ONGOING CONCEPTUAL STUDY OF THE "H.E.R.O." MULTI-ROLE ROTARY WING AIRCRAFT FOR EXCEPTIONAL MANEUVERABILITY AND ADVANCED STEALTH TECHNOLOGY

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1. ABSTRACT

Pankl Aerospace Systems Inc., a supplier to the aerospace industry in manufacturing of helicopter transmission parts and systems, has previously evaluated a possible future rotary wing aircraft concept named "H.E.R.O.", which stands for Helicopter Equipped with Reconnaissance and Onslaught. In each of the three modules, being New Fuselage Material & Active Camouflage, Drivetrain with Four Rotors and Ease-of-Use for Advanced Flight Controls and Interface & Mechanical Systems, radical innovations towards new materials and cockpit philosophy have been proposed. Pankl Aerospace has been undergoing further research in each of these modules, which will be shown in this paper. Goal is to bring certain features to a next technical readiness level, while continuing to evaluate the feasibility of the concept in detail. Development goals for future R&D, specifically for creating an actual scaled prototype, have been defined.

2. INTRODUCTION[1]

The evaluation of current helicopter technology has shown several limitations regarding optimal military performance. Looking at the tactical military mission accomplishment process in terms of a customer process, it can be seen that with new technologies emerging in surrounding industry branches and changing places of conflict a change in customer behavior has taken place.

What it comes down to from a bird's eye view, is defining what job a military customer really wants to get done (see Figure 1):

- Fly to the mission zone quickly and undetected
- Execute mission
- Fly back from the mission zone quickly and undetected, reach base with zero damage and zero personnel left behind

The dilemma lies within the competing classical optimization goals:

- On one hand, maximum protection is wanted for people and machine - more protection means more weight, but more weight means less payload or less speed.
- On the other hand, maximum speed is wanted for rapid response and quicker mission accomplishment - more speed also means more weight (engine power), but more weight again means less payload or less range.
- Then there is the ease-of-use aspect: experts are wanted for ensuring safe flights, but looking at the complexity in flying a typical helicopter, the cost of pilot training and aircraft maintenance is extremely high.

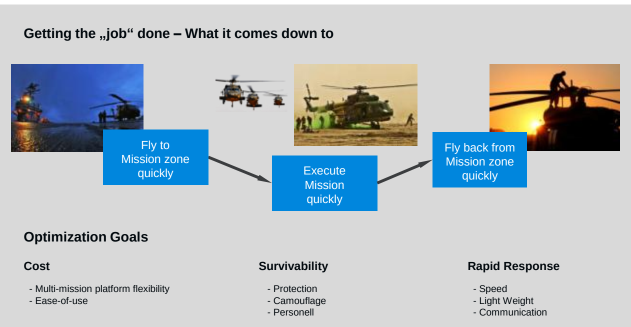

Fig. 1: Bird's eye view of customer process

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[1] Presented at the European Rotorcraft Forum 38th Annual Forum, Amsterdam, The Netherlands, September 4-7, 2012.

But interestingly, if it were possible to reach a higher speed and at the same time be undetectable (maximum camouflage), there would be less and less need for protection. And, thinking even further, if it were possible to integrate some of the "smart" communications technology, which is making more and more things easier for many situations and people, there might be a chance of "driving" a helicopter as easily and intuitively as "driving" a car - which in essence would make the rotary wing aircraft attractive to a much broader range of applications.

As the Defense Advanced Research Projects Agency's (DARPA) Tactical Technology Office (TTO) has defined certain Focus Areas (e.g. "Advanced Platforms") and is specifically searching for advanced innovative systems and aircraft concepts for increased rapid response, survivability, reliability, and multi-mission supportability [1], Pankl Aerospace is taking on these challenges. Pankl Aerospace previously experimented with extreme light-weight concepts for the fuselage, new approaches towards helicopter powertrain technology, advanced stealth technology and exceptional maneuverability features which may have the potential of radically improving helicopter performance while at the same time significantly reducing operational costs [2].

3. CONCEPTUAL DESIGN

In a series of innovation workshops Pankl Aerospace questioned today's industry standards and deliberately thought “outside the box” for radically different view-points. The goal was to come up with a possible future rotary wing aircraft concept which fulfills the goals of military missions better than currently available solutions by tapping into formerly inconceivable potential [2].

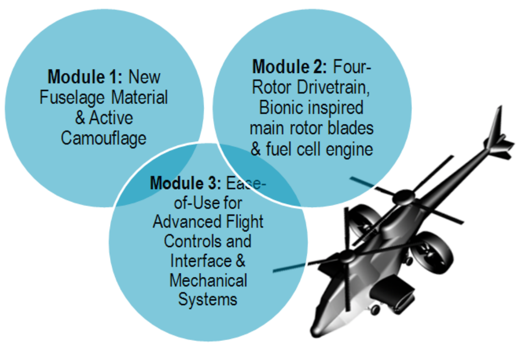

Fig. 2: Pankl Aerospace's rotary-wing aircraft concept "H.E.R.O."

Figure 2 shows the three modules of Pankl Aerospace's helicopter named "H.E.R.O" (Helicopter Equipped with Reconnaissance and Onslaught), and Figure 3 gives an overview of the technical aspects of the conceptual study.

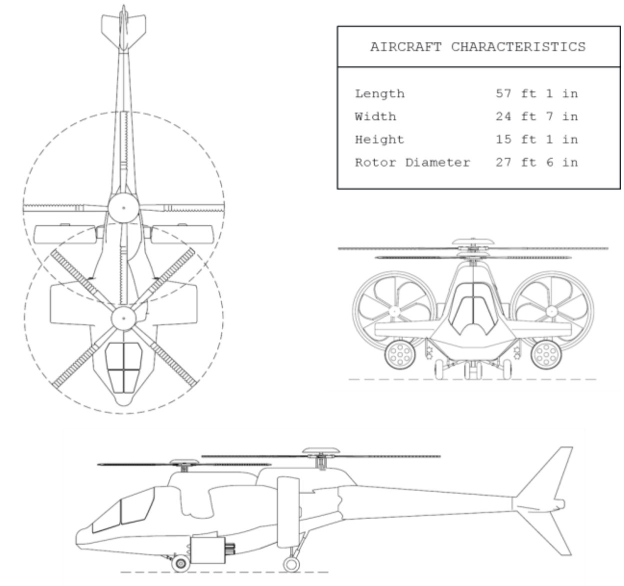

Fig. 3: Technical aspects of Pankl Aerospace's rotary-wing aircraft concept "H.E.R.O." [2]

3.1 Overview Module 1

The first module of Pankl Aerospace's concept has two aspects (see Figure 2):

1. A light fabric skin of a stretchable textile material as a new fuselage material.
2. Active camouflage mechanisms for reducing visual and acoustical detection.

