controller achieved zero overshoot, the shortest settling time, and the lowest RMSE, thus maximizing the efficiency of the limited test time by ensuring rapid and stable pressure regulation. In contrast, the ISE-optimized PID controller failed to maintain the desired stagnation pressure, and both Gradient Descent and ITAE-optimized PID controllers exhibited undesirable overshoots.

The findings of this work underline the potential of the ABC algorithm with the IAE objective function, as a highly effective strategy for PID optimization for complex systems. So, this approach is planned to be tested in the real environment and with different systems in future studies.

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Authorship contribution statement

Kıymet Nihal Nur Taş, *Artificial Bee Colony Design, Revision and Writing.* **Sultan Dinçsoy,** *Literature Research, Revision and Writing.* **Levent Can,** *PID Design, Revision and Writing.* **Berna Tuğbay,** *Supersonic Tunnel Model Design, Revision and Writing.* **Hasan Tabanlı,** *Revision and Improvement of the Text, Supervision.* **Muhammet Öztürk,** *Software, Revision and Writing, Supervision.*

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SELÇUK ÜNİVERSİTESİ YAYINLARI

Review Article / İnceleme Makalesi

The impacts of the great depression on the safety development in civil aviation: Business cycles approach / Büyük buhranın sivil havacılıkta emniyet gelişimine etkileri: İş döngüleri yaklaşımı

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Aviation Safety,
Business Cycles,
Civil Aviation,
Historical Development

Anahtar Kelimeler

Havacılık Emniyeti,
İş Dalgaları,
Sivil Havacılık,
Tarihsel Gelişim,

ABSTRACT

Economics has realised significant advancements with criticisms from Marxist and Neo-Marxist thinkers. One of these criticisms pertains to business cycles and waves. This analysis focuses on the development of aviation safety in light of these waves and cycles. Simultaneously, the primary research method involves a systematic articulation of economic waves and their impacts on the understanding of safety in civil aviation. Thus, this research encompasses three patterns: civil aviation safety, economic conjunctures and wave theory, and a historical approach. This study aims to explain how the Great Depression Safety Wave formed between the periods of the First and Second World Wars. The findings indicate that there was a marked increase in the understanding of safety during the First and Second World Wars. Conversely, due to the Great Depression and its ramifications beyond the economic realm, there emerged a wave between the First World War and the Second World War, impacting historical evolution and the trajectory of safety throughout history.

ÖZET

İktisat, Marksist ve Neo-Marksist düşünürlerin eleştirileriyle büyük sıçramalar gerçekleştirdi. Bu eleştirilerden biri de iş çevrimleri ve dalgalarıdır. Bu analizde, bu dalgalar ve çevrimler dikkate alınarak havacılık emniyetinin gelişimine yoğunlaşılmıştır. Buna paralel olarak, ana araştırma yöntemi ekonomik dalgaların ve sivil havacılıkta emniyet anlayışına etkilerinin sistematik bir şekilde eklemlenmesidir. Bu şekilde, bu araştırmanın üç deseni vardır: Bunlar, sivil havacılık emniyeti, ekonomik konjonktürler ve dalgalar teorisi ve tarihsel yaklaşımıdır. Bu araştırma, Büyük Buhran Emniyet Dalgasının, Birinci Dünya Savaşı ile İkinci Dünya Savaşı Dönemleri arasında nasıl oluştuğunu açıklamayı amaçlamaktadır. Bulgular, Birinci ve İkinci Dünya Savaşlarında, emniyet anlayışında, keskin bir artış olduğunu doğrulamaktadır. Öte yandan, Büyük Buhran ve bunun ekonomik alanın ötesindeki etkileri nedeniyle, dünyada tarihsel evrim ve tarihteki emniyet seyri dışında Birinci Dünya Savaşı ile İkinci Dünya Savaşı arasında bir dalga yaşanacaktır.

