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How Is It Possible To Reduce A Combat Helicopter's Auditory Signature To Increase Its Survivability?

Vidyut C Murali

The International School, Bangalore

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ABSTRACT

The need for silent helicopters has already manifested itself in the civilian and military fields. Helicopters with a reduced auditory signature would give the helicopter tactical advantages in an engagement and hopefully give it the 'edge' allowing it to carry out its duties effectively. The main objective of this paper is to determine what technologies can be incorporated onto new helicopters in order to reduce the amount of noise they produce.

INTRODUCTION

Helicopters, such as the AH-64 Apache and the UH-60 Black Hawk, are one of the least survivable aircraft in the world. They operate at lower altitudes and at lower speeds, which means they have less energy to trade into altitude. This could cost them when evading a Surface-to-Air (SAM) missile such as a Man-portable Air-defense system (MANPADS).

Should a missile hit the helicopter, its pilots cannot eject due to the main rotor overhead. Hence, they are taught to execute an emergency procedure known as an autorotation in the event of the failure of a mission-critical component such as the tail rotor. This means, in most airframes, the pilots must stay in the craft and run the risk of dying during the crash. Methods have been developed to counter the SAM threat such as radar jamming, countermeasures like chaff and flares, and nap-of-the-earth flying (flying very close to the ground). The third, unfortunately, exposes helicopters to small-arms and Rocket-Propelled-Grenade (RPG) fire. RPGs, though inaccurate in strong winds, pose a great threat to combat helicopters. Designed as anti-tank weapons, RPGs can be fatal to helicopters if hit in any mission-critical component[1].

Instead of improving a helicopter's ability to take punishment (which can only go so far given the nature of their airframe) another method must be used: reduction in detectability by radar, visual or auditory means. Being so close to the ground, helicopters emit a huge amount of noise, which enemy combatants can hear from many miles away giving them time to prepare to shoot it down. Hence, the sound a helicopter makes must be reduced. Helicopter noise comes from three components: the main rotor, the tail rotor, and the engine.

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The first RAH-66 Comanche prototype which was a stealth helicopter with an reduced acoustic signature

MAIN ROTOR

The main rotor of a helicopter

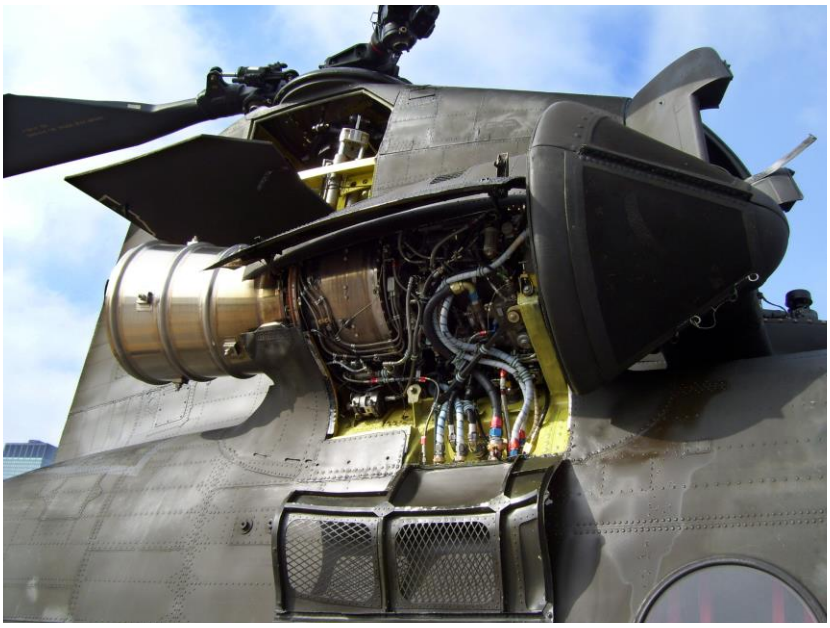
Noise from the main rotor comes in these forms: thickness noise, loading noise, and Blade Vortex Interaction (BVI). Thickness noise is caused by the displacement of air by the main rotor blades which is directed forward of the helicopter. Loading noise is caused by aerodynamic forces, such as lift and drag, acting on the main rotor blades. This noise is primarily directed downwards of the helicopter. Lastly, BVI noise is generated when a blade passes through the vortex created by a previous blade. BVI, or blade slap, creates the most noise and gives the helicopter its unique acoustic signature[2].

