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A Review on Scaled Flying Model for Flight Testing

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ABSTRACT: The work aims to assess scaled flight testing as a means to test and mature disruptive technologies that will enable a significant reduction in the design testing cycle. The idea is to assess the feasibility of using scaled Remote-Controlled models to assess design before prototype aircraft are built for extensive testing. This work will also discuss the sensors needed to capture data from scaled Remote-Controlled aircraft and data synthesis to assume a feasible mathematical model that will form inputs for the design of control laws. It concludes by highlighting future prospects and potential advancements in scaled testing methodologies, aiming to further enhance its role in shaping the next generation of aircraft technologies.

KEYWORDS: Scaled Remote-Controlled Models, Scaled Flight Testing.

I. INTRODUCTION

In the dynamic realm of aeronautical engineering, the quest for innovation and excellence is incessant. Advancements in technology have propelled the evolution of aviation, shaping not only how we traverse the skies but also how we conceive, design, and test aircraft. Central to this evolution is the process of flight testing, a meticulous and indispensable phase in the development of any airborne vehicle. Within this realm, scaled flying models emerge as vital tools, offering a bridge between theoretical concepts and real-world applications. This research endeavours to delve into the assessment of scaled flying models for flight testing, with a particular focus on understanding their handling qualities a critical aspect that underpins the safety and performance of aircraft.

The assessment of scaled flying models for flight testing and evaluating their handling qualities represents a pivotal endeavour in aeronautical research and development. Scaled flying models serve as indispensable tools in the preliminary stages of aircraft design, offering a cost-effective and efficient means to predict the behaviour of full-scale counterparts. By meticulously scrutinising these scaled models, engineers and researchers gain valuable insights into the aerodynamic performance, stability characteristics, and overall flight behaviour of prospective aircraft designs. This assessment process is multifaceted, encompassing a spectrum of methodologies and considerations aimed at ensuring the fidelity and reliability of the scaled model's representation of its full-scale counterpart. The allure of flight has captivated humanity for centuries, from the mythical tales of Icarus to the groundbreaking achievements of the Wright brothers. Over the decades, aviation has transitioned from a daring feat to a sophisticated science, guided by principles of aerodynamics, propulsion, and materials science. Yet, amidst this sophistication, the fundamental challenge of ensuring that an aircraft is not only capable of flight but also exhibits desirable handling characteristics remains paramount.

Key aspects of this assessment include aerodynamic analysis, structural integrity evaluations, propulsion system performance, and, critically, the appraisal of handling qualities. Handling qualities, often regarded as the subjective aspect of aircraft performance, encapsulate the pilot's perception and interpretation of an aircraft's responsiveness, stability, and controllability. Understanding and refining the handling qualities of scaled flying models are paramount, as they directly influence the safety, manoeuvrability, and ultimately, the success of a full-scale aircraft. Through meticulous testing and analysis, researchers strive to ascertain the flight characteristics of scaled models under various operating conditions, simulating real-world scenarios to anticipate and address potential challenges in the design phase. Moreover, the assessment of scaled flying models extends beyond mere performance metrics; it serves as a platform for innovation and refinement in aeronautical engineering. By leveraging advanced simulation techniques, experimental testing methodologies, and computational tools, researchers continually push the boundaries of aerodynamic

understanding, enhancing the accuracy and predictive capabilities of scaled models in emulating the behaviour of their full-scale counterparts. In this context, this paper delves into the intricacies of assessing scaled flying models for flight testing and handling qualities, exploring the methodologies, challenges, and implications inherent in this vital aspect of aeronautical research. By elucidating the intricacies of this process, we aim to contribute to the ongoing discourse surrounding aircraft design and development, fostering advancements that propel the aerospace industry towards safer, more efficient, and technologically sophisticated aviation solutions.