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1. Introduction

Safety is a legal readiness, the early and first step of every civil aviation action. On the other hand, three important revolutionary steps of civil aviation epistemology and practices can be counted as technological, political and economic stages [1] that are formed and subjected to conjunctural and framework waves. For example, Schumpeterian capitalist history gives economics a clear picture of the importance of these cyclic, revolutionary and distinctive waves that form around the main concept of creative destruction. According to Diamond [2], the central message of Schumpeter is this concept, which emphasizes a dynamic, competitive and benchmark for all capitalist motivations and survival. From primitive societies to the Industrial Revolution, this internal inducement of capitalism showed its face in the form of technological development acceleration, which comes to today [3]. The development of capitalism is a problem of economic fluctuations, structural adjustment and the functioning of factor markets [4]. Therefore, it is beyond the personal or communal feeling of being left behind in economic and social circumstances. It includes different competition stages in the light of the Ricardian economic explanation (1817), so it has political roots depending on the theory of relative advantages. The first of the research questions begins to develop here, if there is only one way in the development of civil aviation that is an evolution of safety uniquely, naturally and gradually and vaults of civil aviation can be explained with three dimensions, what is the scientific course of safety in these three revolutionary development types?

Secondly, it needs a structural analysis of civil aviation in parallel with current economic cycles. But, it can be seen that there are a lot of conjunctural waves or business cycle approaches regarding economics. To develop an economic analysis of the civil aviation industry, five of them, which are the Juglar and Kitchin business cycles and Kuznets, Kontradieff and Schumpeterian conjunctural waves that have similarities and differences regarding technology, politics and economics and finance, will be enough. But then, efficient and effective analysis of safety can be realized economically and operationally if it is concentrated on the emphasis of the Schumpeterian "safety entrepreneur" [5]. The second question raised here is whether there is an existence of safety entrepreneurs in the civil aviation industry and what are their duties and responsibilities in the civil aviation context, morally, technically and, of course, managerially, regarding other production factors.

Generally, a business cycle or conjunctural wave is a product of different attractions, changes and relationships between different actors in economic, political and technological contexts. According to heterodox interpretations of the economy, leaps and collapses in the current situation of economies are the main causes of conjuncture, and naturally, companies should be affected by them. Were there industrial-specific events that gave the last shape to the business cycles and waves in civil aviation, and what are their special impacts on the historical development of civil aviation, so safety?

This research mainly aims to scrutinize safety in light of technological, economic, and political developments in or around civil aviation. It realizes this purpose by benefiting from Marxist and Neo-Marxist theories and literature, current and famous waves and cycle approaches such as Schumpeter, Kontradieff, Kitchin, Juglar and Kuznets considering the concept of safety as a revolutionizing object in cultural patterns and forms of civil aviation, a motivating instinct in the capitalist cycles and waves of the civil aviation economy and an accepted tacit or open communication style in dynamic civil aviation sociology and heritage. Methodologically, safety is neither an option nor a technical indicator in civil aviation, although it needs engineering understanding and scientific creativity if it is concentrated on its development stages.

In light of these arguments, safety will be elaborated on in this research rigorously with historical development. On the other side, the Great Depression of 1929 [60, 61] serves as a great contextual playground and experimental basis for this research, with its redefining and clear impacts on the development of safety understanding. Therefore, the examination of safety development during the Great Depression of 1929 can be a research problem and should be elaborated through an articulation method.

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In the first section of this paper, there is a historical development of civil aviation as a literature review that is divided into different subparts, a short timetable of waves and cycles regarding civil aviation, and the place of safety in economic, technological and political development stages of civil aviation will be reconsidered. In the methodological part of this theoretical research, mean-and-end chains, articulations and intentions are explained, and findings, discussions and conclusion take their part at the end of the paper.