TAIL ROTOR

The tail rotor of a helicopter (Flemming, 2007)

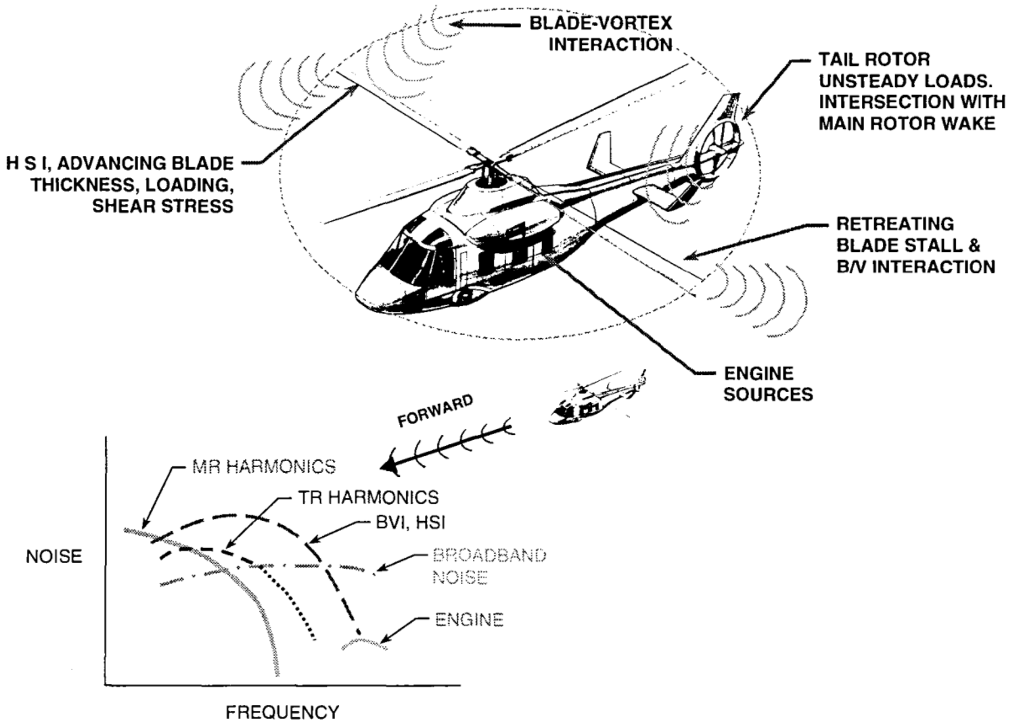
Tail rotors generate noise in the same ways as the main rotor does. However, the tail rotor blades, spinning at a high RPM (revolutions per minute), pass through the vortex of the main rotor blades which can cause an increase in BVI noise[3].