II. LITERATURE REVIEW

Lixin Wang, Xian Shuai Zuo, Hai liang Liu, Ting Yue, Xiaoping Jiab, Junín You has conveyed some ideas of scaled flying models the authors convey, in the preliminary design phase of aircraft, evaluating the flying qualities characteristics of full-size aircraft preliminarily through scaled-model flight test helps to shorten cycle times and reduce the technical risks of aircraft development. In this paper, the flying qualities evaluation criteria for scaled- model flight test are designed. In order to make full-size aircraft and scaled-model dynamically similar, the similarity relations between their configuration parameters, control law parameters, and flight condition parameters are analysed. In addition, the change rules of four different flying qualities parameters with the scale factor of aircraft size are analysed, including Time domain, frequency-domain, low order equivalent system (LOES) and pilot compensation. According to the obtained change rules, the flying qualities evaluation criteria applicable for scaled-model are designed by modifying the evaluation criteria for full-size aircraft. Finally, Lixin Wang et.al concludes the flying qualities evaluations of a sample full-size aircraft and its $\frac{1}{4}$ scaled-model are conducted, and the results show that the flying qualities evaluation of scaled-model can reflect the flying quality characteristics of the full-size aircraft accurately [1].

Alejandro Sobron, David Lundstrom, and Petter Krus have highlighted the growing interest in subscale flight testing, a method used in aeronautical research and development. The method, which has traditionally been used for estimating full-scale characteristics, is now being used as a low-cost technology-testing platform with relaxed similarity constraints. The authors found that subscale flight testing is increasingly shifting from a flight-characteristics estimator to a broader use as a low-cost technology-testing platform. The main challenge is the limited number of flow conditions that can be explored with free-flight subscale models at low altitude without accounting for undesired scale effects. However, the use of subscale flight testing to study both rigid and flexible-body flight dynamics is more common and constitutes an alternative to costly or unfeasible wind-tunnel tests. The authors also found that the general lack of specialized testing instruments, avionics, and analysis tools for subscale platforms is being filled by industrial systems for unmanned aerial vehicles and purpose-built systems mixing commercial off-the-shelf and custom-made solutions[2].

Kulkarni, G. La Rocca, LL.M. Veldhuis, G. Eitelberg the authors stated through this paper by saying that there is growing interest in unconventional aircraft designs coupled with miniaturization of electronics and advancements in manufacturing techniques have revived the interest in the use of Sub-scale Flight Testing (SFT) to study the flight behaviour of full-scale aircraft its early stages of design process by means of free-lying sub-scale models. SFT is particularly useful in the study of unconventional aircraft configurations as their behaviour cannot be reliably predicted based on legacy aircraft designs. In this paper, they surveyed the evolution of various design approaches use ensure similitude between a sub-scale model and its full-scale counterpart, which is an essential requirement to effectively perform SFT. Next, the authors, present an exhaustive list of existing sub-scale models used in SFT and analyse the key trends in their design approaches, test - objectives and applications. From this is review, we conclude that the state-of-the-art sub-scale model design methods available in literature have not been used extensively in practice. Furthermore, argue that one sub-scale model is not sufficient to predict the complete flight behaviour of a full-scale aircraft, but a catalogue of tailored sub-scale models is needed to predict full-scale behaviour. An introduction to the development of such a catalogue is presented in this paper, but the development of a formal methodology remains an open challenge. Establishing an approach to develop and use a SFT SFT catalogue of model's mod to predict full-scale aircraft behaviour will help engineers enhance confidence on their designs and make SFT a viable and attractive testing method. In the early stages of design[3]

Aleksander Olejnik, Stanisław Kachel, Robert Rogalski and Jarosław Mularczyk describes the proposition for developing the similar dynamically downscaled model of a medium range passenger aircraft and its application for researches in area of aerodynamics and flight dynamics. Computer simulations of aerodynamic flows commonly used in advanced aircraft designing, Numerous data on the characteristics of an airplane can be obtained from tunnel tests of