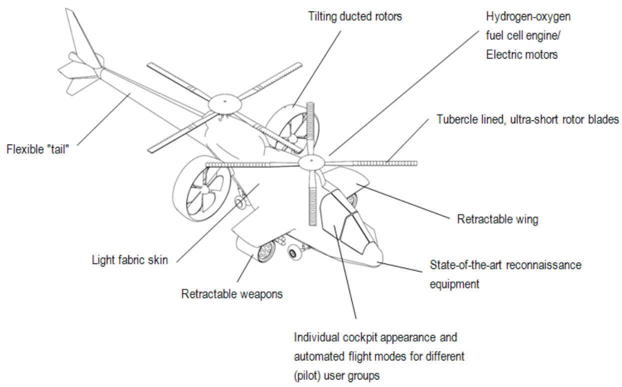

Fig. 4: Core features of Pankl Aerospace's vertical flight aircraft concept "H.E.R.O."

Inspired by BMW's car study "GINA Light Visionary Model", referenced in a BMW design study published in 2008 [3], Pankl Aerospace would suggest a composite fiber-enhanced derivative. This type of flexible material would allow for changing the aerodynamics of the system dynamically while in flight e.g. by positioning extractable ("stretch")/ retractable winglets in numerous different positions throughout the helicopter, for instance as a retractable flex-front wing which might make flying at higher altitudes possible due to increased lift, or a flexible "tail" which might enhance combat maneuverability or reduce start-up vibration [2].

Reducing visual detection while flying in and out of the mission zone could be achieved by applying bendable pentacene TFT displays [4, 5, 6] to the fabric, projecting dynamic, real-time images of the environment onto the fuselage of the helicopter.

Reducing acoustical detection of the overall system could be achieved by installing an active noise cancelling system e.g. based on thin-film carbon nanotube loudspeaker technology [2, 7, 8].

Overview Development Actitivities for a next maturity level	Status
Module 1 "New fuselage material & active camouflage"	
Evaluation fibre-enhanced strechable textile fuselage material	in test, fabric identified, fibre to be determined, 20% completed
Development of a small-scale model of a flexible tail, with WonderWorks Inc.	100% completed
CFD Calculation of flexible tail feature	Planned Q4 2012
Wind tunnel test of flexible tail feature	Planned Q1 2013
Evaluation camouflage system with cameras and bendable displays (or alternatives)	identified method and requirement (camera, display), 40% completed
Development of a flying prototype, small scale, with visual camouflage characteristics, with WonderWorks Inc.	Planned Q2 2013
Evaluation of an active camouflage system for noise reduction	Planned Q4 2013
Module 2 "Four-rotor drivetrain, bionic main rotor blades & fuel cell engine"	
Basic layout of overall system, detailed state-of-the-art research with FH Joanneum Graz	completed June 2012
Phase 2 layout of overall system, in preperation for flying prototype	Planned Q4 2012
Identification of different bionic phenomena to reduce noise and increase lift	completed May 2012
Development of improved bionic rotor blade model based on simulation and experimentation results	Planned Q4 2012
Wind tunnel test of improved rotor blade model	Planned Q1 2013
Evaluation of fuel cell alternatives	Planned Q2 2013
Module 3 "Ease-of-use for flight controls and interface & mechanical systems"	
Evaluation of advanced flight controls with progressive emergency capabilities	surface "look" identified and procedures specified, 35% completed
Evaluation of cockpit layout and user segmentation	identified user and layout, 30% completed
Programming of a graphical user interface and flight-control simulation, with FH Joanneum Graz	Planned Q2 2013
Identification and optimization of mechanical systems with currently non-intuitive components	Planned Q4 2012

Fig. 5: Pankl Aerospace's R&D pipeline for ongoing "H.E.R.O." development activities

Pankl Aerospace has set up a R&D pipeline for development activities regarding H.E.R.O. Figure 5 shows the current R&D pipeline for all modules of the H.E.R.O. concept.

3.2 Evaluation textile fabric fuselage material

One of the core features of the H.E.R.O. concept is a bendable tail, which was inspired by observing the movements of lizards and lizard-like vertebrates. Tails are quite common with these animals, and while aquatic vertebrates use the movement of their tail to generate thrust through water (traveling waves), terrestrial vertebrates use limb action to move forward, with their body performing standing waves (see Figure 6) [34].

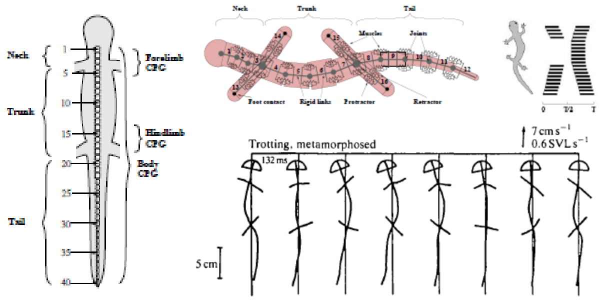

Fig. 6: Schematic view, mechanical model and body axis traces of a salamander [35, p. 2 and 34, p. 115]

Movement of these vertebrates is basically controlled by the interaction of the spinal central pattern generator (circuits which can generate rhythmic muscle activity without rhythmic input), sensory feedback and descending supraspinal control. The central pattern generators are located in the spinal cord within different oscillatory centers [33].

While swimming, the neural network produces an oscillating activity, and a traveling wave is propagated throughout the body. Changing input frequency of the neurons for the travelling wave changes the speed of the animal. While walking, the central pattern generator is forced by the limbs to produce a standing S-shaped wave with the nodes at the girdles (see Figure 6, bottom). The standing wave is coordinated with the movements of the limbs, so that during the swing phase the reach of the limbs is increased [33]. Diagonally opposite limbs are in phase [35].

It is not yet fully understood, though, how the transition from swimming to walking occurs, especially in combination with muscle activity (limbs, trunk). Assumptions are that muscle activity can stiffen the trunk and thereby transmit axial bending forces to the tail [34].