ENGINE

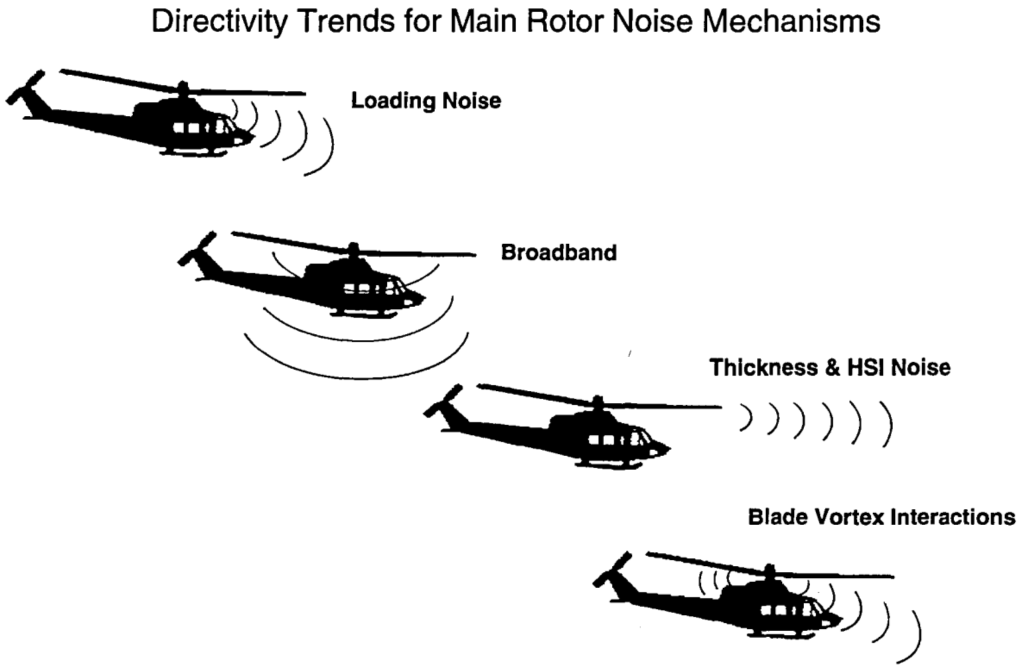


A turboshaft engine used on the CH-47 Chinook helicopter

The engines used to power helicopters are called turboshaft engines, which work similarly to turboprop, turbofan and turbojet engines. However, turboshaft engines have a shaft connected to a fan at the back of the engine which turns the main rotor. The engine produces noise in two different ways: combustion noise and turbomachinery noise. Combustion noise is simply a product of the combustion of jet fuel in the engine while turbomachinery noise is caused by the engine itself [4]. It is important to note that, after using an engine muffler, engine noise is very much secondary to main rotor and tail rotor noise. As a result, it is typically not a target for noise reduction.



Sources of helicopter noise[5]



Each noise source has a unique directivity trend[6]

CURRENT NOISE REDUCTION TECHNIQUES

Considerable research has already been conducted by teams aiming to reduce helicopter noise. One such technique is to reduce the operating tip speed of the main and rotor blades, and to use more blades in the main rotor . This works as it would reduce the size of the tip vortex created hence reducing BVI noise and would change the frequency distribution of the sound. Mostly, it has proven effective but only up to a certain point. If