2. Literature Review

2.1. The safety concept

The place of the concept of safety is so clear in civil aviation. Nonetheless, there are differences in definition regarding three-dimensionality. One of these definitions accepts safety as a thing, which can be only explained by technical details theoretically at first sight; on the other hand, its power gives a last shape to the economy and policy. Apostol et al. [6] and Ranasinghe et al. [7] underline the importance of risk in the design stages of aerospace engineering and the design of aircraft. These ideas support the assumptions in the first definition. The second definition of safety considers it as a policy item at different levels, which needs technical support and economic resource supply. The emphasis of Luxhoj [8] on the National Airspace System of the United States near the Safety Management Systems as a need and requirement of the airline companies in the depiction of Teske and Adjekum [9] and Wolf [10] supports this second description. For the third one, safety is an economic motive framed with technical understanding and policy development. The innovations and inventions of Airbus and Boeing can shed more light on this topic. These three kinds of safety take their roots from risk consciousness after, before, and while processes or periods of accidents and incidents; therefore, the psychology of humankind originates from these. In this regard, the risk can be classified as follows [11]; i) Real risk to an individual, which may be determined based on future circumstances after their full development; ii) Statistical risk, which may be determined by the available data on the incidents and accidents in question; iii) Predicted risk, which may be predicted analytically from the models structured from relevant historical studies; and; iv) Perceived risk, which may intuitively be felt and thus perceived by individuals.

2.2. The Marxist way to explain technology

Marxist historical analysis accepts historical development as a whole of conflicts between and within different classes that are sovereign over different production factors such as capital, labor, knowledge and land. These conflicts can be observed in cultural forms and patterns, traditions, social norms and political and social organizations [12]. Their existence can be formed by the nature of violence or peace [13] and by the values of the classes [14]. Clarke [15] supports that the activities of production and their surroundings are the focus points of these conflicts. Conversely, although Neo-Marxists utilize the Marxist methodology in their work, their tellings and subjects are wider than orthodox Marxism because of the living age. For example, Wallerstein's works "The Modern World-System I, II, III, 1974; 1980; 1989" [55-57] give historical lessons and a bridge between old and new and explain capitalist changes with specific time patterns and conjunctures. These conjunctural and wave changes are defined by the same methodology in the works of Schumpeter, Kontradieff, Kitchin, Juglar and Kuznets, who defend that the capitalist system or capitalist motivation shows cyclic similarities depending on time; for this reason, it is not easily overcome. According to them, each crisis is a need and a bottleneck of capitalism, and capitalists should survive under them with one main revolutionary and dynamic instinct: creativity.

It is a known reality that main economic variables such as GDP growth, employment, interest rates, and consumption follow cyclic waves over time [16] or in the time of globalization [17]. Moreover, economies can be characterized by institutional change concerning labour markets, regulatory arrangements and the organisation of firms, which alters the process of decision-making, decision actors, and interest groups, and changes the balance

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between market and government [18]. The existence of cyclic movements in the economy affirms that market behaviour is not deterministic; it has a rhythm [19]. Current economics defend that economic behaviour has its own idiosyncratic and complex chaotic identity depending on the nature of business [20]. Moreover, Juglar [21] defines cyclic variations in the corporate activities of businesses in which there are oscillations of investments into fixed capital and levels of employment of the fixed capital in the range of 7-11 years. Secondly, Kitchin [22] determines boom-bust cycles for 40 months in commodity prices. Thirdly, Kuznets [23] associates demographic processes such as immigrant policies (inflow/outflow) and construction policies, paralleled by them with new cycles of 15-25 years. For a fourth one, Kontradieff [24] underlines the importance of innovation in the technological revolutions of overwhelming industries and commercialism with his waves of 40-60 years. Yet, in light of these arguments, Schumpeter [25] could realise his important technological explanations under the umbrella concept of innovation and technological development in capitalism.

2.3. Introduction to safety technology

Habermas, the Marxist thinker, defines technology as a project of the human species as a whole. For him, technology is a universal human activity and needs a technocratic consciousness of which features are counted by Oraldi [26]: Technocratic consciousness is "'less ideological' than all previous ideologies" although it is the most "irresistible and far-reaching", it not only hides class interest but, through the suppression of the distinction between the practical and technical dimension, it compromises "the human race's emancipatory interest as such". Like all ideologies, it serves to detach the foundations of society from thought and reflection – but even more than other ideologies it is invulnerable to reflection because it does not put forward an image of the "good life." On the other side, for Heidegger, technology is not only a problem as it causes ecological destruction, nuclear danger, consumerism but also, a solution of them regarding technological understanding of being [27] in an epoch dominated by technology [28]. Therefore, the contributions of technology to a democratic crisis can be very large, as observed in the example of the internet's impacts on virtual communities [29] or the potency caused by the creation and holding of the technology. For these causes, according to Feenberg [30], technology is not a romantic thing and democratizing technology means expanding technological design to include alternative interests and values. So, in a universal description, technology is a thing to the interpretation of nature in terms of age and space [31], it is expected absolutely that it will be impacted by not only the main reasonings and patterns of thinking but also interests and values [32] of the epochs when and where it belongs.

