BELL HILLER MECHANISM

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Abstract—

Swashplate mechanism is the steering control mechanism, used in most helicopters. It is a complex multi-loop closed kinematic chain which controls the angles of attack of the main rotor blades. In most new model helicopters, this mechanism is also equipped with the bellhiller stabilizer bar (flybar), to improve the stability. The main purpose of this paper is the dynamic analysis of a swashplate mechanism, one of the latest architectures, used for hinge less rotor with the flybar. The analyses are based on the parallel manipulators concept and the virtual work principle. Also, an ADAMS rigid body dynamic model was developed to verify the results of the analytical model. In many simulated cases, the results matched.

Keywords: Swatch Plate, main rotor, thrust, lift force , Sliding bar, Flybar, Blades, Using CATIA 2019, ANSYS R18.1

I. INTRODUCTION

This mechanism is used to change direction of flight. The arm called Bell input in the picture permits to directly change the angle of attack of the blades from the swashplate, the response to this input is fast but is inherently instable so, in the cyclic control, this input is mixed with the Hiller's one.A helicopter main rotor or rotor system is the combination of several rotary wings (rotor blades) and a control system that generates the aerodynamic lift force that supports the weight of the helicopter, and the thrust that counteracts aerodynamic drag in forward flight. Each main rotor is mounted on a vertical mast over the top of the helicopter, as opposed to a helicopter tail rotor, which connects through a combination of drive shaft(s) and gearboxes along the tail boom. The blade pitch is typically controlled by a swashplate connected to the helicopter flight controls. Helicopters are one example of rotary-wing aircraft (rotorcraft). The name is derived from the Greek words helix, helik-, meaning spiral; and pteron meaning wing.

HISTORY OF BELL HILLER MECHANISM

1923, invented by Juan de la Cierva.

The use of a rotor for vertical flight has existed since 400 BC in the form of the bamboocopter, an ancient Chinese toy.[1][2] The bamboo-copter is spun by rolling a stick attached to a rotor. The spinning creates lift, and the toy flies when released.[1] The philosopher Ge Hong's book the Baopuzi (Master Who Embraces Simplicity), written around 317, describes the apocryphal use of a possible rotor in aircraft: "Some have made flying cars [feiche 飛車] with wood from the inner part of the jujube tree, using ox-leather (straps) fastened to returning blades so as to set the machine in motion."[3] Leonardo da Vinci designed a machine known as an "aerial screw" with a rotor based on a water screw. The Russian polymath Mikhail Lomonosov developed a rotor based on the Chinese toy.

IMPORTANCE OF BELL HILLER MECHANISM:

In full-scale helicopters the primary stabilizing method, in most cases the only one, is the aero-elastic flapping of the rotor blades due to its high mass and slow response. In model helicopters the stabilization method used is the flapping of the flybar, which is an aerodynamically damped gyroscope device used to increase the stability of the vehicle in the pitch and roll axes and assists in its actuation. This device is well spread in robot helicopters because their small size causes an inherent instability and a fast time-domain response. In model helicopters this is also the only damping mechanism because their rotor hub is hingeless (rigid), so the blades can't move upwards and they are too stiff to flap significantly. This hingeless system is adopted to decrease the control time and give a better sensation of control to the pilot, otherwise in full scale helicopters the blades are free to flap, or springs are mounted on the rotor to increase the stability of the system. This system increases the time that the helicopter needs to respond to the control inputs. The flybar system permits also to reduce the forces that the actuators must apply to control the rotor. The first design of this system came in the 50's for full-scale helicopters and it used the gyroscopic effect of a bar with weights to regulate the tilt angle of the blades. To reduce the flapping motion of this mechanism was used a separate damper, this is the so called Bell stabilizing system. Lately an airfoil replaced the damper and weights to generate the Hiller system. The modern design is called Bell-Hiller flybar mixer because puts together some design aspects of both the configurations.