geometrically scaled models. To get complete characteristics from both stable and unstable flight conditions, dynamically scaled models are constructed and applied in static or dynamic tests. The dynamically similar scaled model is, in fact, reduced model of the real airplane which has specific qualities similar to qualities of a real aircraft and these relations strictly defined with specific similarity numbers (factors). The article presents methodology for determining scale factors in relation to geometric, aerodynamic, and structural properties (mass, stiffness) of the aircraft. The methodology is presented on the example of Tu-154 aircraft that crashed in April 2010 with the President of the Republic of Poland and many military and government officials on board. Dynamically similar downscaled model was designed in Faculty of Mechatronics and Aerospace of the Military University of Technology (FMA MUT, Warsaw, Poland) and is still being developed in the framework of ongoing research project. This paper presents only general assumptions taken for the process and the current stage of successively developed model. Aleksander Olejnik, et.al found that, developing dynamically scaled aircraft models is not easy and rather complicated process, but anyway it is relatively inexpensive in relevance to manufacturing costs of real aircraft. Thanks to the dynamic scaled models, the results of tests in-flight can be obtained at the conceptual design stage, which allows significantly to reduce the time and costs of new aircraft development. Moreover, the dynamic scaled models' tests given the opportunity to study the behaviour of aircraft in dangerous flight conditions. Increasing the popularity of such research should definitely increase the safety of aviation. Clearly, a significant amount of accurate experimental work is required in order to fully understand the correlation between accuracy of different structure parameters scaling and aerodynamic similarity. Research with the use of dynamic scaled model of Tu-154M aircraft has been started at Military University of Technology in Warsaw, which will allow to confirm the above theses in practice[4].

J.J. van Gorcum Ready for Take-off: Scaled Flight Testing An investigation into influence of scaling on the aerodynamic properties the analysis of the aerodynamic properties is split between the clean wing and the wing with an additional surface in the form of a flap. The aerodynamic properties investigated were the lift, moment and drag curve and the maximum lift coefficient. The clean wing was analysed using a quasi-3D analysis called Q3D, which is a combination of a vortex-lattice method (AVL) and a vortex panel method (XFOIL). A modification of XFOIL, called RFOIL, is used to analyse the difference in maximum lift coefficient between the aerofoil of the scaled and full-scale case. RFOIL is selected because of the better results near stall. The wing with flap is investigated using a vortex lattice method, in this case again AVL, where the aerofoil with flap is investigated using the Euler solver MSES. Finally the maximum lift coefficient for the wing with flap is analysed with the semi-empirical Pressure Difference Rule. The Pressure Difference Rule states that there is a ratio between the peak pressure and the trailing edge pressure, on a surface, at which maximum lift occurs. The methods are limited in their incorporation of viscous effects, the 2D-analysis tools (XFOIL, RFOIL and MSES) only include viscous effects in the small boundary layer region. AVL does not include viscous effects directly, but only via a correction factor for the lift-curve slope. The difference between the full and scaled case can be reduced by an optimization. If an optimization is to be done, it must be done on the whole of configurations and flight conditions. As the next step into a development of a scaled flight test model, the exact extend of tests must be determined, only then can it be investigated how scaling affects the results of testing. No direct solutions exist to completely overcome the gap between the full and scaled aerodynamic properties of a flight-testing model, however aerofoil shape optimization does provide a better similarity [5].

III. ODD CONFIGURATION AIRCRAFTS

Odd-configuration aircraft encompass a diverse range of designs that depart from the conventional layout of fixed-wing airplanes or rotary-wing helicopters. Examples include blended-wing body (BWB) aircraft, tailless drones, flying wings, and tiltrotor aircraft, among others. These designs often feature novel aerodynamic principles, such as distributed propulsion, boundary layer control, and lifting body concepts, which challenge traditional notions of aircraft performance and efficiency. Scaled flight testing provides a cost-effective and flexible means of evaluating the performance, stability, and handling qualities of aircraft designs before full-scale prototypes are constructed. Odd-configuration aircraft offer several advantages as applications for scaled flight testing.



Fig. 1 DRDO Ghatak SWiFT(web).