Safety is a technological public need and requirement, and for this reason, it is open to development and reform [33]. Besides these, safety develops mainly the understanding of the risk associated with an action, and turns it into an operation. In the transportation industry, the safety of aviation and the acceptability of the risks associated with air travel are fundamental to its broad public use as a reliable and effective method of transportation [34]. Without a strict safety understanding, it is not possible to set up resilient civil aviation; therefore, safety has a legal basis with national and international civil aviation regulators [35]. Therefore, it should be an unforgettable reality that safety is a problem of organizational climate, organizational culture and organization, near the individual efforts [36] in micro, macro and international levels.

3. Methodology

There are important leaps and collapses in the history of civil aviation with economic, technological and political transformation of the world that have also had deep impacts on the safety understanding of civil aviation. Moreover, the selection of important economic, technological and political events is also problematic regarding safety. Throughout this analysis, the articulation of new concepts and aircraft understanding in the safety paradigm, and the dynamic and revolutionary movements in a safety context, because of these developments in technological, political and economic dimensions, will be examined as conjunctural changes and waves. When the analysis

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realises this, it will focus on the development of this peak (up-swing) and deep (down-swing) times in light of the tools given by Juglar, Kitchin, Kuznets, Kontradieff and Schumpeter in Figure 1 and Figure 2.

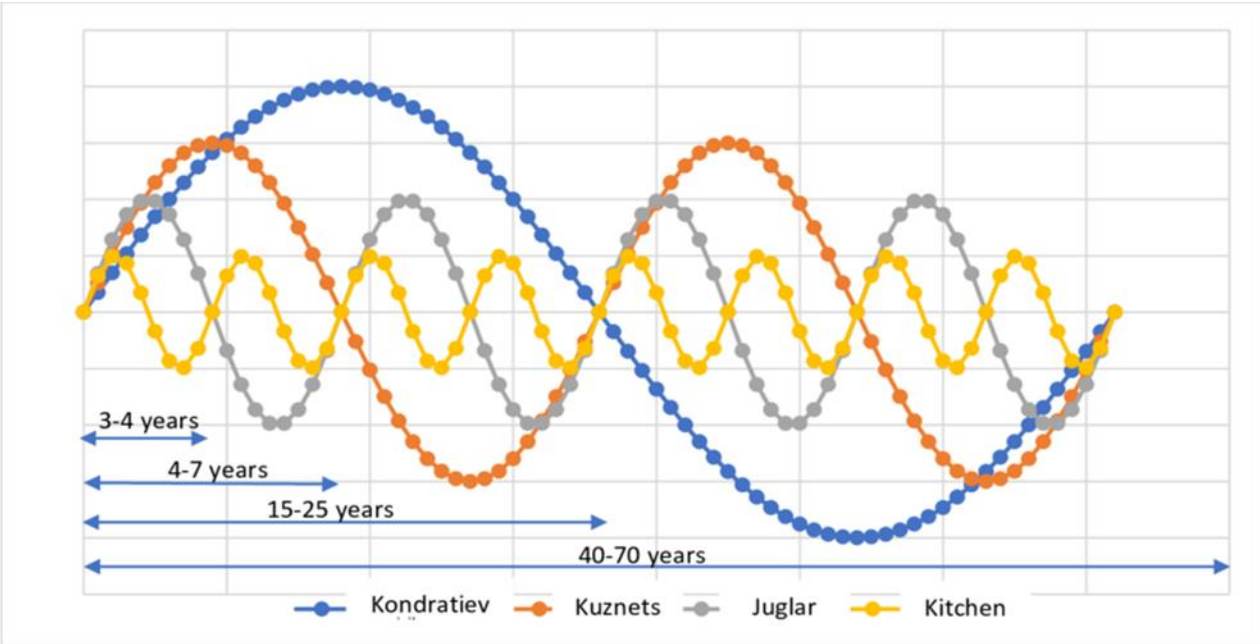

Figure 1. Wave and cycle illustrations [37]