II.METHODOLOGY

The following system of methods are used to Design and Analyze the required Bell Hiller Mechanism.
 • Create a model of a Missile Handling System assembly in CATIA2019.
 • Analyze it under static structural analysis in ANSYS18.1

III.DESIGN OF BELL HILLER MECHANISM

DesignProcedure

The helicopter rotor is powered by the engine, through the transmission, to the rotating mast. The mast is a cylindrical metal shaft that extends upward from—and is driven by— the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub, and the hub can have 10-20 times the drag of the blade.[7] Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub. There are three basic classifications: rigid, semirigid, and fully articulated, although some modern rotor systems use a combination of these classifications. A rotor is a finely tuned rotating mass, and different subtle adjustments reduce vibrations at different airspeeds.[8] The rotors are designed to operate at a fixed RPM[9][10][11] (within a narrow range of a few percent),[12][13] but a few experimental aircraft used variable speed rotors. Unlike the small diameter fans used in turbofan jet engines, the main rotor on a helicopter has a large diameter that lets it accelerate a large volume of air. This permits a lower downwash velocity for a given amount of thrust. As it is more efficient at low speeds to accelerate a large amount of air by a small degree than a small amount of air by a large degree,[15][16] a low disc loading (thrust per disc area) greatly increases the aircraft's energy efficiency, and this reduces the fuel use and permits reasonable range.[17][18] The hover efficiency ("figure of merit")[19] of a typical helicopter is around 60%.[20] The inner third length of a rotor blade contributes very little to lift due to its low airspeed.[
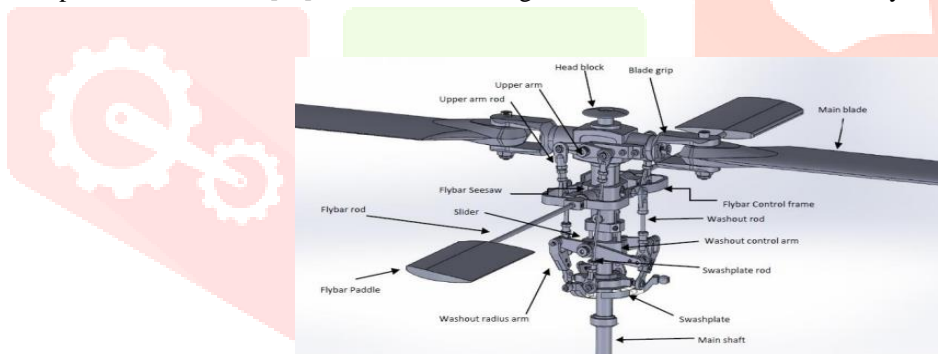

Parts and functions

The simple rotor of a Robinson R22 showing (from the top):
 • The following are driven by the link rods from the rotating part of the swashplate.
 • Pitch hinges, allowing the blades to twist about the axis extending from blade root to blade tip.
 • Teeter hinge, allowing one blade to rise vertically while the other falls vertically. This motion occurs whenever translational   relative wind is present, or in response to a cyclic control input.
 • Scissor link and counterweight, carries the main shaft rotation down to the upper swashplate
 • Rubber covers protect moving and stationary shafts
 • Swashplates, transmitting cyclic and collective pitch to the blades (the top one rotates)
 • Three non-rotating control rods transmit pitch information to the lower swashplate
 • Main mast leading down to main gearbox.

Swash plate

Controls vary the pitch of the main rotor blades cyclically throughout rotation. The pilot uses this to control the direction of the rotor thrust vector, which defines the part of the rotor disc where the maximum thrust develops. Collective pitch varies the magnitude of rotor thrust by increasing or decreasing thrust over the whole rotor disc at the same time. These blade pitch 21 variations are controlled by tilting, raising, or lowering the swash plate with the flight controls. The vast majority of helicopters maintain a constant rotor speed (RPM) during flight, leaving the angle of attack of the blades as the sole means of adjusting thrust from the rotor. The swash plate is two concentric disks or plates. One plate rotates with the mast, connected by idle links, while the other does not rotate. The rotating plate is also connected to the individual blades through pitch links and pitch horns. The non-rotating plate is connected to links that are manipulated by pilot controls— specifically, the collective and cyclic controls. The swash plate can shift vertically and tilt. Through shifting and tilting, the non-rotating plate controls the rotating plate, which in turn controls the individual blade pitch.
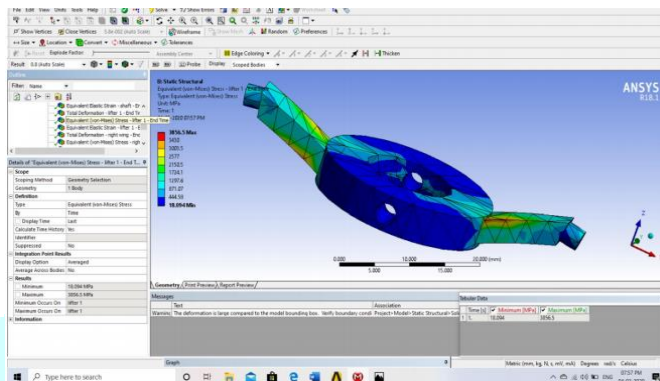
Slider:

Glide over the main shaft and it is blocked in the rotation around it by two guides.