the tip speed is reduced to a certain point, the rotor solidity must be increased to maintain the cruise velocity of the helicopter and the torque in the drive system will go up. This means there must be more rotor control hardware, stronger drive-train components, and added anti-torque capabilities. All of this increases the weight of the helicopter which in turn reduces its performance and increases its unit cost[5[.

Table 3-1. Weight/Torque/Cost Impacts

Rotorcraft Function	5 dB Over-Flight Noise Reduction Candidate
Main Rotor Tip Speed Decrease	9.3%
Gross Weight Increase	4.7%
Empty Weight Penalty	8.2%
Fuel Weight Penalty	1.2%
Main Rotor Torque Increase	15.6%
Non-Recurring Costs	$40.73m
Recurring Production Costs	$0.15m

THE EFFECTS OF A REDUCTION IN TIP SPEED OF THE MAIN ROTOR[5]

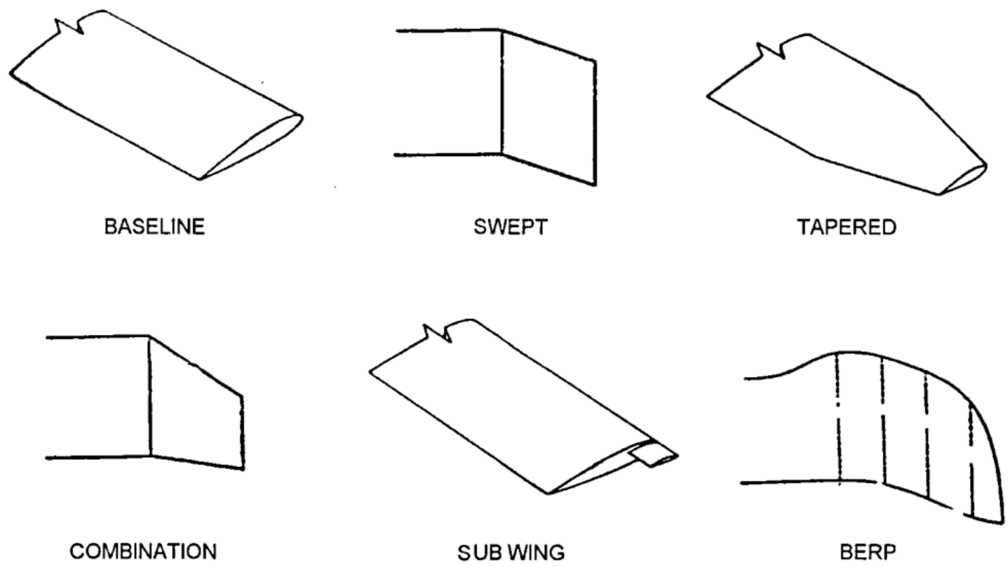
Another way in which helicopter noise is being reduced today is with the BlueEdge blades designed by Airbus Helicopters; a French aerospace laboratory, ONERA; and the German Aerospace Center. Due to its unique shape, it minimizes the formation of blade vortices, hence reducing BVI-generated noise. BlueEdge blades are used on helicopters such as the H160 and H145, and are able to reduce noise levels by 3-4 decibels[6]. However, it is not in widespread use and is used exclusively on civilian Airbus helicopters.