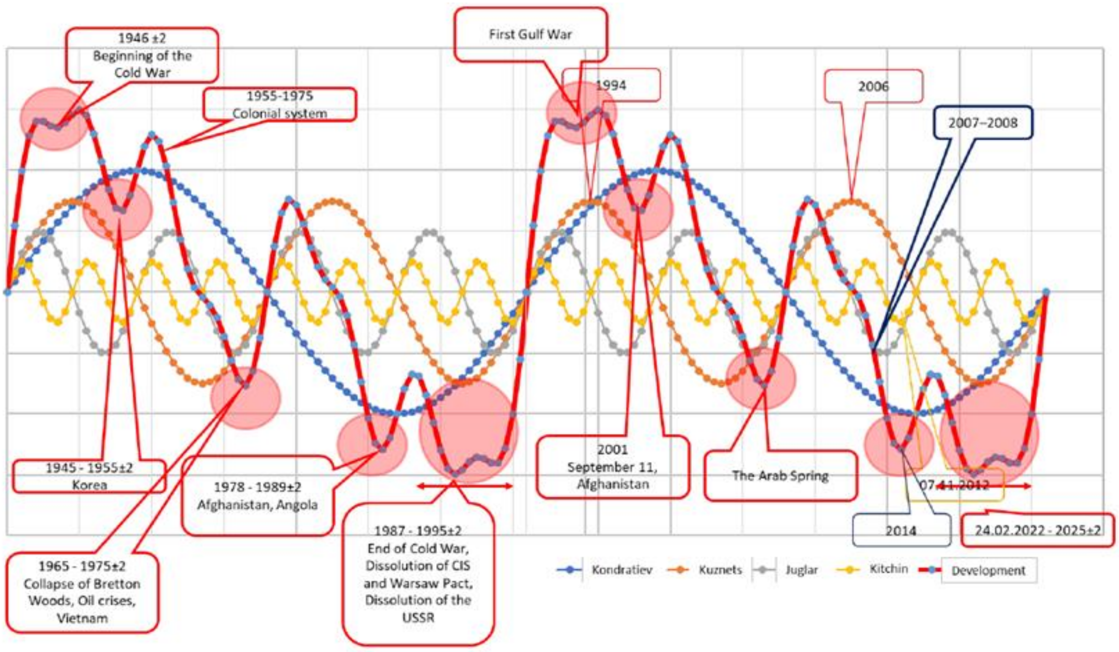

Figure 2. Cycles and Waves' illustrations regarding the world economy between 1945 and 2025 [38]

The illustrations show that the events and deep causes analysis are so important in the development of waves and cycles. In civil aviation history, generally, accidents and incidents are referred to as crisis time without a root-cause analysis regarding technological, political and economic incongruences at national, regional and international levels. For example, Concorde-type supersonic aircraft suffered from unbalanced decisions among regulatory (political and economic) bodies such as international airport authorities for a long time because of the

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aviation-related externalities of its high technological structures, like noise [39] and emissions [40] and [41]. Secondly, although aircraft manufacturers have electrical and hybrid-type aircraft production technologies, international regulatory bodies such as the European Union have anxieties about these technologies regarding infrastructural needs and requirements of the aviational industry chain and airports [1].

These cycles and waves sign historical accumulation under different titles, so relatively small events or momentous catastrophes can be the beginning of a crisis after these accumulations such as the Tenerife Accident of 1977 that shows the negligence in air traffic governance in the reality of meteorological events and as 11th September Terrorist Attacks that prove that the importance of international political consensus in aviational security matters.

As far as it is possible, one should be careful to interpret the positivity or negativity of an event in the civil aviation industry because a technological up-swing can cause a down-swing in political or economic dimensions or vice versa.