Washout control arm: transmits the motion from the swashplate to the washout rod through the washout radius arm.

Flybar control frame:

Flybar control frame can rotate along the seesaw main axis and controls the flybar pitch angle.

Flybar seesaw:

It controls the roll movement of the flybar and its fulcrum is a hole in the head block which enables it to rotate perpendicularly to the control frame rotation axis. Because of two openings in the other direction it is also permitted the previous pitch movement. These two swinging structures, the inner and the outer, are connected only by 2 rotation.

Upper arm:

Upper arm gathers the inputs from the swashplate rod and from the flybar mechanism through the upper arm rod, its action is to rotate the blade carrier and definitively change the angle of attack of the blades.

Blade grip:

It rotates around its main axis and is connected to the head block by bearings. One blade grip can rotate independently by the other.

Fully articulated

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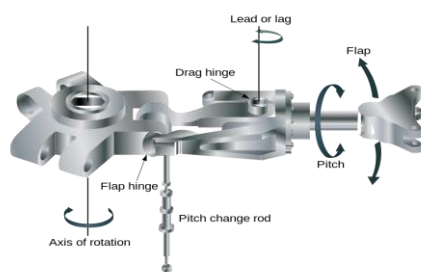
Juan de la Cierva developed the fully basis of his design permitted successful helicopter development. In a fully articulated rotor system, each rotor blade is attached to the rotor hub through a series of hinges that let the blade move independently of the others. These rotor systems usually have three or more blades. The blades are allowed to flap, feather, and lead or lag independently of each other. The horizontal hinge, called the **flapping hinge**, allows the blade to move up and down. This movement is called flapping and is designed to compensate for dissymmetry of lift. The flapping hinge may be located at varying distances from the rotor hub, and there may be more than one hinge. The vertical hinge, called the **lead-lag hinge** or **drag hinge**, allows the blade to move back and forth. This movement is called lead-lag, dragging, or hunting. Dampers are usually used to prevent excess back and forth movement around the drag hinge. The purpose of the drag hinge and dampers is to compensate for acceleration and deceleration caused by the Coriolis effect. Later models have switched from using traditional bearings to elastomeric bearings. Elastomeric bearings are naturally fail-safe and their wear is gradual and visible. The metal-tometal contact of older bearings and the need for lubrication is eliminated in this design. The third hinge in the fully articulated system is called the feathering hinge about the feathering axis. This hinge is responsible for the change in pitch of rotor blades excited via pilot input to the collective or cyclic.

Rigid

The term "rigid rotor" usually refers to a hingeless rotor system[21][22] with blades flexibly attached to the hub. Irv Culver of Lockheed developed one of the first rigid rotors, which was tested and developed on a series of helicopters in the 1960s and 1970s. In a rigid rotor system, each blade flaps and drags about flexible sections of the root. A rigid rotor system is mechanically simpler than a fully articulated rotor system. Loads from flapping and lead/lag forces are accommodated through rotor blades flexing, rather than through hinges. By flexing, the blades themselves compensate for the forces that previously required rugged hinges. The result is a rotor system that has less lag in control response because of the large hub moment typically generated.[23] The rigid rotor system thus eliminates the danger of mast bumping inherent in semirigid rotors.[24]

Aircraft

- MBB Bo 105
- Eurocopter EC135
- HAL Dhruv/HAL Rudra
- HAL Light Combat Helicopter
- Sikorsky X2
- Sikorsky S-97 Raider
- Sikorsky–Boeing SB-1 Defiant
- Westland Lynx

Semirigid

The semirigid rotor can also be referred to as a teetering or seesaw rotor. This system is normally composed of two blades that meet just under a common flapping or teetering hinge at the rotor shaft. This allows the blades to flap together in opposite motions like a seesaw. This underslinging of the blades below the teetering hinge, combined with an adequate dihedral or coning angle on the blades, minimizes variations in the radius of each blade's center of mass from the axis of rotation as the rotor turns, which in turn reduces the stress on the blades from lead and lag forces caused by the Coriolis effect. Secondary flapping hinges may also be provided to provide sufficient flexibility to minimize bouncing. Feathering is accomplished by the feathering hinge at the blade root, which allows changes to the pitch angle of the blade.

