

# A NEW HELICOPTER SIMULATION AND ANALYSIS TOOL: HELIDYN+

**Ilkay Yavrucuk<sup>1</sup>, Onur Tarimci<sup>2</sup>, Mehmet Katircioglu<sup>3</sup>, Eser Kubali<sup>4</sup>, Deniz Yilmaz<sup>5</sup>**

<sup>1,5</sup> Department of Aerospace Engineering  
Middle East Technical University  
06531, Ankara, Turkey

<sup>2,3,4</sup> Aerotim Dynamics, LLC. ,  
ODTU Kosgeb  
06531, Ankara, Turkey

*yavrucuk@metu.edu.tr (Ilkay Yavrucuk)*

## Abstract

A new software tool - called Helidyn+ is developed for comprehensive helicopter analysis, simulation and design. Helidyn+ allows the user to generate a helicopter math model through its component build up algorithm by selecting model libraries for various helicopter sub-components, such as models for the main rotor, inflow, tail rotor, fuselage, landing gear etc. The software is capable of modeling a helicopter, running a simple performance analysis, trimming for different flight conditions, linearizing, running batch simulations, as well as generating dynamic link libraries ready to be integrated into existing simulations and software environments. This paper explains capabilities and features of Helidyn+ and shows some recent applications.

## Introduction

Helicopter math models are engineering tools with a variety of applications. The fidelity of these models can be various and can be used in engineering analysis, design, education and products like simulators. Often the requirement is to have models that have acceptable execution time, but also detailed enough to suit the application. The theory for such models is well established in literature [1, 2]. Yet, there are few off-the-shelf software products that provide helicopter dynamic math models that can be tailored for various applications and used as an engineering tool. Some of them are too complex to use, others don't have the required modeling fidelity. Most companies and universities still develop their own helicopter math models.

Many companies and/or university labs with would benefit from an off-the-shelf, simple to use, verified helicopter dynamic modeling and analysis tool. This would save the effort to build and verify a new math model.

There are few off-the-shelf modeling tools for helicopters. A popular helicopter modeling, simulation tool is Flightlab [3]. Flightlab allows the user to build high fidelity helicopter math models and is a very comprehensive tool for helicopter dynamics with many features. It is widely used - mostly at universities and companies involved in helicopter simulation and analysis.

The software tool, Helidyn+, presented in this paper is designed to build fast and accurate helicopter models, analyze and simulate them. It has the key feature to extract independent model libraries to be used in external applications and integrate with FlightGear [4] for fast visualization.

Helidyn+ is an effective and easy to use tool for companies and universities. Few recent applications at the Middle East Technical University demonstrated its effective use both in the lab and in class. The software is used in class assignments, where students are asked to build their own main rotor model and integrate it with a helicopter model (with no main rotor dynamics) generated in Helidyn+. Helidyn+ is also used in the design of controllers for unmanned helicopters. The tool is used to test the controllers in Simulink/Matlab [5], C/C++, or Fortran by integrating Helidyn+ models as function libraries into the various software environments. Similarly, Helidyn+ models are used in an in-house build simulator using virtual reality tools.

## Helidyn+ Software Description

Helidyn+ is a dynamic modeling tool for helicopters. The user can establish a simulation model of the desired helicopter by providing geometric, inertial and aerodynamic data. The model libraries belong to various helicopter components and the final model is established using component build-up. Component built-up refers to the calculation of the forces and moments generated by each helicopter component.