Transferring these insights to the helicopter, a bendable tail could act as a sort of damper to take on vibrations or perform movements counteracting the torsion induced by the fuselage, thus improving maneuverability. The benefits might be:

- quicker yaw and pitch motions of the helicopter for quicker movement changes/ turns

- a more precise weapons' positioning while stopping from a quick turn
- counter-acting external payload swinging
- dampening typical vibrations during start-up

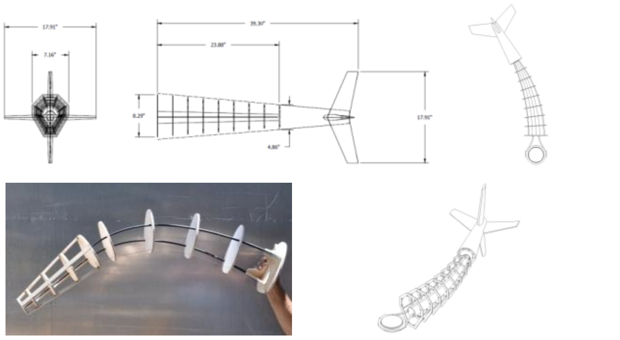

Fig. 7: 3D and physical model of a bendable tail for the H.E.R.O. concept (preliminary version)

Figure 7 shows a preliminary design of a possible flexible tailboom structure, designed by Pankl Aerospace. The length of the tail structure is 99.8 cm (39.30 in), consisting of ten ribs connected with a wire of 0.8 cm (0.3 in) in diameter and a steering wire to produce and hold the bend in position. Width of the largest rib segment near the fuselage is 18.2 cm (7.16 in), height of the same is 21.1 cm (8.29 in). Both width and height decrease continuously at an angle of 4.1 degrees along the entire length. Distance between two rib elements is approximately 10.7 cm (4.2 in).

3.3 Module 1 - Concluding Remarks

Pankl Aerospace has set up a R&D pipeline for ongoing development activities regarding the "H.E.R.O." concept (see Figure 5). The experiments with a small-scale model of a bionic flexible tail have shown that moving the tail during turns possibly enhances the movement of the fuselage/ body which might improve maneuverability of the rotary-wing aircraft in quick-turn combat situations or with external payloads.

3.4 Overview Module 2

The second module of Pankl Aerospace's concept relates to the drivetrain and has three aspects (see Figure 2):

1. Four rotors: two main rotors, counter rotating to eliminate the requirement of a tail rotor, in addition to two side rotors for additional forward thrust and thus higher speed.
2. Ultra-short, tubercle lined main rotor blades for less noise, securing more clearance at ground handling and increased lift at higher angles of attack.
3. A hydrogen-oxygen fuel cell engine which produces the power for the electric motors for all four rotors and for the electrical aggregates.

Pankl Aerospace had previously begun evaluating the potential of several natural phenomena for increasing lift and efficiency and reducing noise, one being the humpback whale. Wind tunnel tests show that main rotor blades shaped with a sinusoidal scalloped leading edge similar to the humpback whale's flippers provide an increased lift at higher angles of attack compared to traditional blade concepts with straight leading edges [2, 9, 10, 11, 12, 13, 14].

Utilizing a low-temperature hydrogen-oxygen fuel cell in combination with electric motors could possibly show benefits in maneuver agility by allowing to control each electric motor separately while reducing the overall complexity of the system by eliminating the need for a gear box, also resulting in lower operating cost. In addition, the low temperature (80˚C) and noise conditions have the potential to reduce detection of the helicopter by guided weapon systems [2, 15, 16, 17].

3.5 Basic layout H.E.R.O.

With the introduction and suggestion of different innovations throughout the various systems of the helicopter [2] and as a basis to be able to produce a flying prototype of the H.E.R.O. concept it was a necessary next step to estimate the required engine power for a first basic configuration of the H.E.R.O. helicopter (Figure 8).

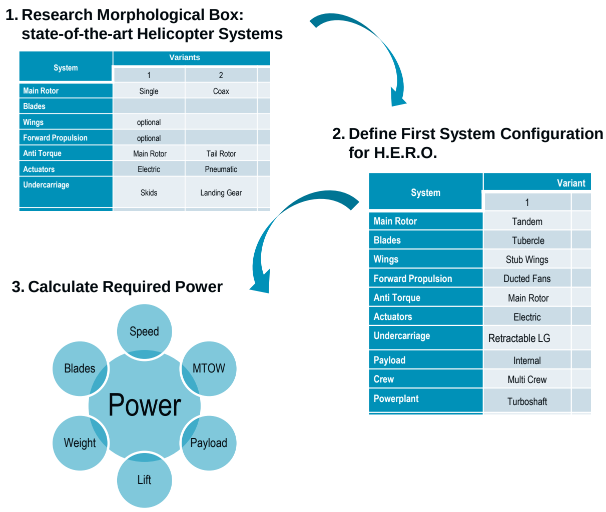

Fig. 8: Pankl Aerospace's approach to generate the first basic system configuration and power calculation for H.E.R.O.

The approach was to generate a morphological box of all state-of-the-art helicopter systems and to benchmark the H.E.R.O. concept with these systems as to those affected by H.E.R.O.-innovations and those not affected, and then derive a first basic system configuration under assumptions of the characteristics (weight, required power) of the different systems.

This section will first introduce basic methods how the required power for a specific helicopter configuration can be calculated. Power calculation for a rotary wing aircraft is generally quite complex as not only flight speed and altitude have to be considered. Additionally, two different flight conditions need to be accounted for:

1. Vertical flight, meaning a negligible component of forward speed during start, landing and hovering.
2. Forward flight, meaning a typical cruise situation.

Figure 9 shows a typical power versus speed diagram for a CH-47 helicopter at Sea Level with ISA conditions. It shows that the required power is strongly dependent on the take-off weight. Power at zero forward speed is relatively high and decreases with increasing forward speed until the minimum power speed is reached, which enables the aircraft to stay airborne for the maximum amount of time. Beyond this point, the required power for a further increase of speed strongly increases due to the quadratic increase of the drag forces. It is obvious that the power required for hover also enables the aircraft to fly in a broad band of velocities. However for high speed flight the available power has to be increased significantly.

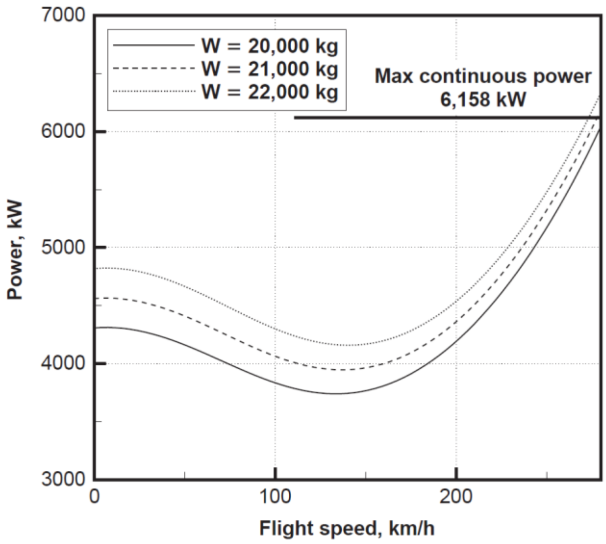

Fig. 9: Typical power versus speed curve for a Boeing CH-47 [18, p. 376]

Therefore it seems reasonable to consider the flight condition "vertical flight" for the first basic power estimation. Subsequently the individual power components for this flight state are presented.