Fly-bar (stabilizer bar)

A number of engineers, among them Arthur M. Young in the U.S. and radio-control aeromodeler Dieter Schlüter in Germany, found that flight stability for helicopters could be achieved with a stabilizer bar, or flybar. The flybar has a weight or paddle (or both for added stability on smaller helicopters) at each end to maintain a constant plane of rotation. Through mechanical linkages, the stable rotation of the bar mixes with the swashplate movement to damp internal (steering) as well as external (wind) forces on the rotor. This makes it easier for the pilot to maintain control of the aircraft. Stanley Hiller arrived at a similar method to improve stability by adding short stubby airfoils, or paddles, at each end. However, Hiller's "Rotormatic" system also delivered cyclic control inputs to the main rotor as a sort of control rotor, and the paddles provided the added stability by damping the effects of external forces on the rotor.

The Lockheed rotor system used a control gyro, similar in principle to that of the Bell stabilizer bar, but designed for both hands-off stability and rapid control response of the hingeless rotor system.

In fly-by-wire helicopters or RC models, a microcontroller with gyroscope sensors and a Venturi sensor can replace the stabilizer. This *flybar-less* design has the advantage of easy reconfiguration and fewer mechanical parts. Even though a real RC helicopter with flybar must keep a gyroscope on each axis.

Aircraft

- Bell 47
- Bell 206/OH-58
- Bell UH-1 Iroquois
- Bell AH-1 Cobra
- Robinson R22
- Robinson R44
- Robinson R66
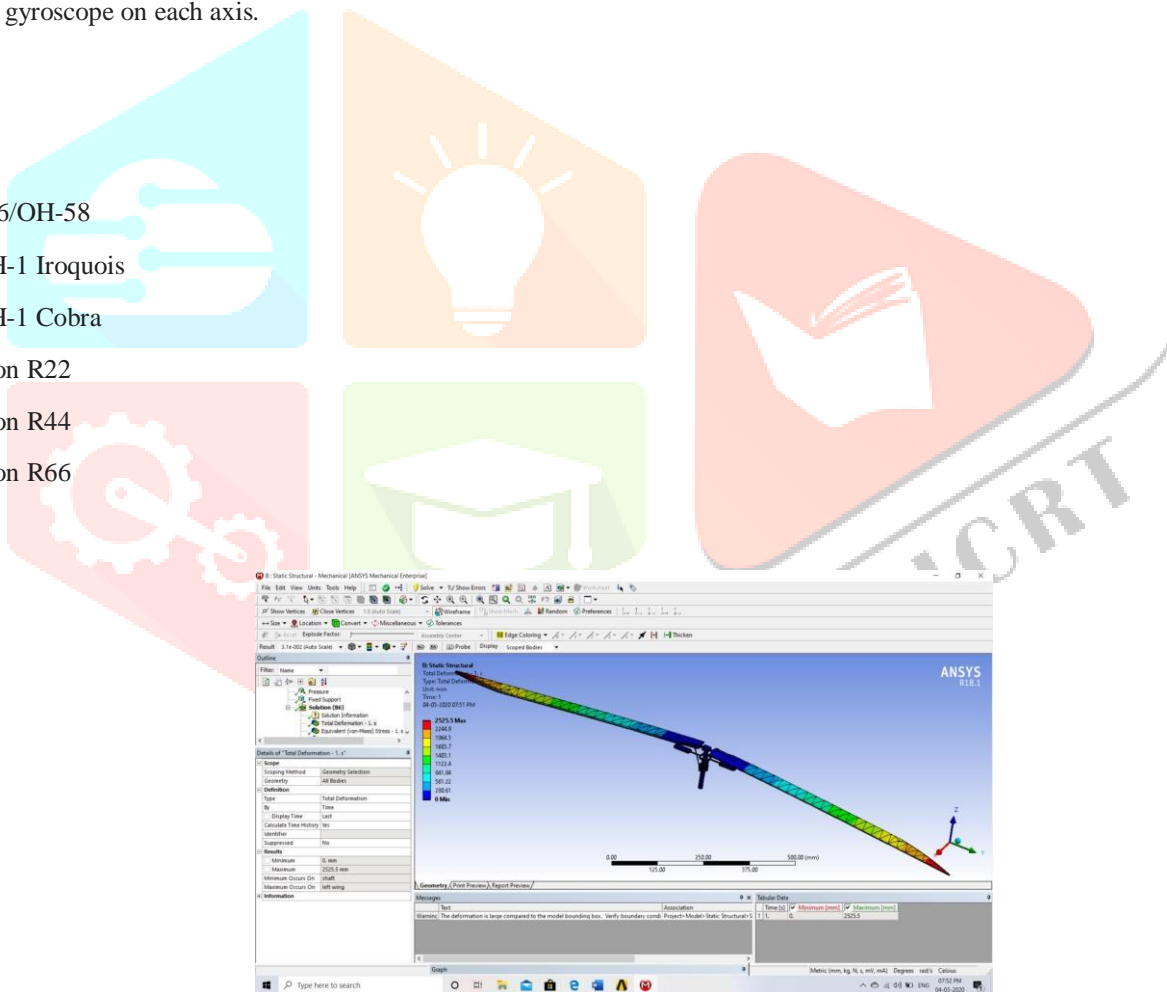
Combination