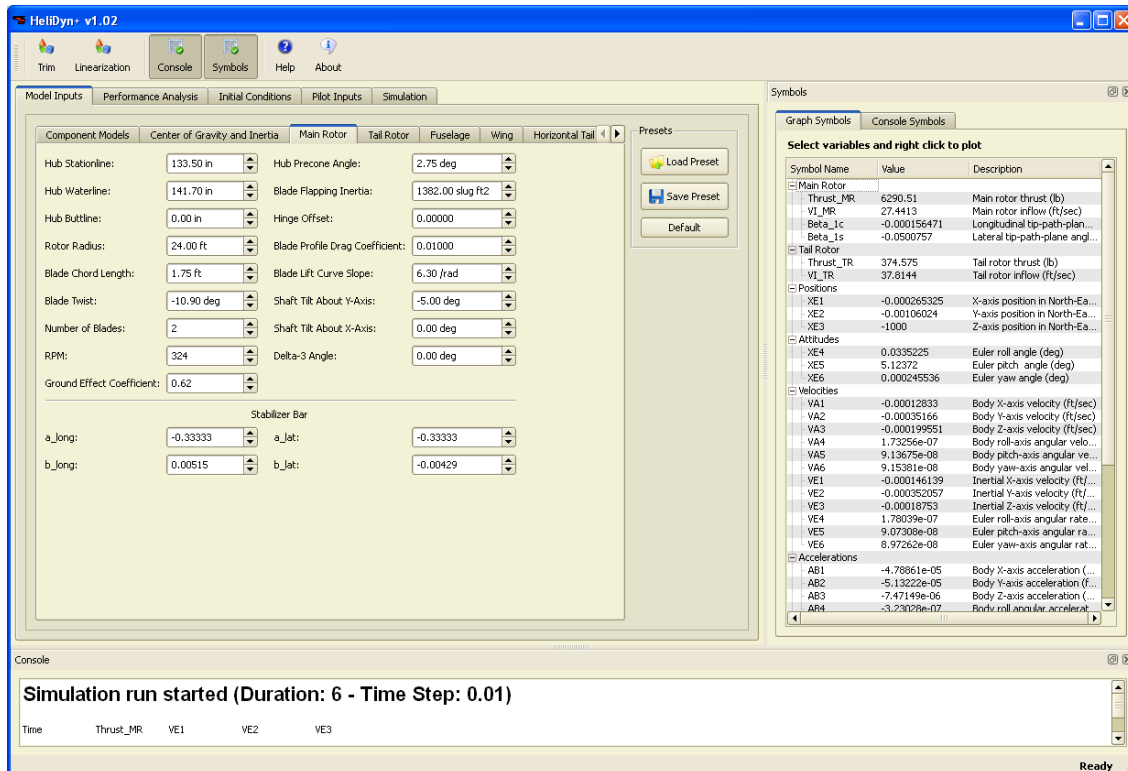


Fig. 1 Screen shot of the Model Input Tab in Helidyn+.

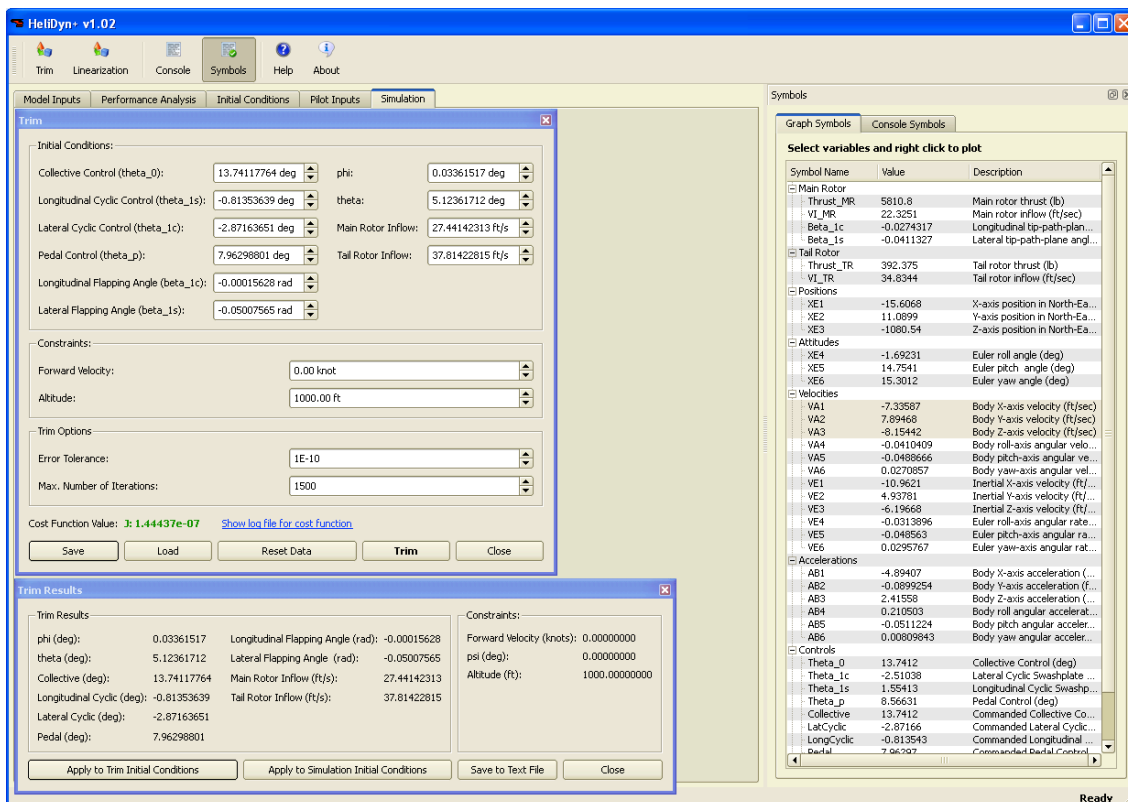


Fig. 2 Screen shot of the Trimming windows in Helidyn+.