3.5.1 Momentum Theory

The most elementary method for converting the rotating power of a rotor into useful thrust for generating lift is based on the one-dimensional momentum theory for airflow that passes through the rotor disk. According to the basic momentum theory, the rotor is reduced to a rotating disk which adds axial momentum to the air passing through [18, 19, 20].

Figure 10 shows the usual reference sections as well as the slipstream contraction. The theory allows for calculating the power which is needed for the rotor disk to add the velocity v_h to the inflow. The resulting speed difference between inflow and outflow generates the thrust, which has to counteract the helicopter weight.

$$v_h = \sqrt{\frac{T}{2\rho A}} = \sqrt{\frac{W}{2\rho A}} \tag{1}$$

Equation 1 gives the induced velocity by the rotor disk. As stationary hover is mainly of interest for the first estimation, the required thrust T may be substituted by the weight W of the helicopter.

$$P_h = W\sqrt{\frac{W}{2\rho A}} = \frac{W^{3/2}}{\sqrt{2\rho A}} \tag{2}$$

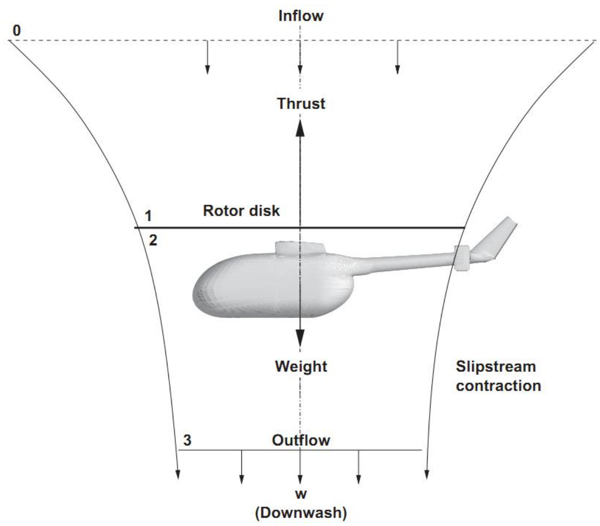

Fig. 10: Hover condition with stream tube around the rotor disk and airframe [18, p. 316]

The product of thrust and induced velocity equals the ideal power for the helicopter as shown in Equation 2.

$$(3) \qquad P_i = k_i \frac{W^{3/2}}{\sqrt{2\rho A}}$$

As the momentum theory is an idealization, it does not take into account several disruptive factors like tip vortices, blade/ vortex interaction or the non-uniform downwash. To compensate this simplification, the induced power factor k_i is introduced. By multiplying the ideal power with the induced power factor k_i we can calculate the actual induced power (Equation 3). A typical value for the induced power factor is $k_i = 1.15$ [21, 22, 23, 24].

3.5.2 Blade Element Theory

The Momentum Theory enabled us to calculate the power which is necessary to lift the helicopter. In the real world, the rotor is not a uniform disk but rather consists of several blades which are connected to the hub. Moving the blades through the air needs additional power to overcome the profile drag of the blades. This power component is found by taking the drag of a blade element and integrating over the span. For a rotor with N blades we receive Equation 4.

$$(4) \qquad P_o = \frac{1}{2}\rho c N \Omega^3 R^4 \int_0^1 C_D(\alpha, Re, M) r^3 \, dr$$

The local drag coefficient is not only a function of the local angle of attack, Reynolds and Mach numbers, but may also depend on blade design as chord length or profile may vary.

$$(5) \qquad P_o = \frac{1}{8}\overline{C_D}\rho\sigma A U_{tip}{}^3$$

For our basic power estimations we disregarded those variations of the profile drag coefficient and preferred to use the average profile drag coefficient C_D which leads to the more convenient Equation 5 for the profile power P_o.

3.5.3 Total Power

Total power for hover is basically the sum of the induced power P_i and the profile power P_o. In addition, we need to consider additional power, to compensate different power losses throughout the system, in order to obtain a more realistic result.

The required power for the main rotor system needs to be transferred from the power source via a transmission. The transmission power losses P_t are proportional to the torque and power transmitted and their order of magnitude is about 5% (Equation 6) [20, 24].

$$(6) \qquad P_t \approx 0.05 * (P_i + P_o)$$

If like in most cases a single main rotor system is applied, a tail rotor is necessary to compensate the main rotor torque. The tail rotor power P_{tr} amounts to about 10% of the main rotor power (Equation 7). The total required power is now the sum of the four just introduced power types (Equation 8).

$$(7) \qquad P_{tr} \approx 0.1 * (P_i + P_o)$$

$$(8) \qquad P = P_i + P_o + P_{tr} + P_t$$

Finally we receive Equation 9 for a first power estimation.

$$(9) \qquad P = (1 + 0.05 + 0.1) * \left(k_i \frac{W^{3/2}}{\sqrt{2\rho A}} + \frac{1}{8}\overline{C_D}\rho\sigma A U_{tip}{}^3\right)$$

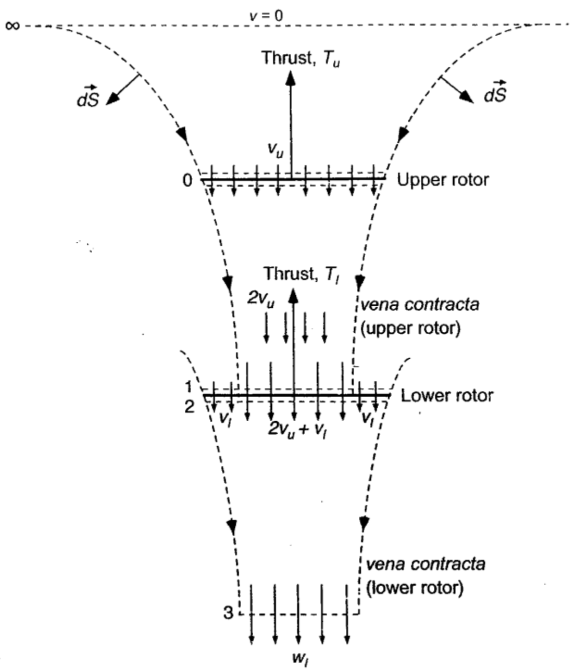

Fig. 11: Hover condition for a coaxial system with stream tube around the two rotor disks [19, p. 102]

3.5.4 Coaxial Systems

The preceding sections covered the basic power calculation for a classic tail rotor configuration. Those equations cannot be directly applied for helicopters with a coaxial rotor system as there are significant differences. However understanding them is helpful as they can be directly derived for the use in coaxial systems.