Modern rotor systems may use the combined principles of the rotor systems mentioned above. Some rotor hubs incorporate a flexible hub, which allows for blade bending (flexing) without the need for bearings or hinges. These systems, called "flexures",[25] are usually constructed from composite material. Elastomeric bearings may also be used in place of conventional roller bearings. Elastomeric bearings are constructed from a rubber type material and provide limited movement that is perfectly suited for helicopter applications. Flexures and elastomeric bearings require no lubrication and, therefore, require less maintenance. They also absorb vibration, which means less fatigue and longer service life for the helicopter components.

Aircraft

- Bell 407

- Bell 430
- Eurocopter AS350

Blade Design

The blades of a helicopter are long, narrow airfoils with a high aspect ratio, a shape that minimizes drag from tip vortices (see the wings of a glider for comparison). They generally contain a degree of washout that reduces the lift generated at the tips, where the airflow is fastest and vortex generation would be a significant problem. Rotor blades are made out of various materials, including aluminium, composite structure, and steel or titanium, with abrasion shields along the leading edge.

Rotorcraft blades are traditionally passive; however, some helicopters include active components on their blades. The Kaman K-MAX uses trailing edge flaps for blade pitch control and the Hiller YH-32 Hornet was powered by ramjets mounted on the blade ends. As of 2010, research into active blade control through trailing edge flaps is underway.[32] Tips of some helicopter blades can be specially designed to reduce turbulence and noise and to provide more efficient flying. An example of such tips are the tips of the BERP rotors created during the British Experimental Rotor Programme.

The two families of airfoils are

- symmetrical airfoils
- asymmetrical airfoils

Symmetrical blades are very stable, which helps keep blade twisting and flight control loads to a minimum. This stability is achieved by keeping the center of pressure virtually unchanged as the angle of attack changes. Center of pressure is the imaginary point on the chord line where the resultant of all aerodynamic forces are considered to be concentrated. Today, designers use thinner airfoils and obtain the required rigidity by using composite materials.

In addition, some airfoils are asymmetrical in design, meaning the upper and lower surface do not have the same camber. Normally these airfoils would not be as stable, but this can be corrected by bending the trailing edge to produce the same characteristics as symmetrical airfoils. This is called "reflexing." Using this type of rotor blade allows the rotor system to operate at higher forward speeds. One of the reasons an asymmetrical rotor blade is not as stable is that the center of pressure changes with changes in angle of attack. When the center of pressure lifting force is behind the pivot point on a rotor blade, it tends to cause the rotor disc to pitch up. As the angle of attack increases, the center of pressure moves forward. If it moves ahead of the pivot point, the pitch of the rotor disc decreases. Since the angle of attack of the rotor blades is constantly changing during each cycle of rotation, the blades tend to flap, feather, lead, and lag to a greater degree.
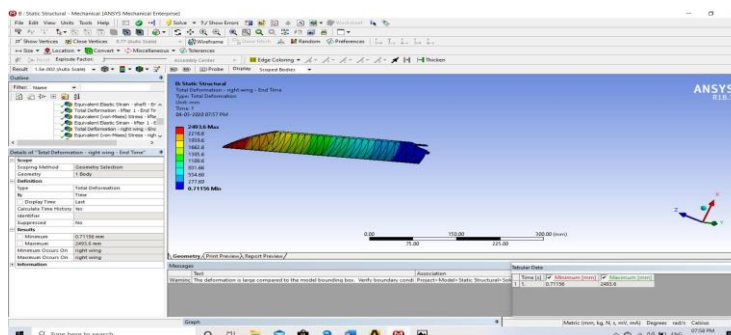
Dynamic Analysis:

Thismechanism also induces a delay in the response to the pilot inputs, which is a counter part to the fact that the machine is less affected by external disturbances and quick changes in state (cross-wind, ground effect, etc.). The presence of the aerodynamic forces also affects the forces that the actuators must exert on the swashplate. Those effects can be proven by the following test conducted with and without the airfoils:

Change in cyclic input tilt (stepped function)

To assess the behaviour of the mechanism through the different rotational speeds an eigenvalues calculation is needed:

Identify the natural frequencies of the system in the linearized configuration of the rotating frame.
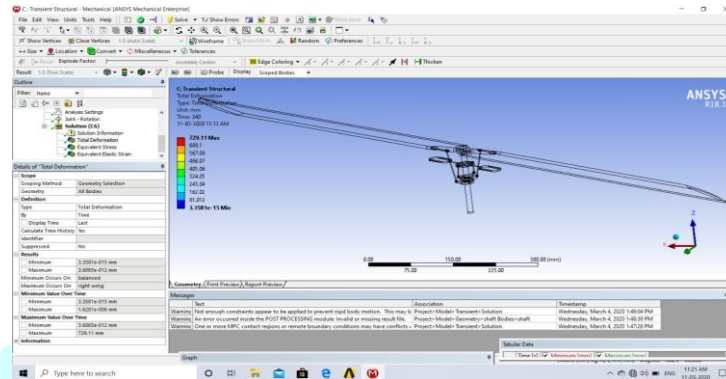
The main geometry parameters of the system are presented below, note that for simplicity the rotor and the whole paddles have been modelled with plastic density and the other parts in steel:

Items	Value
Number of rotor blades	2
Rotor radius [m]	0.56
Half mass of rotor blades [kg]	0.1174
Stabilizing bar radius [m]	0.22
Inside radius of paddle [m]	0.144
Half mass of paddles [kg]	0.01326
Distance between swashplate and rotor blades [m]	0.0823
Average chord length of paddle [m]	0.043
Average chord length of blade [m]	0.0456
Total mass [kg]	0.6418

Some parts have been merged using the command Merge two bodies. Even if the parts in reality are not made of the same material, for example the rods or the shaft, they have been modelled with the same material due to the characteristics of the command.

The mass of the parts has been obtained by imposing the density of the material (plastic or steel) to the part and using the geometry from the Cad. Even if this is an approximation it is acceptable for our purpose and moreover, because the mass of the parts is very low.

Some CM of the parts has been modified in order to obtain the most accurate equilibrium configuration. To do this the common CM of the symmetric parts has been manually adjusted using the tool Aggregate Mass. Even if the operation has been carried out with accuracy still some hundreds of millimetre differences are present, whcih leads to some little instabilities.

The results of this inaccuracy will been explained.

Body i	Body j	Type of Joint
Ground	Shaft	Rotational
Shaft	Ball joint	Cylindrical
Ball joint	Swashplate outer ring	Spherical
Ball joint	Swashplate inner ring	Spherical
Swashplate outer ring	Swashplate inner ring	Parallel
Swashplate inner ring	Swashplate rod	Spherical (-1)
Swashplate inner ring	Washout radius arm	Spherical
Washout control arm	Slider	Rotational
Washout control arm	Washout rod	Spherical (-1)
Slider	Shaft	Translational
Washout rod	Flybar control frame	Spherical
Flybar control frame	Flybar seesaw	Rotational
Flybar seesaw	Shaft	Rotational
Flybar seesaw	Upper arm rod	Spherical (-1)
Upper arm rod	Upper arm	Spherical
Upper arm	Blade grip	Rotational
Upper arm	Swashplate rod	Spherical
Blade grip	Shaft	Rotational
Paddle	Flybar control frame	Fixed
Mian blade	Blade grip	Fixed

The swashplate mechanism has 3 DOF, two rotations about perpendicular axis in its own plane (cyclic inputs) and one translation along the shaft (collective input). Because the outer and inner rings of the swashplate rotate around the ball joint, which is a portion of a sphere with 2 parallel bases included in two parallel secant planes, the spherical joint that connects those parts to the ball joint are overlapping on its centre of mass which is also the rotational centre. A configuration where the spherical joints are put on the centres of mass of their respective bodies will lead to a locked mechanism. These three DOFs of the swashplate are controlled by three servo-actuators fixed to the helicopter's body; they also prevent the rotation of the outer ring which is in-built with the fixed frame. Another independent DOF is the rotation of the shaft. So the controllable DOFs are four, three from the swashplate and one from the shaft. It is also present an internal DOF, this additional motion is the flapping of the flybar, so the final DOFs are five. To properly count these DOFs, the Planar joint that was punt at a first stage has been substituted with a Parallel joint. The first joint constraints the rotations along the axes in plane and also the translation along the other direction (Z axis), the latter constraint doesn't exist in the reality because the inner and outer rings are not fixed between each other and they slide one over the other simply because of gravity. The correct joint is so the parallel joint which constraints only the rotations on the plane (X/Y axes).