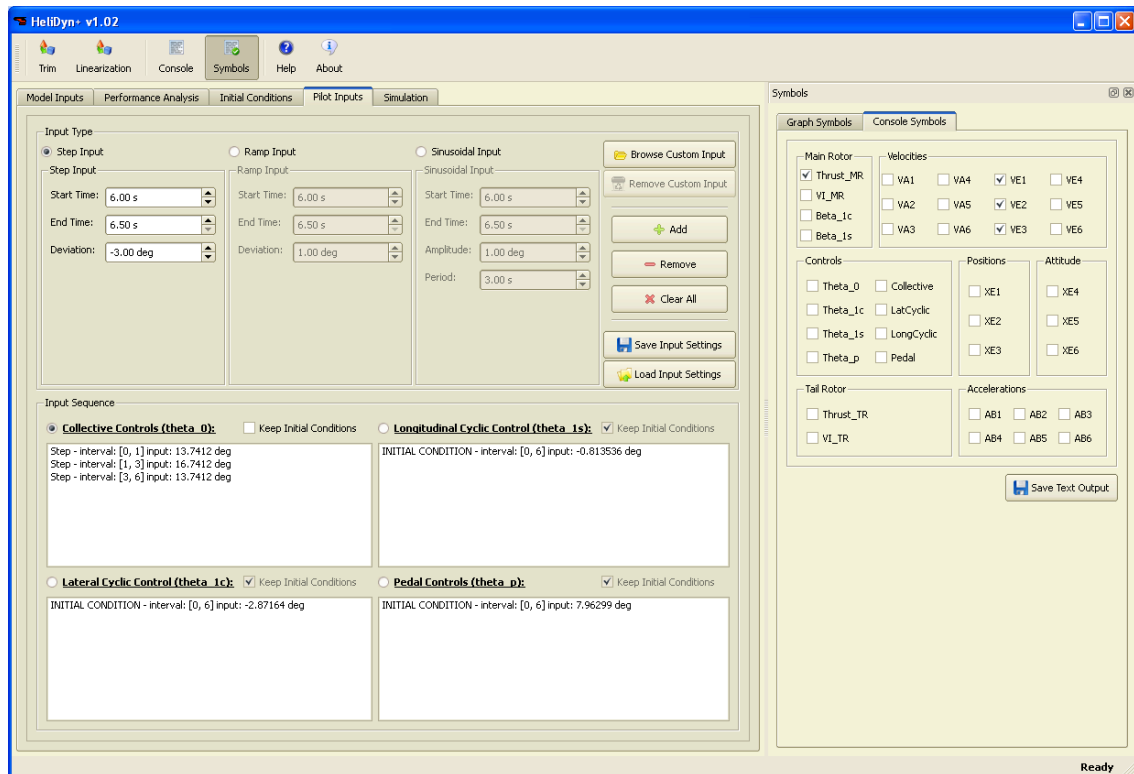


Fig. 3 Screen shot of the Pilot Input Tab in Helidyn+.