Besides these, the articulation finds a place in the postmodern explanation of facts and realities as a method. Humankind began to lose its descriptive force in science and knowledge accumulation, and these facts and realities in even an ordinary life require more complex explanations. Lyotard [58] explains this reality as a Postmodern condition. Because there is a restricted zone between the thinkable and the unthinkable in modernism, which gives birth to the postmodern condition for reasoning. Foucault [59] also defends and utilises different articulation processes and objects in conceptualizing objects such as madness and potency beyond the familiar human sciences such as psychology, sociology or anthropology. For him, the detailed articulation of knowledge or knowledge pieces explains that the whole and main focal point of this wisdom is the anthropology of knowledge. On the other hand, in the case of this paper, safety is considered as a postmodern condition at the crossroads of politics, technologic and economic ratiocinations and is tried to explain with a kind of knowledge articulation in its historical development process. Conversely, there are some knowledge restrictions regarding literature, especially on the development of civil aviation during the years of the Great Depression.

In light of these arguments, it will be focused on the important timespan between the First World War and the Second World War, and the safety understanding of civil aviation will be analysed, benefiting from three dimensions, emphasizing the importance of the Great Depression of 1929.

4. Findings

The period between the First World War and the Second World War is important and has a wave structure that can be described regarding economic, technological and political dimensions. Besides these, scaling the findings can be considered as an important tool.

4.1. Pre-WWI developments

The first corporate governance structures were seen in France and Europe, accepting aviation as a sports and safety and proficiency-related activity and encouraging it through skill development in the Fédération Aéronautique Internationale (FAI) of France in 1905 and the 1910 Paris International Air Navigation Conference. The air borders of a country were subject to strict national rules and regulations in 1911 with the Aerial Navigation Act in Great Britain [42]. Bilateral agreements began to come into force in Europe before the First World War. The civil aviation industry suffered from the absence of international harmony in the years of the First World War, politically, legally and economically. A multilateral conference was held with the aerial community of South and North America in 1916[2] .

[1] https://defence-industry-space.ec.europa.eu/eu-aeronautics-industry/alliance-zero-emission-aviation_en , *Access time: 03.06.2024.*

[2] *https://applications.icao.int/postalhistory/1910_the_paris_convention.htm#:~:text=The%201910%20Paris%20International%20Air,was%20a%20great%20historical%20importance , Access Time: 04.06.2024.*

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4.2. The development from the First World War to the Second World War

The years of The First World War had tremendous positive impacts on aircraft technologies in the development of aircraft engines and aircraft design in capacity, volume and production speed, on the other side, ground infrastructures and systems were demolished on the European side, but on the United States [1] However, a holistic safety understanding was an unanswered problem for civil aviation. But, if it is concentrated on the Paris Convention of 1919, the civil aviation community seemed to exceed the first important teaching and barrier of safety, therefore security, because of the sovereignty principle of nations over their geographies and freedoms of air [43] and maybe, this was the important first sign of internationalism in civil aviation politically. Again, Stannard [44] underlines the importance of the Paris Convention of 1919, emphasising the impartiality of the Soviet Republic and the United States. It is understood that safety is beyond aviation corporations; it has become a national and state-based policy. Even after the First World War, the trust of ordinary people in civil aviation increased year by year, as shown in Goldstrom [45], depending on the developments in this safety understanding that accepts safety as a competitive element within European countries, between European countries and the United States.