BlueEdge helicopter blades have a unique shape which minimizes blade vortices.

A third way helicopter manufacturers can reduce noise produced by the tail rotors on a helicopter is with the use of fenestrons. Fenestrons are ducted fans which act as the anti-torque rotor at the tail end of the helicopter where the tail rotor would go. Developed in the 1960s, it was originally meant to protect the ground crew from a spinning tail rotor but it also helped to considerably reduce the noise produced by the tail rotor. Firstly, the ducted fan would block the noise that was aimed downwards which reduced noise heard on the ground. Secondly, the blades inside the fenestron would not interact with the blade vortices left behind by the main rotor, drastically reducing the production of BVI noise. Thirdly, the leaves inside the fenestron are placed with different angles from each other so the noise produced is spread over different frequencies[7]. This is very similar to the concept of modulated blade spacing which will be explored later in this paper. However, after tests carried out on a 11-blade fenestron, many concluded that only light helicopters could benefit from fenestrons: the 11-blade fenestron was too heavy, loud and consumed too much power[8].

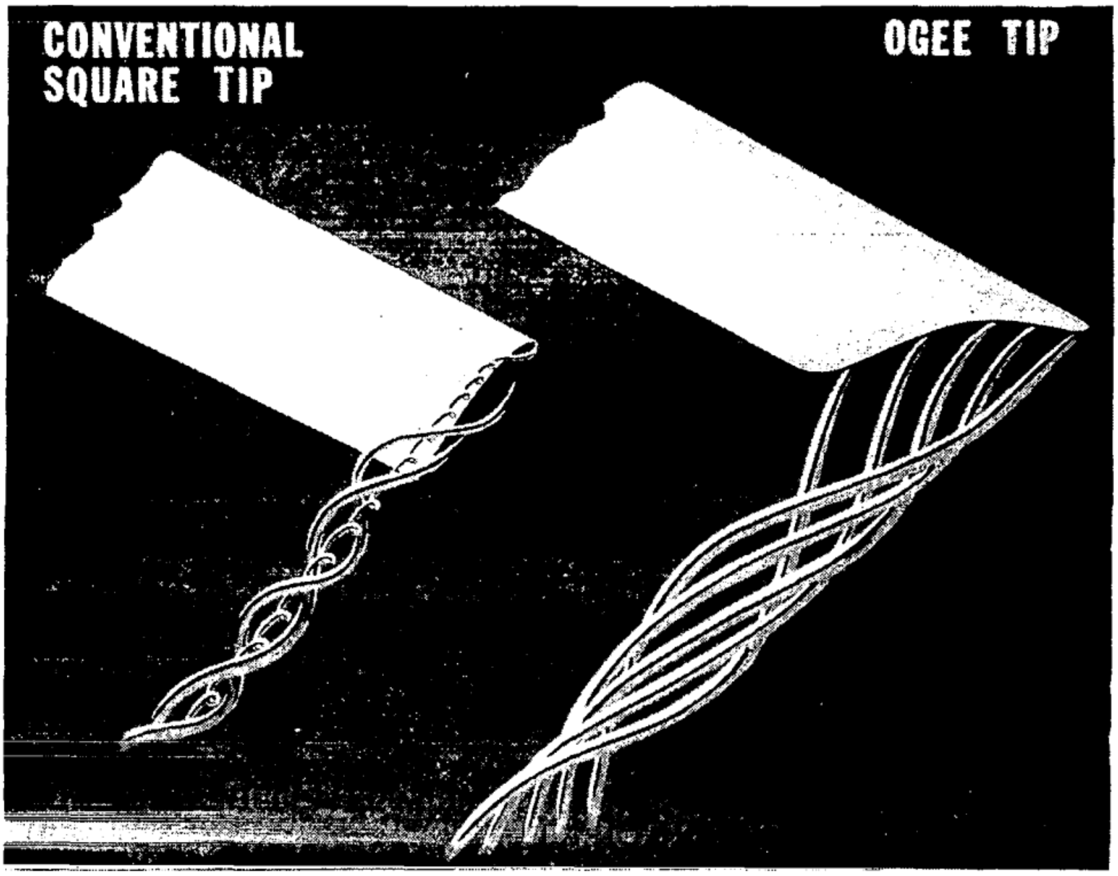
The fenestron anti-torque tail rotor

Another feature being used on helicopters is the modification of blade tips. This provides two benefits: improved aerodynamics and reduced noise. There are many blade tips that were devised as demonstrated by the figure below.



Examples of blade tip modifications (Edwards, 2002)

Many blade tip designs aim to reduce BVI noise through the creation of two vortices or reduced size instead of a single large vortex which eventually cancel each other out[5][9]. The sub wing and Westland Vane designs have been shown to carry this out quite effectively with the latter demonstrating a 5.6 dB noise reduction[9]. The Ogee tip has also been shown to reduce noise levels by spreading out the vortex, reducing BVI noise by as much as 15 dB[10].



Ogee planform and vortex diffusion concept[10]

NEW NOISE REDUCTION TECHNIQUES

On May 2, 2011, two MH-60 Black Hawk helicopters of the 160th Special Operations Aviation Regiment (Airborne) carried 23 US Navy SEALs of Seal Team Six (or DEVGRU) to a compound in Abbottabad, Pakistan. This covert CIA-sanctioned action, which led to the death of Al-Qaeda leader Osama bin Laden, would eventually become known to the public as Operation Neptune Spear. Later, it became known that the Black Hawks had a number of features for increased stealth capabilities: a reduced radar cross section, infrared suppression paint and a reduced acoustic signature[11]. Clandestine operations like these illustrate the virtues of a helicopter with a reduced acoustic signature. This section will discuss some new noise reduction techniques that can be used on military helicopters to reduce their acoustic signature.

Helicopter blades have always been spaced equidistant from each other. This generally leads to a single blade-passage frequency which appears on a spectral plot as large peaks. It stands to reason that spacing the helicopter blades unevenly could potentially reduce noise levels. This is the core idea behind modulated blade spacing. With this, several blade-passage frequencies are produced and the acoustic energy is spread over these frequencies. The concept has already been applied to ducted tail rotors and has shown promise[12]. There are two benefits: reduced dB and SEL levels, and multiple blade-passage frequencies which distribute the acoustic energy.