Figure 11 shows the airflow between upper and lower rotor of a coaxial rotor configuration. The lower rotor operates in the slipstream of the upper rotor, and thus the two rotors cannot be regarded separately. Two fully separated rotors would lead to a 41% power increase compared to a single rotor. If we take the slipstream effect into account, the increase goes down to 28%. If we further assume that both rotors operate at equal torque, the increase is only 22%. This is the lowest value which can be obtained from basic equations which still seem to overpredict, as experiments performed from Dingeldein (1954) showed an increase of 16% [19, p. 103].

$$P_i = k_i k_{int} \frac{W^{3/2}}{\sqrt{4\rho A}} \quad \text{with } k_{int} \approx 1.16 - 1.22 \tag{10}$$

Equation 10 gives the induced power for a coaxial system. In addition to the induced power coefficient, the interference coefficient factor k_{int} is introduced to take the power increase into account. It is also considered that the rotor area is doubled due to the second rotor [21, 23].

$$P_o = \frac{1}{4} \overline{C_D} \rho \sigma A U_{tip}{}^3 \tag{11}$$

Equation 11 gives the profile power for a coaxial system, which is simply doubled compared to a single rotor, as a coaxial system uses two identical rotors turning at the same speed but opposite direction [19].

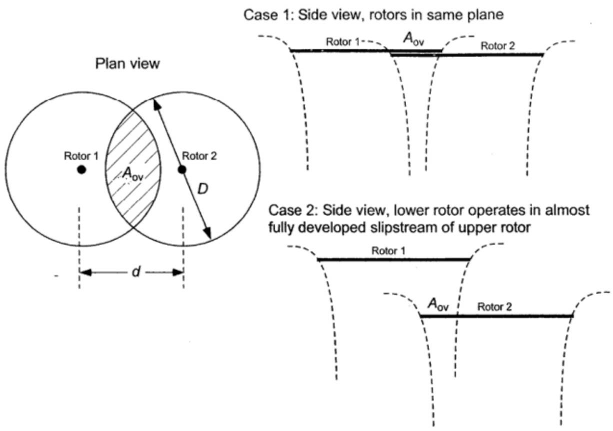

Fig. 12: Hover condition for a tandem system with stream tube around the two rotor disks [19, p. 107]

$$P = 1.05(P_i + P_o) \tag{12}$$

To calculate the total power for hover, induced and profile power is added and multiplied by 1.05 to add transmission losses (Equation 12).

3.5.5 Tandem Systems

A tandem system uses two rotors for generating lift, similar to the coaxial system. Therefore the power calculation for both systems is comparable.

Figure 12 shows the airflow of the rotors, and similar to the coaxial setup the lower rotor can operate in the slipstream of the upper one if both rotors are vertically separated. The plan view also shows that the overlap area A_o is dependent on the distance d.

$$P_i = k_i k_{ov} \frac{W^{3/2}}{\sqrt{4\rho A}} \tag{13}$$

Equation 12 shows that the power calculation for a tandem configuration is close to the coaxial configuration. Instead of an interference coefficient, an overlap coefficient k_{ov} is introduced.

Figure 13 shows that the overlap coefficient k_{ov} is dependant on the distance between the two rotor hubs and is thus an important factor for the helicopter layout. The profile power is hereby calculated as for coaxial systems in Equation 11.

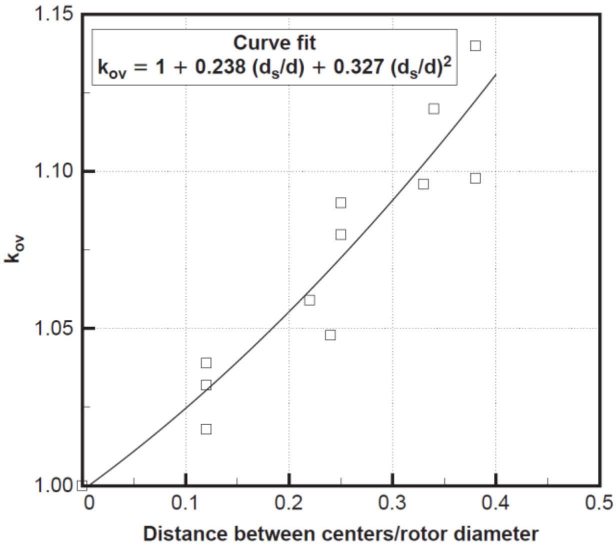

Fig. 13: Overlap factor for tandem rotors [18, p. 374]

3.5.6 Power for Forward flight

All discussed power calculations are only valid for vertical flight with a negligible forward flight component. They may not be used for forward flight calculations as they have to be modified to take account of the added velocity of the free airstream. For simplification reasons we have only considered vertical flight so these modifications will be handled in a later layout stage. For sake of completeness it is worth to mention that additional power requirements need to be added at forward flight.

3.5.7 Parasite Power

At low speeds most of the power is needed to generate enough lift to compensate the weight of the helicopter. At higher horizontal speeds the drag of the aircraft becomes important as drag increases quadratically with the flight speed. The increase of this power type is clearly involved in limiting the forward speed and can only be reduced by proper fuselage design.

3.5.8 Power for Additional Forward Propulsion

The increasing drag at high velocities may be countered with an additional device delivering forward thrust. This additional propulsion has to also be provided with power for the ability to fulfill its function. To increase the forward velocity this power will be needed in a situation where the power requirement is already at its maximum. This means that the power for additional forward propulsion also has to be added to the total power even if it is not used continuously.

3.5.9 Solutions for Fast Forward Flight

The following chapters present an analysis of several benchmarks drawn from the state-of-the-art research. The challenges of fast forward flight will be discussed together with some current design approaches which address the problems associated with fast forward flight. This knowledge is then applied to the four rotor configuration for the H.E.R.O. concept.

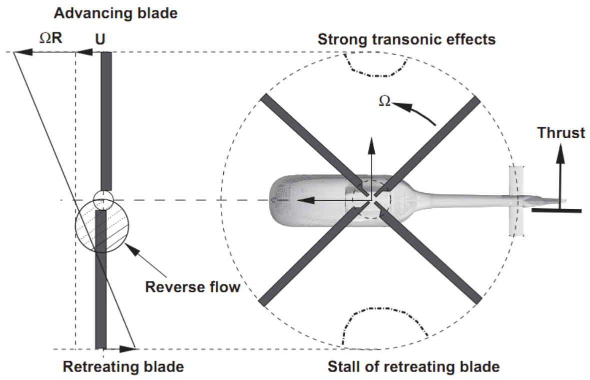

Fig. 14: Sketch of local speeds on the blade during forward flight and dissymmetric effects [18, p. 338]

Since the first useful commercial helicopters were launched to market, a lot of research was carried out leading to the multi-faceted line-up of rotary wing aircraft we know today. Despite this remarkable development there is still a field lacking significant improvement. In terms of maximum forward velocity there seems to be a frontier at about 150kt which is hard to exceed for the traditional helicopter designs. Forward speed is limited by several factors like maximum tip speed, vibration, stability or engine power.