RESULTS

• After computing the final model of Bell Hiller Mechanism

S. No.	VARIABLES	MINIMUM VALUE	MAXIMUM VALUE
1.	Equivalent Stress(N/m^2)	5.4512e-009 N/m^2	36810 N/m^2
2.	Equivalent Strain	4.8764e-013	0.52476mm
3.	Total Deformation (m)	0mm	2525.5mm

TABLE 6.1 Various Parametric Conditions Observed In ANSYS (R18.1)

CONCLUSIONS

From the first kinematic analysis the relation between the input, seen as the translation and rotation of the swashplate, and the output of the blades rotation and paddles pitch was found for this particular mechanism. This result is important to assess the differences between the static value that a quantity has and its value influenced by the dynamics of the mechanism, mainly by the flybar flapping effect. To make an overall check of the stresses on the blades and the mechanism responses, a complete simulation was performed considering the presence of the aerodynamic forces on the paddles and the combined effect of collective and cyclic pitch. The effect of the flybar, seen in the rigid body simulation, and the destabilizing effect caused by the blades aerodynamic forces are both present.

REFERENCES

Leishman, J. Gordon. Principles of Helicopter Aerodynamics. Cambridge aerospace series, 18. Cambridge: Cambridge University Press, 2006. ISBN 978-0-521-85860-1. pp. 7-9. Web extract Archived 2014-07-13 at the Wayback Machine

Taking Flight: Inventing the Aerial Age, from Antiquity Through the First World War. Oxford University Press. 8 May 2003. pp. 22–23. ISBN 978-0-19-516035-2.

Joseph Needham (1965), Science and civilisation in China: Physics and physical technology, mechanical engineering Volume 4, Part 2, page 583-587.

John D. Anderson (2004). Inventing Flight: The Wright Brothers & Their Predecessors. JHU Press. p. 35. ISBN 978-0-8018-6875-7. video.

Savine, Alexandre. "TsAGI 1-EA." ctrl-c.liu.se, 24 March 1997. Retrieved 12 December 2010.

Harris, Franklin D. "Rotor Performance at High Advance Ratio: Theory versus Test Archived 2013-02-18 at the Wayback Machine" page 119 NASA/CR—2008–215370, October 2008. Accessed: 13 April 2014.

Head, Elan (April 2015). "A better track and balance". Vertical Magazine. p. 38. Archived from the original on 11 April 2015. Retrieved 11 April 2015.

Croucher, Phil. Professional helicopter pilot studies page 2-11. ISBN 978-0-9780269-0-5.

Quote: [Rotor speed] "is constant in a helicopter".

Seddon, John; Newman, Simon (2011). Basic Helicopter Aerodynamics. John Wiley and Sons. p. 216. ISBN 1-119-99410-1. The rotor is best served by rotating at a constant rotor speed

Robert Beckhusen. "Army Dumps All-Seeing Chopper Drone" Wired June 25, 2012. Accessed: 12 October 2013. Archived on 22 April 2015. Quote:The number of revolutions per minute is also set at a fixed rate

The UH-60 permits 95–101% rotor RPM UH-60 limits Archived 2016-08-18 at the Wayback Machine US Army Aviation. Accessed: 2 January 2010

Trimble, Stephen (3 July 2008). "DARPA's Hummingbird unmanned helicopter comes of age". FlightGlobal. Archived from the original on 14 May 2014. Retrieved 14 May 2014. The rotor speed on a typical helicopter can be varied around 95-102%

Datta, Anubhav et al. Experimental Investigation and Fundamental Understanding of a Slowed UH-60A Rotor at High Advance Ratios page 2. NASA ARC-E-DAA-TN3233, 2011. Header Accessed: May 2014. Size: 26 pages in 2MB

Paul Bevilaqua : The shaft driven Lift Fan propulsion system for the Joint Strike Fighter Archived 2011-06-05 at the Wayback Machine page 3. Presented May 1, 1997. DTIC.MIL Word document, 5.5 MB. Accessed: 25 February 2012.