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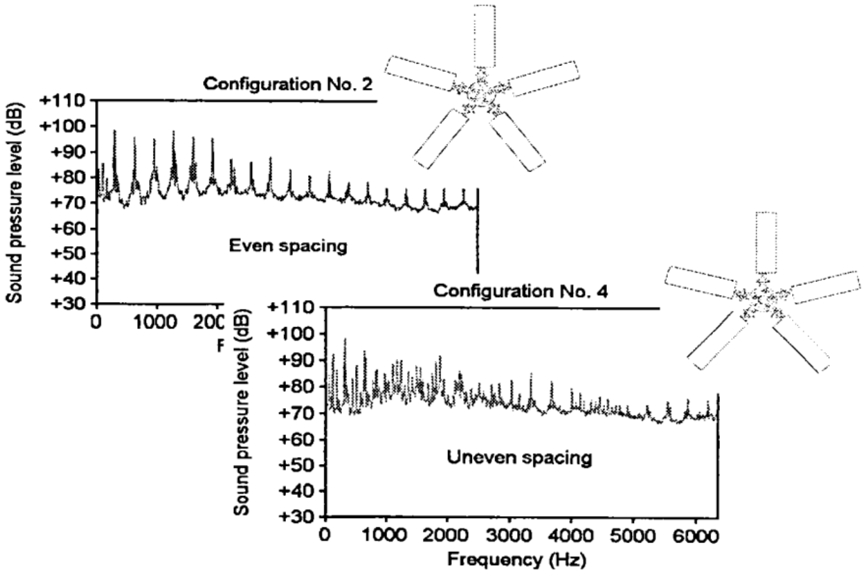
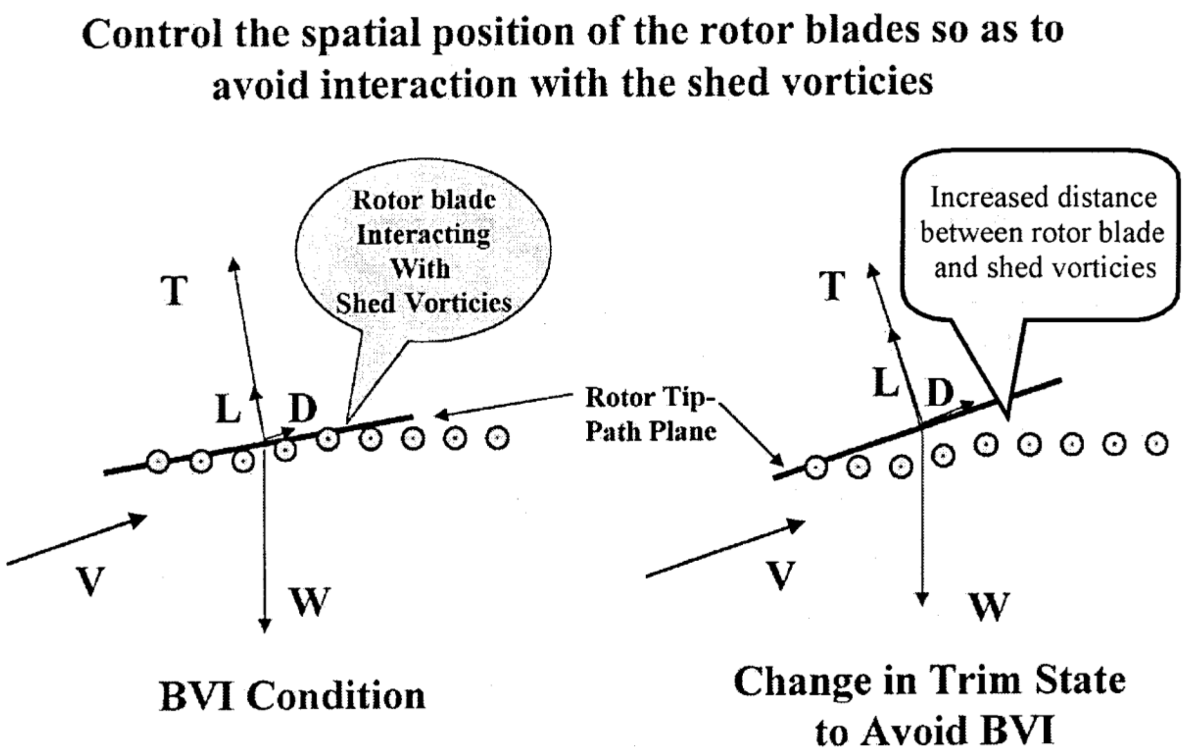
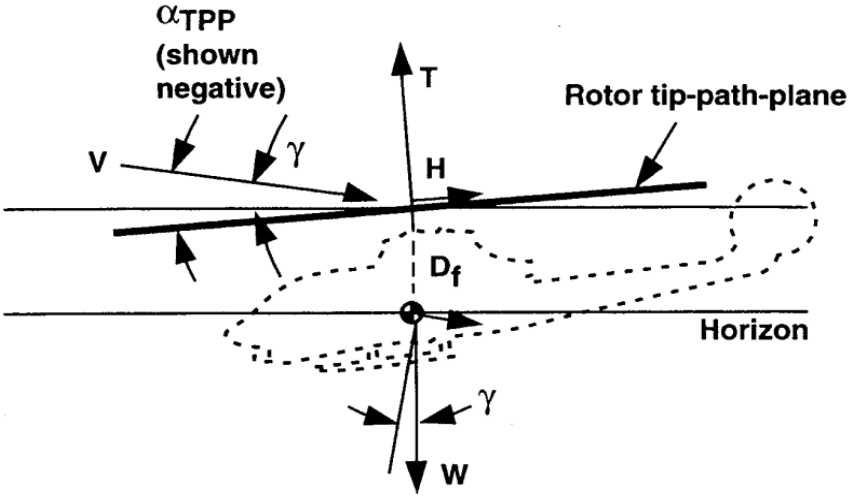