One of the most important factors is certainly the dissymmetry of aerodynamic forces during fast forward flight. Figure 14 shows the effect of the incoming airflow, whereby the incoming airflow adds to the local speed component of the blade. At the advancing blade, both components have the same direction and so they add to a higher speed which tends to the speed of sound near the tip. In these tip zones, strong transonic effects occur which increase the drag of the air foil and reduce the efficiency. On the retreating blade there are two different problem zones. Starting from the rotor hub a zone of reverse flow develops, as the flight speed increases to a higher value than the local speed due to the rotation, which is actually in the opposite direction. In the tip region a zone develops where the blade stalls due to a downward flapping motion. As a result, the lift distribution during forward flight is strongly dissymmetric which leads to an unwanted rolling motion [19].

On the other hand there is the challenge that the main rotor has to provide lift as well as forward propulsion. The wing of an airplane benefits from the increasing airspeed which makes generating lift easier, and the thrust can be used to compensate the drag of the aircraft. A rotor system unfortunately requires power to generate lift in addition to counteract the quadratically increasing body drag.

The current approach to this problem is the separation of generating lift and forward thrust similar to airplanes. Two possible solutions are discussed on the basis of two available experimental designs.

3.5.10 Eurocopter X³

The Eurocopter X³ features a single main rotor and two propellers for forward propulsion mounted on short wings. The propellers are connected to the main gearbox via shafts, however one propeller is driven at a higher rpm to compensate the torque of the single main rotor. To control the forward thrust, variable pitch propellers are used.

At higher speeds the short wings take over a large part of lift generation and may even compensate the dissymmetry of the main rotor with control surfaces. As the lift of the main rotor gets less important, its rpm is reduced to decrease the tip speed. This prevents compressibility effects and the related drag increase. Instead of the typical tail rotor, a large empennage and stabilizers are added to increase stability and maneuverability at high speeds [28, 29].

3.5.11 Sikorsky X2

The Sikorsky X2 helicopter features a coaxial rotor system and therefore eliminates the need for a separate anti torque device. At one end of the tailboom a pusher propeller is mounted to deliver additional forward thrust.

The main rotor rpm is also variable in order to prevent transonic effects of the advancing blade. The lift loss on the retreating side is accepted in this configuration. The coaxial design prevents any dissymmetries, and lift of the advancing side is sufficient. The pusher propeller is integrated into the tailboom which is in any case necessary for directional stability during forward flight [30].

3.5.12 H.E.R.O. Basic Configuration

The knowledge gained during the initial research is now applied to discuss a possible base configuration for the H.E.R.O. concept. Benchmark is a Sikorsky UH-60M Blackhawk.

Design Parameters	UH-60	H.E.R.O.
MTOW	9979kg	9980kg
Rotor Radius	8.2m	6m
Number of Blades (per rotor)	4	3
RPM	258	286
chord	0.52m	0.3m
Estimated c_l mean	0.5	0.5

Fig. 15: Design parameter comparison H.E.R.O. vs. UH-60M [25, 26]

Figure 15 shows possible design parameters for this basic configuration. It features a tandem rotor system with significantly lower rotor diameter to reduce transonic effects on the advancing blade. Stub wings are installed to assist with lift generation during fast forward flight and to act as attachment points for external payloads. Tiltable ducted fans are installed on the sides. They act as additional forward propulsion to increase the maximum speed. Due to the fact that they are tiltable they also may improve maneuverability and assist at hover to lift higher loads.

For the H.E.R.O. concept, two 3-bladed main rotors were chosen, as uneven blade numbers decrease unwanted oscillations. Rotor radius and rpm are chosen with regard to the tip velocity, which should be high enough to ensure safe hover but low enough for high speed. This configuration leads to a tip velocity of 180 m/s during hover which is already very low. Therefore the critical tip Mach-No. of 0.95 is not reached until 280kt (520km/h), which improves high speed capabilities. The choice is a compromise as both rpm and radius should be low for minimum power, but decreasing the radius requires an increase in rpm in order to keep the tip velocity high enough.

	UH-60	H.E.R.O.
MTOW	9979kg	9980kg
Power installed	2974KW	
Power calculated	2714KW	1981KW

Fig. 16: Basic power calculations for comparison of UH-60M and H.E.R.O.

3.5.13 Power Estimation for H.E.R.O. Basic Configuration

For this sample configuration some basic power calculations were performed in comparison to the UH-60M based on the theory introduced in the previous chapters (see Figure 16). The calculated power is for hover out of ground effect at sea level for the maximum takeoff weight (MTOW). All calculations were performed with MATLAB with excerpts of the corresponding m.file attached in the Appendix.

The results for the Blackhawk configuration are in the order of magnitude of the real installed power. The excess power is necessary to ensure maneuverability of the helicopter. The calculations may be quite conservative as all power loss coefficients were estimated also conservatively. Thus the real spread between required and installed power may be even higher. However as the conservative estimations were done for both designs it seems acceptable to use these results in order to compare both designs. The results show that H.E.R.O.'s tandem rotor concept would consume 27% less power during hover than UH-60M's conventional tail rotor configuration.

Figure 17 shows that less power consumption during hover is typical for tandem rotors in comparison to single rotors. Unfortunately this benefit vanishes at higher speeds where the tandem configuration performs slightly worse compared to the single rotor.

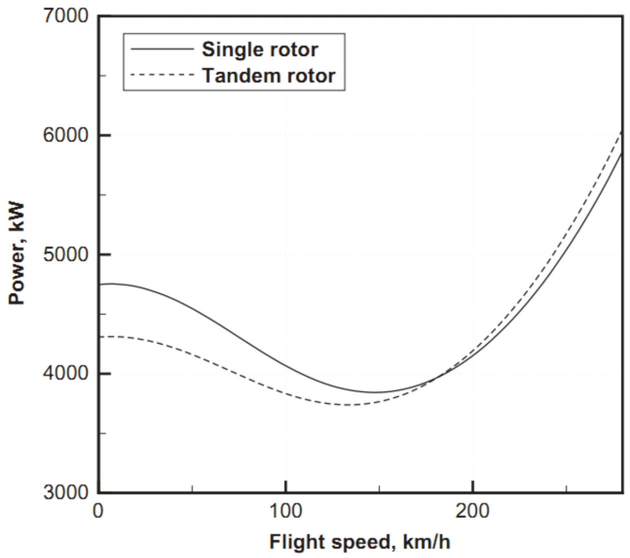

Fig. 17: Comparison of power versus speed diagrams for a single and tandem helicopter with the same weight [18, p. 379]

For the H.E.R.O. concept this means that H.E.R.O. is overpowered during hover if the installed power is the same. This excess power may be used for the ducted fans instead. For higher speeds the fans are also more efficient in producing forward thrust which means that it does not follow a curve as shown above and hence would fly faster.