IV. SCALED FLYING MODELS

Scaled flying models are reduced-scale replicas of full-scale aircraft used for testing and evaluating aerodynamic performance, handling qualities, and other flight characteristics. They provide a cost-effective and efficient way to conduct comprehensive testing in a controlled environment before committing to full-scale prototypes. Scaled flying models are typically designed to accurately represent the aerodynamic characteristics of their full-scale counterparts, while incorporating simplified systems and components to reduce cost and complexity. They can range from small radio-controlled models to larger unmanned aerial vehicles (UAVs), depending on the specific testing requirements. Treating a scaled flying model involves several meticulous steps, starting with planning and design. Begin by selecting an existing aircraft to replicate and gathering detailed blueprints and dimensions to ensure accuracy. Decide on the scale, which determines the size of your model. Scaled R.C flying models offer a unique and accessible introduction to aviation principles and aerodynamics. Through the process of building and flying these models, enthusiasts gain hands-on experience with aircraft design, assembly, and maintenance. This hands-on exposure can help foster a greater interest in aviation and potentially inspire the next generation of aviation professionals. The technological advancements in scaled R.C flying models have been remarkable, with innovations in design, materials, and electronics steadily pushing the boundaries of performance and realism. The scaled-model has the advantages of small size, light weight, and low manufacture cost. Evaluating the flying qualities characteristics of full-size aircraft preliminarily through scaled-model flight test will reduce the technical risks of aircraft development. The numbers on the left side of the colon or slash represent the size of the original object, usually 1. In other words, 1= full size. After the colon or slash, the number will reflect the model's size.

V. SCALED FLYING MODEL FOR FLIGHT TESTING

Aircraft development is an intricate and highly technical process that involves multiple stages of design, testing, and validation. One crucial step in this process is flight testing, which helps engineers and designers understand how an aircraft will perform under various conditions. Scaled flying models play a significant role in this phase, offering a practical and cost-effective means to gather critical data and insights. These models, which are miniature versions of full-scale aircraft, allow for the replication of aerodynamic and performance characteristics, enabling detailed analysis and refinement of designs before full-scale prototypes are built and tested. The use of scaled models in flight testing has a long history dating back to the early days of aviation. Pioneers like the Wright brothers employed wind tunnel tests with scaled models to study and perfect their aircraft designs. Over the years, advancements in materials, construction techniques, and computational tools have significantly enhanced the precision and utility of scaled models. Today, these models are not just limited to wind tunnel tests but are flown in actual conditions, providing a wealth of real-world data.

Aerodynamic Similarity and Scaling Laws

One of the primary challenges in using scaled models is ensuring aerodynamic similarity, meaning the scaled model should exhibit the same aerodynamic behaviour as the full-scale aircraft. This is achieved through the application of scaling laws, particularly the Reynolds number, which is a dimensionless quantity used to predict flow patterns in different fluid flow situations. By maintaining the same Reynolds number, engineers can ensure that the airflow

characteristics around the model and the full-scale aircraft are comparable. This often requires adjustments in the testing environment, such as using high-speed wind tunnels or adjusting the viscosity of the fluid medium.

Types of Tests that can be Conducted

Scaled flying models are employed in a variety of tests, each serving a different purpose in the development process. Aerodynamic testing involves assessing lift, drag, and other forces acting on the aircraft. Stability and control tests help determine how the aircraft responds to control inputs and external disturbances. Structural testing examines the integrity of the model under different loads and stresses. Additionally, performance testing evaluates the overall efficiency and effectiveness of the aircraft design. These tests can be conducted in wind tunnels or in open flight, each offering distinct advantages and insights.

Advantages of Using Scaled Models

The use of scaled flying models offers numerous advantages. One of the most significant is cost reduction. Building and testing full-scale prototypes is an expensive endeavour, often costing millions of dollars. Scaled models, being smaller and simpler, are much cheaper to construct and operate. They also allow for quicker turnaround times; multiple iterations can be tested and refined in a shorter period, accelerating the overall development process. Furthermore, these models provide a safe testing platform, minimizing the risks associated with testing new designs at full scale. Another advantage is the ability to conduct tests in controlled environments. Wind tunnels, for instance, allow for precise control over test conditions, such as airspeed, temperature, and pressure, providing consistent and repeatable results. Open-flight tests with scaled models can simulate real-world conditions more closely, offering insights that might not be possible in a wind tunnel.

Challenges and Limitations

Despite their benefits, scaled flying models also come with challenges and limitations. Achieving perfect aerodynamic similarity is often difficult, and certain phenomena, such as turbulence, may not scale linearly. The complexity of modern aircraft, with their advanced avionics and systems, can also be challenging to replicate accurately in a scaled model. Additionally, the data obtained from scaled models must be carefully interpreted and validated, often requiring sophisticated computational tools and simulations to correlate the results with full-scale performance.

Technological Integration

The integration of modern technology has significantly enhanced the capabilities of scaled flying models. Advanced sensors and telemetry systems allow for real-time data collection and analysis during flight tests. Computational fluid dynamics (CFD) simulations complement physical tests by providing detailed insights into airflow and other aerodynamic factors. The use of machine learning algorithms to analyse test data is also becoming more common, enabling more accurate predictions and optimizations.

Scaled flying models are a cornerstone of modern aircraft development, offering a practical and efficient means of testing and refining aircraft designs. Their ability to replicate key aerodynamic and performance characteristics of full-scale aircraft in a cost-effective manner makes them invaluable in the iterative design process. Despite certain challenges and limitations, the integration of advanced technologies and continuous improvements in construction techniques ensure that scaled models will remain a vital component of the aerospace industry, driving innovation and enhancing the safety and performance of future aircraft.

VI. HANDLING QUALITIES

The flying qualities of an airplane is related to the stability and control characteristics and can be defined as those stability and control characteristics are important in forming the pilot's impression of the airplane. The pilot forms a subjective opinion about the ease of difficulty of controlling the airplane in the steady and manoeuvring flight. In addition to the longitudinal dynamics, the pilot's impression of the airplane is influenced by the feel of the airplane, which is provided by the stick force and stick force gradients. The Department of Defence and Federal Aviation Administration has a list of specification dealing with airplane flying qualities. These requirements are used by the procuring and regulatory agencies to determine whether an airplane is acceptable for certification. The purpose of the requirements is to ensure that the airplane has flying qualities that place no limitation in the vehicle's flight safety nor



restrict the ability of airplane to perform its intended mission. The flying qualities are specified in terms of three levels. The levels are determined on the basis of the pilot’s opinion of the flying characteristics of the airplane.

Table.1 Flying Qualities

SL.NO;	LEVEL	DESCRIPTIONS
1	Level 1	Flying qualities clearly adequate for the mission flight phase.
2	Level 2	Flying qualities adequate to accomplish the mission flight phase but with some increase in pilot work load and/or degradation in mission effectiveness or both.
3	Level 3	Flying qualities such that the airplane can be controlled safely but pilot work load is excessive and/or mission effectiveness is in-adequate or both. Category A flight phases can be terminated safely and B and C flight phases can be completed.

VII. CONCLUSION

At the conclusion of this project report, it is clear that scaled flight test is presented as a valuable tool for testing and refining disruptive technologies with the aim of significantly accelerating the design testing cycle. There is a lot of potential for efficiency and cost savings when employing remote-controlled scale models to assess designs before building aircraft prototypes for aircraft testing. Studying the sensors needed to capture aircraft data at scale and then synthesizing them to develop a feasible mathematical model to serve as the basis for the design of control laws has proven to be a promising approach. Accurate data collection and analysis at this early stage of the design process can provide valuable insights to optimize the performance and safety of future aircraft.

However, it is crucial to recognize the limitations of this approach. Aspects such as extrapolating data from scale models to full-size aircraft, the complexity of replicating real flight conditions in reduced models, and the need to verify the accuracy of mathematical models derived from these synthesized data must be addressed. Ultimately, this project highlights the importance of scale flight testing and SFT as a valuable tool in the aircraft design process, although caution should be exercised and the inherent limitations of this approach should be recognized. Integrating accurately collected data from scale models into robust mathematical models can boost innovation in aircraft design and accelerate the development of disruptive technologies in the field of aviation.

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