Before the Air Corps Act of 1926 or Air Commerce Act of 1926 which aimed to utilize a free market of aircraft manufacturers in the United States, technological development made felt its force doubling its speed and volume on both shores of the Atlantic Ocean alongside the vulgar competitive attitudes of aircraft manufacturers regarding associationalism in the United States [42]. Also, this event was important regarding the commercialization of civil aviation, which suffered from ambiguities under the impacts of a hodgepodge of small, inefficient carriers and unconnected routes [46]. Besides these, the legislation tasked the Secretary of Commerce with fostering air commerce, issuing and enforcing air traffic rules, licensing pilots, certifying aircraft, establishing airways, and operating and maintaining aids to air navigation [47]. In early 1928, the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce in the United States asked the National Advisory Committee for Aeronautics (N.A.C.A.) to develop a common approach for the analysis and reporting of aircraft accidents. In response to this request, the N.A.C.A. organized the Special Committee on the Nomenclature, Subdivision, and Classification of Aircraft Accidents [48]. After the formation of the Bureau of Air Commerce in 1935, with the new developments in aircraft technologies, new and large airports were developed, and primitive-long-distance air traffic management systems were developed [45]. Even before the Second World War, the concept of learning from deficiencies was promulgated in aviation. Safety was viewed as an industry-wide problem, rather than one for any single operator, manufacturer or State. The concept was further developed in wartime aviation [49]. On the other side, bilateral agreements are a weapon of countries that have developed aviation industries, such as the United States, because of their importance in creating new routes, destinations and capacities regarding passenger transportation. Kraus [50] analysed an example of this kind of agreement between China and the United States, emphasising the importance of military conflicts in the Asia-Pacific Region. The finding of Oster and Strong [51], which points out the requirement of government regulation in a context where there are changes regarding technology and global integration, is important for the safety concept. On the other side, Human Factors in aviation transformed into a scientific phenomenon during the Second World War [52].

4.3. The impacts of the Great Depression

The impacts of the Great Depression were felt by the industry. Between fiscal years 1932 and 1935, the organisation's budget was cut in half and research and development activities came to a virtual stop with the order of President Roosevelt in the USA. Aviation safety began to deteriorate in the same period. In 1935, the nation's air carrier passenger fatality rate was 4.78 per 1 million passengers; the following year, it jumped to 10.1. [47]. Although there is a financial crisis regarding the economies and finances of aviation companies and a decline in safety understanding, the industry has not seemed to lose its reputation and spread in the minds of people [53]. In

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the European side of aviation, it was observed a large development was observed regarding the exploiter policies of Hitler in military aviation for the raw material resources of Europe [54]; these extreme policies also mirrored the civil aviation comprehension of the European countries. In the years of war preparation and depression, civil aviation continued its development in European states and the United States, politically and technologically. Nevertheless, it was observed that the occurrence of negativities was under the impact of economic variables, especially in the United States, where there was extensive aircraft manufacturing and the existence of substitutions regarding other transportation modes. Safety development in the world of civil aviation context regarding business wave cycles is shown in Figure 3.