3.5.14 Weight Estimation for H.E.R.O. Basic Configuration

To determine weights for the H.E.R.O. concept Pankl Aerospace chose the approach to benchmark with a helicopter that comes near the desired MTOW, in this case a UH-60M. The weight of removed systems (e.g. mechanical flight controls vs. fly-by-wire) is estimated and subtracted. The weight of additional systems is also estimated and added to the empty weight. The result is the new empty weight and the payload (see Figure 18).

Empty Weight	5224kg
Fly by wire	-220kg
2nd rotor + structural changes	+300kg
Tail rotor	-250kg
Ducted fans	+300kg
New Empty weight	5354kg
Payload	4626kg

Fig. 18: Weight configuration for H.E.R.O.

This calculation shows that there might only be a minor change of adding 130kg to the empty weight, especially when considering new advanced materials now available which were not available at the time the UH-60 was designed.

3.6 Module 2 - Conclusion

The basic layout of the H.E.R.O. concept shows that H.E.R.O. would be capable to lift greater loads at hover and low speeds than the UH-60M. At higher speeds this advantage would decrease, but due to the ducted fans H.E.R.O. would be able to reach a higher maximum speed. As the same power sources are considered, H.E.R.O. would have more lifting power at hover or low speeds, or a longer range due to its higher speed.

Further development is planned for the general layout and for system characteristics of the H.E.R.O. concept as well as for the bionic rotor blades (see R&D pipeline in Figure 5).

3.7 Overview Module 3

The third module of Pankl Aerospace's concept incorporates an "extreme" ease-of-use philosophy and has two aspects (see Figure 2):

1. Advanced flight controls and interface concept for rotary-wing aircraft with progressive emergency capabilities and user group segmentation.
2. Application of ease-of-use philosophy to mechanical systems for reduced maintenance effort.

Pankl Aerospace's concept is a more radical approach regarding automation and user interface for more overall safety and less educational cost. The cockpit would have touch-screen interfaces in addition to a docking station for a pilot's Tablet-PC/ Smartphone. This would allow for user segmentation (e.g. "novice" or "expert") in combination with an extremely fast change of visual appearance, the benefit for all pilot user groups being to be able to focus on the mission and on the situation developing outside the cockpit, resulting in higher overall awareness and a more accurate reaction (enhanced operational safety) [2, 27].

3.8 Ease-of-use Analysis

Racing against the clock, rescue flights launch into action to retrieve wounded service members and other battlefield casualties in the military world, but also for commercial medical evacuation after an accident, helicopters are used by hospitals and other health care providers. Current flight control technology, though, disregards the situation if a crew member of the mission gets injured or has any other condition preventing him or her from completing the flight task.

Thinking about a common computer at ones house, where one quite naturally would have different logins for all family members, therefore creating different user groups, our strategy in the ease-of-use concept is to create an expert and “novice” setting on the flight control computer. The novice would have a pre-programmed flight route to base requiring minimal pilot input, hence increasing chances of a successful mission with reduced training. This could be further supported by state-of-the-art mobile features such as “Facetime”, with a trained pilot at base actually flying the aircraft back, or even a remote option.

The ease-of-use concept also suggests a more user-friendly surface design which should be much more intuitive in its handling and a more active warning system for the pilot, activated especially in critical flight situations such as “low rotor rpm” or “settling with power” (i.e. acoustic signal comes on when rotor rpm has dropped below recommended value or vibration and loss of elevation at "settling with power") [2, 31]. These conditions are experienced by pilots usually only when in full effect. In all flight situations that require pilot input to prevent a dangerous condition, an immediate understanding of the condition and an immediate correction is extremely critical. Pilots in different environments confirmed that satisfactory functions in the helicopter controls are still not fully developed and can be improved upon.

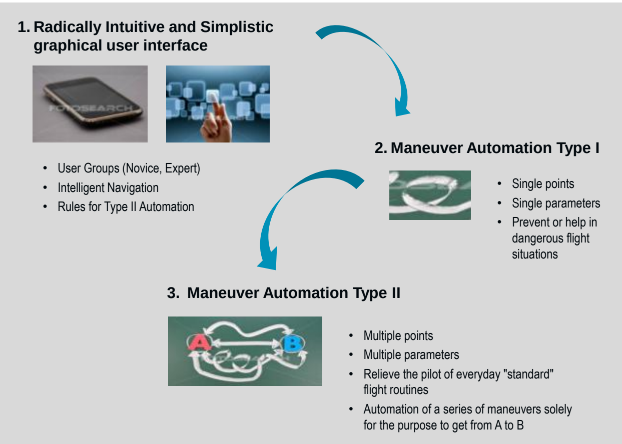

Fig. 19: Pankl Aerospace's ease-of-use strategy

Pankl Aerospace has identified two main types of automation in combination with the proposed segmentation in user groups (see Figure 19). Maneuver automation type I is an automation which helps in or even prevents emergency situations.

3.8.1 Ease-of-use in Emergency Procedures

One emergency maneuver a pilot needs to train for over and over is autorotation, which is considered the single most important emergency procedure to be used in many different emergency situations, such as engine failure, loss of tail rotor effectiveness, cockpit fire and other electrical emergencies.

This life critical recovery maneuver depends on a very immediate and sequential action by the pilot. The initiation in a common piston/ turbine helicopter includes:

1. Push down collective very rapidly, which will cause the helicopter to yaw, and so needs
2. immediate torque pedal input to counteract helicopter movement.
3. In addition there is aft cyclic movement necessary to load the rotor to stay within constant rpm.

In an emergency situation such as cabin fire the workload for the pilot increases exponentially. The investigated ease-of-use concept would assist with an autorotation emergency button - hitting this button should initiate the entire action sequence (similar to a secured emergency door open button in an airplane), thus allowing the pilot to focus on other vital tasks associated with the emergency situation, like scanning the area and fly the aircraft to a suitable landing spot. The workload would be significantly reduced for the pilot with also less risk of error/ failure to perform necessary functions.