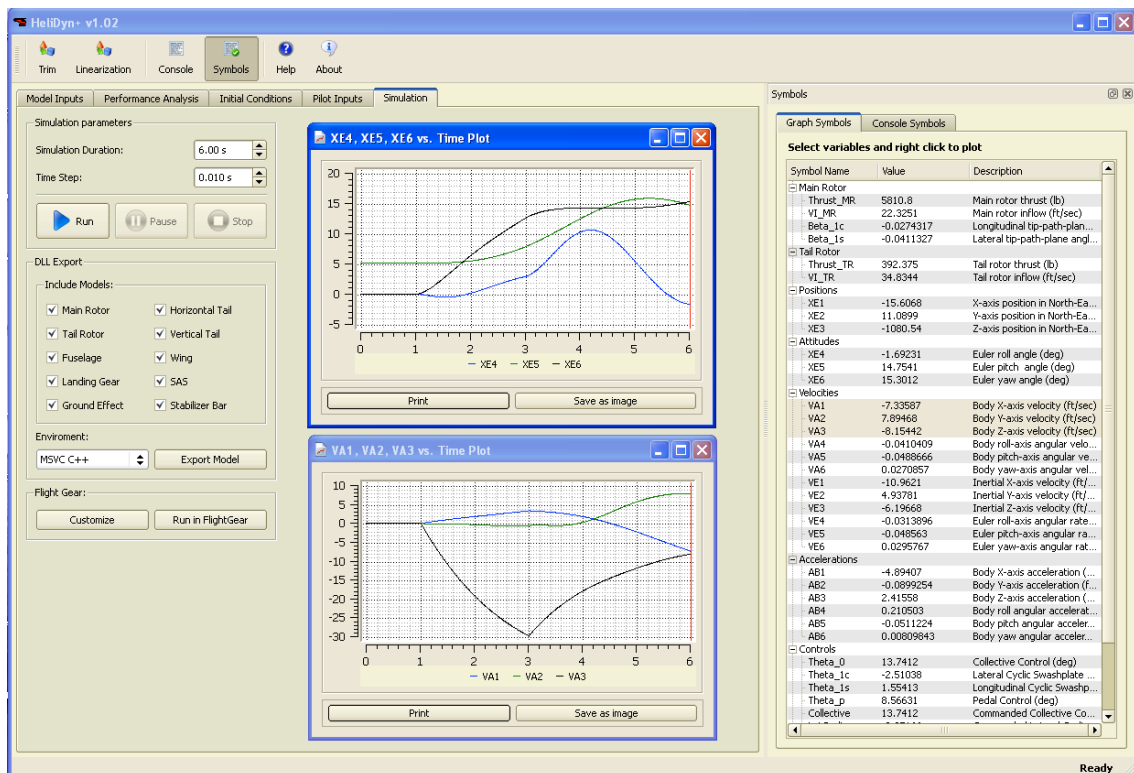


Fig. 4 Screen shot of the Simulation Tab in Helidyn+.

The forces and moments are then carried to the center of gravity of the helicopter allowing calculations for 6 degree of freedom rigid body dynamics. Therefore, models of different components can easily be interchanged, such that the user can build helicopter models of various fidelities.

Helidyn+ uses model libraries to allow the user to build a helicopter models. Model libraries include low fidelity as well as higher fidelity model components. The lowest fidelity model available in the code is the well-known “Minimum Complexity” model [6]. This model covers a conservative portion of a helicopter’s flight regime and includes only the response characteristics a pilot would need to see in a rather simple simulation. The minimum complexity model is composed of main rotor calculations with first order flapping, uniform inflow and an iterative approach to the classic Momentum and Glauert Theories for force and moment calculations. Other components such as wings, horizontal stabilizer, vertical tail, etc. are modeled by using simple calculations with constant aerodynamic coefficients.

Higher fidelity models include 3-state Peters-He [7] inflow models, main rotor blade element solutions, 360deg fuselage aerodynamics, ground effects, ground reactions, SAS models etc. Each component model library can be chosen through the graphical user interface and the appropriate data that is needed for the model is displayed in the related tab (Fig.1). Once the model is built it can be saved and loaded later.

Helidyn+ has a numeric search algorithm to find trim conditions (Fig.2). Once the model is trimmed, it can be linearized around the trim condition. The linear models are in the form of a state space representation of the full nonlinear model.

Helidyn+ allows the user to run batch simulations starting from a trimmed flight condition or any other initial flight condition. The pilot control inputs can be input either using simple functions like step, ramp or sinusoidal, or custom prescribed control input history data (Fig.3). The batch simulations can be plotted and recorded as figures and text files for future use (Fig.4).

Using Helidyn+ it is possible to run a quick performance analysis. The toolbox calculates classic performance indicators for a helicopter such as maximum cruise speed, maximum range

velocity, maximum endurance velocity, and plots for Power required, Torque Required vs. forward velocity.

Generated models, trim conditions, batch simulation inputs and results can all be saved and loaded for future use.

### *Exporting Dynamic Models*

The tool allows the user to extract a dynamic link library (.dll) of the generated model ready to be integrated into a C/C++, Fortran or Matlab/Simulink [1] simulation code. Exporting a model is enabled through a simple user interface. The user can export the whole helicopter model as a library, but can also exclude individual components while exporting. Therefore, it is possible to turn any of the model sub-components on and off while extracting the library. For instance, aside from being able to exporting a full helicopter dynamic model, it is possible to export only a main rotor math model, or a helicopter model without a tail rotor. This becomes handy when it is desired to integrate a custom build model component into the simulation. Say for instance, a user would like to design a flight controller in Matlab for a new conceptual helicopter model with an innovative, new horizontal tail configuration. First, the conceptual helicopter model is built in Helidyn+ using the available model libraries. Next, the user can choose to export the model “without” a horizontal tail, and then embed this model into the Matlab environment, where the horizontal tail could be modeled independently. Now, the controller can be designed using the new horizontal tail configuration. Note that the model will still have Helidyn+’s high fidelity main rotor and fuselage models in the simulation.

Helidyn+ is fully integrated into the open source simulation platform called FlightGear for visual simulation. Using a single button activation in the graphical user interface in Helidyn+ the model is exported as a dynamic link library, copied into the FlightGear folder and is ready for simulation with FlightGear. The model can be flown using a joystick or keyboard instantly and makes use of the full functionality of FlightGear. This feature is a fast approach to model, test, integrate and observe real time flying characteristics. A screenshot of Flightgear is shown in Fig.5



Fig. 5 A screenshot from FlightGear.

### Recent Helidyn+ Applications

The application of this tool can be in various areas. