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Research on Propeller Application Configurations on Aircraft

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Abstract- This paper studies the use of propellers on aircraft. For single-engine aircraft, the propeller is commonly installed at the nose, on the fuselage, or at the tail, with the nose-mounted configuration being the most optimal. Multi-engine aircraft generally use symmetrically arranged propellers on both sides of the wings to increase power and safety. Propeller aircraft offer high efficiency at low speeds and low fuel consumption, making them suitable for transport, training, sport aviation, UAVs, and short-range flight. Their main limitation is the decrease in efficiency at high speeds, so they are less suitable for high-speed missions.

Keywords— Aircraft propeller; Propeller configuration; Propeller aerodynamics; Variable-pitch propeller; Propeller performance; Propulsion system; Turboprop engine; Aircraft propulsion.

I. INTRODUCTION

Throughout aviation history, propellers have played an important role in generating aircraft thrust and remain widely used today. Despite the widespread use of jet engines, propeller-driven aircraft offer advantages in fuel economy, low-speed efficiency, and operational flexibility. They are commonly used for short-range transport, pilot training, sport aviation, reconnaissance, and unmanned aerial vehicles (UAVs). Propeller configurations range from nose-, fuselage-, and tail-mounted arrangements on single-engine aircraft to symmetrical wing-mounted configurations on multi-engine aircraft. Therefore, optimizing propeller design and operation remains important for improving efficiency and expanding applications in modern aviation

II. BASIC CHARACTERISTICS OF AIRCRAFT PROPELLERS

1. Geometric Parameters of Aircraft Propellers

For propeller aircraft, as well as helicopters, the propeller is the component that generates thrust. When the propeller operates (rotates), it accelerates the airflow rearward. The reaction of the airflow on the propeller blades generates the propeller's thrust.

Propeller diameter D: The diameter of the circle traced by the blade tip during rotation.

R = D/2 — propeller radius.

Number of blades m: The number of blades is normally from 2 to 4. Increasing the number of blades causes adverse interference between the blades, leading to a reduction in important subsonic propeller aerodynamic characteristics.

Blade airfoil profile: The concept of a blade profile is similar to that of a wing airfoil. It is characterized by parameters such as relative thickness and relative camber. Subsonic propellers commonly use profiles with a rounded, relatively blunt nose and maximum thickness at approximately one-third of the chord. Supersonic propellers use special supersonic profiles with a sharp nose and maximum thickness near the middle of the profile.

Blade section: A blade section is the intersection of a blade with a cylinder coaxial with the propeller. r is the radial distance from the propeller axis to the blade section.

Blade-section chord: The chord is the straight line connecting the leading and trailing edges of the blade section under consideration. The chord length

2. Represents the Width of the Blade Section.

Blade sweep angle γ: The sweep angle is the angle between the tangent to the blade axis at a given point and the blade's axis of rotation. The sweep angle varies along the blade and increases toward the blade tip.

Propeller plane of rotation: The plane perpendicular to the propeller axis and passing through the axis of rotation.

Blade-section installation angle φ: The installation angle is the angle between the chord of a blade section and the propeller plane of rotation.

Reference blade section: The reference section is a selected blade section used to evaluate the required propeller parameters. The reference section is usually located at a specified relative radius. The installation angle at the reference section is denoted by φ0 or φ0.75.

Blade twist: Blade twist is the variation, with radius, of the installation angles of the blade sections relative to the reference section: $\varphi - \varphi 0 = f(r)$.

Propeller swept area: The area F of the circle whose radius equals the propeller radius: $F = \pi D^2/4$.

Azimuth angle ψ: The position of a blade on the circular path is characterized by the azimuth angle ψ. It is measured from the projection of the undisturbed-flow velocity vector onto the propeller plane of rotation, in the direction of propeller rotation.

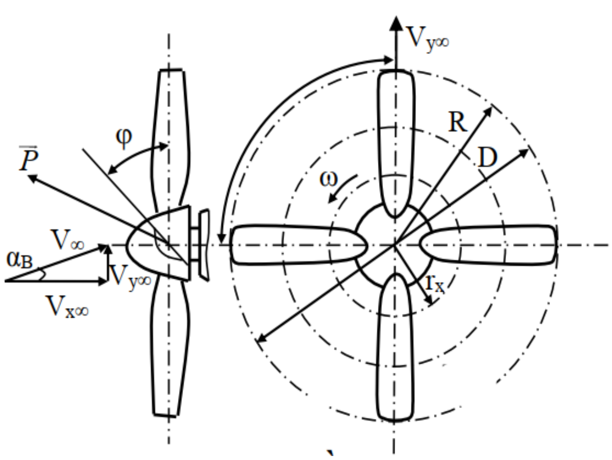

Figure 1. Propeller diagram

3. Characteristics of Different Aircraft Propeller Types

Propeller design must ensure sufficient maximum power to meet aircraft requirements under all operating conditions, including takeoff, climb, level flight, and acceleration. Based on the required propeller characteristics and power, different propeller blade forms are designed.

Propellers classified by blade shape and profile

Because the actual velocity components and loads acting on different blade elements vary, different blade shapes are manufactured according to the required characteristics of each aircraft in order to optimize propeller performance. Common blade forms include: blades that taper toward the tip, swept or scimitar blades, and non-deformed/straight blade forms.

Propellers classified by blade installation-angle configuration

- Fixed-pitch propellers: The blades are manufactured as an integral unit or assembled but their installation angle cannot be adjusted. The propeller maintains one installation angle during operation.
- Ground-adjustable-pitch propellers: The blade angle can be adjusted while the aircraft is on the ground before the engine is operated. This type commonly has a central hub, and the blade angle is determined from the aircraft's technical parameters.
- Two-position propellers: The blade pitch can be changed from one fixed position to a second predetermined position by the pilot during flight.
- Variable-pitch propellers: The pilot can change the blade angle during flight or engine operation, generally through a hydraulic pitch-control mechanism.
- Constant-speed propellers: These use a hydraulic mechanism to automatically adjust blade pitch. During operation, the propeller automatically changes its blade angle to maintain a constant rotational speed. If engine power increases, blade pitch increases so that the propeller absorbs the additional power without changing rotational speed. If engine

power decreases, blade pitch decreases, reducing rotational resistance and maintaining constant propeller speed.

- Feathering propellers: This is a constant-speed propeller capable of changing its blade angle to produce approximately zero thrust in the event of engine failure, thereby reducing drag. The blades are positioned so that the propeller's aerodynamic forces do not drive the propeller rotation, minimizing drag.
- Reversible-pitch propellers: These are constant-speed propellers whose blade pitch can be reversed to produce negative thrust. They are commonly used for aircraft operating from short runways or aircraft with high weight and inertia.

Propellers classified by blade material

- Wooden propellers: Wooden propellers were first used on private and commercial aircraft before World War II. A blade is not necessarily made from one solid block of wood; it may be laminated from multiple smaller elements. Many types of wood can be used, with yellow birch, sugar maple, black cherry, and black walnut among suitable choices. Thin wooden blade laminations tend to reduce blade bending. A standard laminated propeller commonly uses 5 to 9 thin blade elements with an effective thickness of approximately 3/4 inch.
- Metal propellers: High-strength steel propellers were developed for military purposes in the nineteenth century. Modern aluminum-alloy propellers are high-strength, heat-treated, and machined as integral components. Metal propellers are now widely used on aircraft. Their general shape is similar to that of wooden propellers, but they are usually thinner.
- Composite propellers: The main advantages of composite materials are the ability to manufacture structures according to different technical requirements, high stiffness and mechanical strength of the reinforcing components, and a matrix that provides cohesive bonding. Composite structures can withstand heat and corrosion under harsh environmental conditions. Composite propellers are lightweight, strong, environmentally resistant, easy to install, and have high specific strength and elastic properties, as well as good resistance to chemical corrosion and low thermal and electrical conductivity.

Propellers classified by operating characteristics

Based on operating characteristics, aircraft propellers can be divided into subsonic and supersonic propellers.

- Subsonic propellers are used for low-speed aircraft. Their rotational speed is selected so that the resultant velocity W, combining blade rotational velocity and aircraft velocity, remains subsonic over the blade.
- Supersonic propellers are intended for high-speed aircraft operating near or above the speed of sound. Their rotational speed is selected so that the resultant velocity over the blade is supersonic.
- However, the distinction between subsonic and supersonic propellers is relative. Some propellers have subsonic flow over blade sections near the root and supersonic flow over sections near the tip. These may be referred to as mixed-regime propellers.

Propellers classified by energy source

The energy source for propeller aircraft may be a gas-turbine engine, an internal-combustion engine, or an electric motor powered by solar energy, batteries, or accumulators.

- Turboprop engines: Most of the energy of the combustion gas flow is converted into mechanical power on the turbine shaft to drive the propeller, either through a reduction gearbox or directly. Part of the power drives the compressor and other equipment, while the thrust produced by the exhaust gas is relatively small. The propeller generates thrust by accelerating part of the air rearward to a velocity relatively greater than the aircraft speed, causing the airflow reaction to produce thrust. Turboprop engines are used on aircraft with Mach numbers below about 0.5 and flight altitudes generally not exceeding approximately 12–14 km.
- Piston engines: Propeller-driven piston engines are commonly two-stroke or four-stroke engines. They offer high efficiency at low speeds

and low altitudes, have simple construction, and are easy to maintain. Their simple operating cycle allows significant power increases and good specific efficiency.

- Electric motors: Electric motors can also power propellers. Their advantages include very low heat generation during operation, relatively low energy consumption, and low acoustic signature. Their main disadvantages are limited power and difficulties in maintaining continuous energy supply when batteries are used. Solar-powered systems have relatively high cost and manufacturing challenges. Therefore, electric propulsion is generally used on ultralight aircraft, UAVs, and model aircraft.

III. PROPELLER APPLICATION CONFIGURATIONS ON AIRCRAFT

As science and technology, and aviation engineering in particular, have developed, propeller theory has advanced rapidly and propeller structures and flight characteristics have become increasingly refined. One key requirement is to provide adequate thrust, power, and efficiency at the selected altitude and flight speed. In addition to engine and propeller power, performance also depends on how the propeller is installed and used on the aircraft.

Figure 2. Nose-mounted propeller configuration on the Beechcraft T-6 Texan II trainer aircraft (USA).

Single-engine Aircraft

For single-engine aircraft, the engine and propeller are generally arranged in the vertical plane containing the aircraft longitudinal axis. The engine may be installed at the front/nose, on the fuselage, or at the rear/tail. The nose-mounted propeller and engine configuration is the most favorable because it is less restricted during ground taxiing and optimizes blade operation. In this arrangement, the airflow entering the propeller is relatively undisturbed. Its disadvantage is that propeller noise affects the pilot.

Figure 3. Fuselage-mounted propeller configuration on the SeaMax M-22 (USA).

Figure 4. Rear/tail-mounted pusher propeller configuration on the Prescott Pusher (USA).

Fuselage-mounted and rear-mounted configurations have more difficulties and limitations. Increasing propeller diameter is constrained by aircraft dimensions and by tip compressibility/wave-drag effects. Increasing blade width, especially with more than four blades, increases blade-to-blade interference and reduces propeller efficiency. In addition, the airflow entering the propeller may already be disturbed by upstream aircraft components, causing thrust losses.

Multi-engine propeller aircraft

Multi-engine propeller configurations are commonly used on aircraft requiring high power, such as heavy propeller-driven aircraft. In this configuration, the propellers are arranged symmetrically on both sides of the wings.

Figure 5. Four-propeller configuration on the An-22 heavy transport aircraft (Russia).

The advantages of this configuration are high power and increased safety. If one engine fails, the aircraft can continue to operate.

Propeller configurations according to engine/turbine arrangement

Depending on the turbine architecture, with one or multiple stages, the propeller may be arranged coaxially with the compressor shaft. This produces a turboprop configuration with a coaxial arrangement. The propeller may also be driven by a separate turbine stage, with the propeller shaft mechanically independent of the compressor shaft. This is a free-turbine turboprop engine.

In addition, propellers may be arranged in one or multiple rotating stages. When two, three, or more rotating stages are used, the system is referred to as a two-, three-, or multi-stage turboprop configuration.

Propeller configurations according to reduction-gear arrangement

The installation of aircraft propellers can also be described according to the arrangement of the reduction gearbox. If the propeller is located in front of the engine, the reduction gearbox is arranged longitudinally with the engine and is referred to as an in-line reduction arrangement. On aircraft where the propeller shaft is perpendicular to the engine shaft, an offset or non-coaxial reduction gearbox is required. For multi-stage propellers with counter-rotating stages, planetary or differential planetary gear systems are commonly used.

Advantages and limitations of propeller aircraft

The main advantage of propeller aircraft is that the propeller produces thrust efficiently at low speeds. Compared with jet-powered aircraft, propeller aircraft can achieve very high propulsive efficiency in the low-speed regime, resulting in low specific fuel consumption and economical operation. This increases range and endurance. Consequently, propeller aircraft are generally used at relatively low flight speeds, approximately Mach 0.15–0.5. Typical applications include transport aircraft, trainer aircraft, sport aircraft, UAVs, and short-range passenger aircraft.

Conversely, as flight speed or propeller rotational speed increases, the airflow over the blades may become supersonic. Significant velocity differences develop along the blade, and these cannot be adequately resolved by changing blade pitch, resulting in reduced propeller efficiency. Therefore, propeller aircraft are less widely used in high-speed regimes where they are less efficient and economical.

In summary, regardless of the selected configuration, propeller aerodynamic quality is a critical factor. It depends primarily on the number of blades, blade shape (twist, geometric dimensions, etc.), propeller diameter, and blade profile. The blade profile must be selected appropriately for subsonic or supersonic operation to achieve maximum aerodynamic performance.

IV. CONCLUSION

The propeller is one of the key components determining aircraft performance and economy. The study shows that each propeller type has its own advantages and disadvantages. Fixed-pitch or simply adjustable propellers have compact, lightweight structures and are easy to manufacture and maintain, but their efficiency is limited when flight conditions change. Variable-pitch, constant-speed, and reversible-pitch propellers improve adaptability, efficiency, and safety, but require more complex structures and higher costs. In terms of materials, wooden propellers are inexpensive and lightweight but less durable; metal propellers are strong and widely used; while composite propellers are increasingly preferred because of their high strength, low weight, and good corrosion resistance.

In operation, propeller aircraft have major advantages at low speeds, with high efficiency and low fuel consumption, making them suitable for short-range transport, training, sport aviation, and UAVs. However, efficiency decreases significantly at higher speeds, limiting their applications. Therefore, selecting an appropriate propeller type and installation configuration is critical to flight quality and also opens up further development opportunities in modern aviation.

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