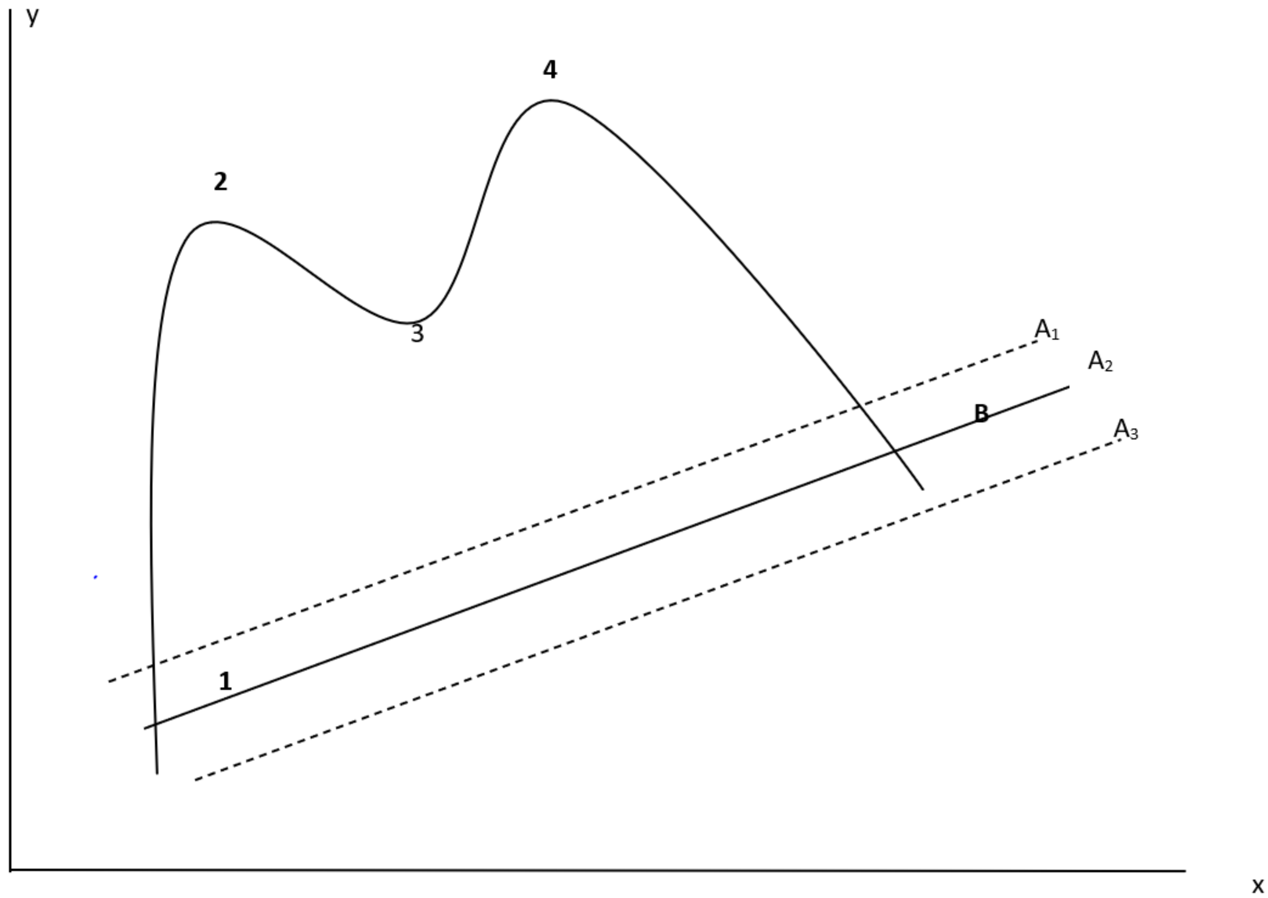

Figure 3. Shows the distribution of the events in a specific five-period criteria

There are two axes in the safety development stages of the civil aviation industry. As the X-axis shows time, the y-axis shows increased safety understanding in civil aviation. B curve the changes in civil aviation, on the other side A2 line is a reminder of the continual increasing process in comprehension of civil aviation regarding the development of safety in light of the arguments in technological, political and economic dimensions (It can be added here, social attitudes can be added to interpret to this line). A1 ve A3 lines show the possibilities of deviations from the A2 line (Sudden and unexpected events can change the industry structure). Point 1 illustrates the Wright brothers' flight on 17th December 1903 in the United States as the first aircraft when it was assumed at the beginning of civil aviation activities. Point 2 shows the First World War period between the years of 1914-18, Point 3 depicts the Great Depression process, and Point 4 points to the Second World War period of 1939-45.

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5. Conclusion

According to the findings, the period, which was subjected to this research, is one of the intensive periods of civil aviation politically, economically and technologically. The research shows that the conformity of these three dimensions is important regarding aviational safety. If there is a gap in only one of these dimensions, a safety problem is an indispensable reality. On the other hand, wave and cycle understanding of Marxist and Neomarxist is very important in economics to describe the triggering events in history. Accordingly, the great depression changed the reasoning of economics regarding state policies, the birth of Keynesian economics, and the patterns of consumption, saving and spending of economic actors. Depending on the changes in business cycle understanding, it can be concluded that safety problems occurred in the following years of the Great Depression, especially in the United States. These findings contribute to answering the historical journey of the safety concept regarding economic, political and technological dimensions.

The main acceptances, which indicate that technological and political changes have an impact on safety development, are also corrected. The aviational safety experienced a boom during the periods of World War 1 and World War 2 periods in parallel with business cycles. Civil aviation has an idiosyncratic structure and character; for this reason, the realities should be interpreted rigorously. A similar analysis can be designed for other political, technological and economic events, such as the position of global aviation security on the 11th of September or the impacts of COVID-19 on civil aviation. Nevertheless, a 3-dimensional approach should be used for a total description.

Conflicts of Interest: The author declares no conflict of interest.

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