3.8.2 Ease-of-use in Standard Flight Routines

Maneuver automation type II is essentially the automation of a series of standard flight maneuvers in getting from A to B, thus relieving the pilot from routine activities, with two major benefits:

1. Making more pilot's time available for other mission-related activities.
2. Being able to fly at maximum speed independent of certain weather conditions like fog or natural light.

Such automation might be considered as a "terrain chasing" maneuver, whereby the automation should keep the helicopter below the radar level and at the same time follow the terrain contour and evade obstacles on a pre-programmed or on-the-fly programmed route to and from the mission zone.

The "bring-to" and "return-from" mission zone automation might consist of the following or of a combination of the following procedures:

- Automatic vertical take-off into forward flight
- Automatic straight and under-radar-level forward flight
- Automatic turns and descents/ ascents
- Automatic approach

- with integrated automation of emergency procedures, or preferably prevention of certain emergency situations (maneuver automation type I, see previous chapter 3.8.1).

3.9 Module 3 - Conclusion

Pankl Aerospace portrayed a radical ease-of-use strategy with a more intuitive graphical user interface and different maneuver automation types, all incorporating different requirements for different user groups (e.g. "Novice" and "Expert") and situations. Pankl Aerospace will continue to work with operators (pilots in commercial and military environments) to discuss further automation possibilities in flight situations and adopt them into the design of suitable flight computer options.

4. CONCLUDING REMARKS

Pankl Aerospace has shown some details of its ongoing R&D for the 3 modules of the H.E.R.O. concept, especially regarding feasibility and basic layout aspects. Pankl Aerospace has founded a new company Pankl Aerospace Innovations for the purpose of continuing to develop the H.E.R.O. concept, with the goal of advancing certain aspects to the next technical readiness level, whereby assessing possible limitations such as protection capabilities, drive propulsion technology or regulations.

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APPENDIX

```
%Excerpt m.file MATLAB
%Advanced Project in Engineering
%Power Comparison of a single rotor
vs. a tandem and a coaxial config.
clear all
clc
%gravitiy [m/s]
g=9.81;
%altitude[ft] air density[kg/m³] speed
of sound[KT] sigma[rho/rho0]
ISA=[0    1.2243 661 1;
    1000 1.1889 659 0.9711;
    2000 1.1542 656 0.9428;
    3000 1.1204 654 0.9151;
    4000 1.0873 652 0.8881;
    5000 1.0550 650 0.8617];
%design parameters Single Rotor
%Data for UH60
W=97903.8;          %Weight [N]
Wkg=W/g             %Weight [kg]
R=8.2;              %Rotor Radius [m]
RPM=258;            %Rotor Speed [RPM]
B=4;                %Number of Blades
c=0.52;             %blade chord [m]
C_l=0.5;           %lift coefficent
!!!estimated!!!
Btr=4;    %number of tail rotor Blades
```

```
ctr=0.1;  %blade chord tail rotor [m]
Rtr=1.7;            %tail rotor radius
ki=1.15;          %induced power Factor
ktr=1.05;         %transmission factor
kint=1.16;    %interference factor coax
kov=1.1;          %overlap factor tandem
C_d=C_l/20;       %blade drag coeffcent
!!!Assumption!!!
omega=2*pi*RPM/60; %angular frequency
S=B*c*R;         %main rotor blade Area
A=(R^2)*pi;          %Disk Area
Atr=(R^2)*pi;     %Tail Rotor Disk Area
Str=Btr*ctr*Rtr;%tail rotor blade Area
Vtip=omega*R;        %tip Velocity [m/s]
Dl=W/A;              %Disk Loading
kat=(Str/S)       %tailrotor powerfactor
%design parameters Coaxial/Tandem
Configuration
R_t=6;                 %Rotor Radius [m]
RPM_t=286;          %Rotor Speed [RPM]
B_t=3;                 %Number of Blades
c_t=0.30;               %blade chord [m]
C_l_t=0.5;              %lift coeffcent
!!!estimated!!!
C_d_t=C_l_t/20; %blade drag coeffcent
!!!Assumption!!!
omega_t=2*pi*RPM_t/60;%ang. frequency
S_t=B_t*c_t*R_t;%main rotor blade Area
A_t=(R_t^2)*pi;        %Disk Area
Vtip_t=omega_t*R_t %tip Velocity [m/s]
Dl_t=W/A_t;            %Disk Loading
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Calculation
sigma_r=S/A
%solidity ratio
sigma_r_t=S_t/A_t
%solidity ratio tandem/coax
%tail rotor configuration
rho=ISA(1,2);
%rho at sea level
Pi=ki*((W^(3/2))/(sqrt(2*rho*A)));
%induced Power during Hover
Po=1/8*C_d*rho*sigma_r*A*Vtip^3;
%rotor Profile Power during Hover
FoM=Pi/(Pi+Po);
%figure of merit
P=ktr*(ki*Pi+Po)+kat*(ki*Pi+Po)
%Total Power for Hover at Sea Level
%tandem
Pit=ki*kov*((W^(3/2))/(sqrt(4*rho*A_t)
))  %induced Power during Hover
Pot=1/4*C_d_t*rho*sigma_r_t*A_t*Vtip_t
^3  %rotor Profile Power during Hover
FoM_t=Pit/(Pit+Pot);          %figure of
merit
Pt=ktr*(Pit+Pot)              %Total
Power for Hover at Sea Level
%coax
Pic=ki*ktr*((W^(3/2))/(sqrt(4*rho*A_t)
));  %induced Power during Hover
Poc=1/4*C_d_t*rho*sigma_r_t*A_t*Vtip_t
^3;
%rotor Profile Power during Hover
FoM_c=Pic/(Pic+Poc);        %figure of
merit
Pc=ktr*(Pic+Poc);           %Total
Power for Hover at Sea Level
%Predefinition of Power Matrices
Mtip=NaN(1,401);
%Knots fpr x-Axis
leg=0:1:400;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Calculate Vmax for maximum Mtip
Mmax=0.95;
%Maximum Tip Mach Number
Mtip=(((Vtip_t)*3.6)/1.852)/ISA(1,3);
%Tip Mach Number at hover
KT=0;
i=1;
    while Mtip < Mmax    %stop when
maximum Tip Mach Number is reached
    V=KT*1.852/3.6;      %Airspeed
    mu=V/Vtip;           %advance ratio
    rho=ISA(1,2);        %rho for
actual Flight Level according ISA
%Tip Mach Number on advancing Blade
Mtip(1,i)=(((Vtip_t+V)*3.6)/1.852)/ISA
(1,3);
    KT=KT+1;
    i=i+1;
    end
maximum_kt=i;              %Maximum Speed
[kt] for maximum Mtip 0.95
maximum_ms=i*1.852;      %Maximum Speed
[m/s]
```