Bensen, Igor. "How they fly - Bensen explains all" Gyrocopters UK. Accessed: 10 April 2014.

Johnson, Wayne. Helicopter theory pp3+32, Courier Dover Publications, 1980. Accessed: 25 February 2012. ISBN 0-486-68230-7

Wieslaw Zenon Stepniewski, C. N. Keys. Rotary-wing aerodynamics p3, Courier Dover Publications, 1979. Accessed: 25 February 2012. ISBN 0-486-64647-5

Jackson, Dave. "Figure of Merit" Unicopter, 16 December 2011. Retrieved: 22 May 2015. Archived on 26 November 2013.

Whittle, Richard. "It's A Bird! It's A Plane! No, It's Aircraft That Fly Like A Bird! Archived 2015-05-01 at the Wayback Machine" Breaking Defense, 12 January 2015. Accessed: 17 January 2015.

Landis, Tony and Jenkins, Dennis R. Lockheed AH-56A Cheyenne - WarbirdTech Volume 27, p.5. Specialty Press, 2000. ISBN 1-58007-027-2.

"Model 286". Archived from the original on 2016-03-04. Retrieved 2010-07-07.

Connor, R. Lockheed CL-475". Smithsonian National Air & Space Museum. Revised on 15 August 2002. Accessed at archive.org on 3 September 2007. original link Archived 2007-07-07 at the Wayback Machine.

Cox, Taylor. "Blades and Lift". Helis.com. Retrieved: 10 March 2007.

FAA Flight Standards Service 2001

Alpman, Emre and Long, Lyle N. "Understanding Ducted-Rotor Antitorque and Directional Control: Characteristics Part II: Unsteady Simulations." Archived 2015-04-02 at the Wayback Machine Journal of Aircraft Vol. 41, No. 6, November–December 2004.

Frawley 2003, p. 151.

"NOTAR Fleet Marks 500,000 Flight Hours". American Helicopter Society. Retrieved: 25 February 2007.

"The Boeing Logbook: 1983-1987". Boeing.com. Retrieved: 25 February 2007.

"Cierva", Flight: 340, 17 April 1947

Markus Waibel. "Quadcopter, Hexacopter, Octocopter ... UAVs". IEEE Spectrum, 2010-02-19.

Mangeot et al. New actuators for aerospace Archived 2011-07-14 at the Wayback Machine Noliac. Retrieved: 28 September 2010.

"Rotorcraft Flying Handbook", page 2-1. FAA

Rotorcraft Flying Handbook (PDF). U.S. Government Printing Office, Washington D.C.: U.S. Federal Aviation Administration. 2000. pp. 11–10. ISBN 1-56027-404-2. FAA-8083-21. Archived from the original (PDF) on 2011-06-06.

Jim Bowne (February 2004). "These boots are made for flying: Rotor blades get new protective shields". RDECOM Magazine. U.S. Army Research, Development and Engineering Command (Provisional). Archived from the original on 2009-09-18. Retrieved 2009-09-04. The 'corona effect' is characterized by distinctive glowing rings along metal or fiberglass rotor blades operating in desert conditions.

Mamedov, R. K.; Mamalimov, R. I.; Vettegren', V. I.; Shcherbakov, I. P. (2009-06-01). "Time-resolved mechanoluminescence of optical materials". Journal of Optical Technology. 76

(6): 323. doi:10.1364/jot.76.000323.

Warren (Andy) Thomas; Shek C. Hong; Chin-Jye (Mike) Yu; Edwin L. Rosenzweig (2009-0527). "Enhanced Erosion Protection for Rotor Blades: Paper presented at the American Helicopter Society 65th Annual Forum, Grapevine, Texas, May 27 – 29, 2009" (PDF). American Helicopter Society. Archived from the original (PDF) on 2010-06-20. Retrieved 2009-09-02. A secondary concern with the erosion of metal abrasion strips pertains to the visible signature that occurs ... causing a corona effect in sandy environments.

"Office of Naval Research Broad Agency Announcement(BAA): Advanced Helicopter Rotor Blade Erosion Protection" (PDF). United States Department of the Navy, Office of Naval

Research: 3. BAA 08-011. Archived from the original (PDF) on 2009-07-11. Retrieved 200909-02. An equally important problem with Ti protection is that a visible corona or halo is generated around the rotor blades at night from the sand impacting the Ti leading edge and causing Ti to spark and oxidize.

"How a Combat Photographer Named a Phenomenon to Honor Soldiers". petapixel.com. Retrieved 14 April 2020.