THE CONCEPT OF MODULATED BLADE SPACING[5]

BVI noise is generated when the blade rotor tips pass inside or in close proximity to a tip vortex from a previous blade[13]. Sometimes, when the blades do not pass directly through a vortex, a miss distance can be measured. This is the distance between the blade and the vortex and BVI noise significantly decreases as the miss distance moves away from zero. It is possible to control this miss distance with the help of x-forces. These forces can be in two different directions: in the direction of thrust or of drag. With the help of these x-forces, it may be possible to move the tilt-path-plane and increase the miss distance, thereby reducing BVI noise. The main goal of researchers studying x-force control is on finding an arrangement where enough drag is produced where the geometry of the forces on the helicopter is changed while maintaining steady flow with minimum buffeting[5].



THE BASIC PRINCIPLE OF X-FORCE CONTROL[5]



Changing the geometry of the helicopter rotor force balance[13]

METHODS

The primary method of gathering information for this research paper was through an analysis of existing literature on the subject. Also, for determining which technology should be incorporated on future military helicopters, each noise reduction concept must be analyzed in terms of its advantages, disadvantages, corporate risk and payoff. The summary of this analysis can be seen below.

Noise reduction concept	Advantages	Disadvantages	Risk	Payoff potential
Tip speed reduction	Benefits already proven, successfully implemented previously	Can only be effective to a certain extent, unit cost will increase due to rotor solidity requirements, decrease in performance	Low	Low
Blade tip modification	Benefits already proven, relatively small weight increase	Rotor design must be changed due to increased centrifugal force, could possibly increase drag	Low	Medium
Blue Edge Blades	Already incorporated onto helicopters	Difficulties regarding design being patented	Low	Medium
Fenestrons	Already incorporated on light helicopters, added safety benefits for ground crew	Significant reduction in performance when fitted on large helicopters	Low	Medium in light helicopters, high in heavy helicopters
Modulated Blade spacing	Effective on tail rotors, minimal performance changes	Hub manufacturing more complex and more costly	Low	High
X-force control	Potential improvement to BVI noise, possible application to tiltrotor aircraft	Non-standard flight controls due to changing of tilt-path-plane	Medium	High

RESULTS

Upon analysis, it becomes clear that each class of helicopter would require a different set of noise reduction concepts. For light helicopters, tip speed reduction, blade tip modification, BlueEdge blades, fenestrons and modulated blade spacing would be beneficial. For medium helicopters, tip speed reduction, blade tip modification, BlueEdge blades and modulated blade spacing will work. However, further research in fenestrons on medium helicopters is necessary to better understand their effect on noise reduction. In the case of heavy helicopters, fenestrons would cause more problems than solve. Tip speed reduction, blade tip modification, BlueEdge blades and modulated blade spacing. The use of a tandem configuration and NOTAR technology may be beneficial for noise reduction.

CONCLUSION

This paper, after a thorough analysis, came to the conclusion that several noise reduction concepts show promise and would greatly benefit manufacturers to incorporate these into combat helicopters currently under development. Some, such as modulated blade spacing and blade tip modification, have better risk-to-payoff ratios and are a better choice than others. But whether the helicopter is a light, medium and heavy helicopter should be taken into consideration.

Nevertheless, such claims cannot be justified without experimental data. Therefore, the path forward is to create scale models of rotor blades using this technology and study their acoustic signature before any.

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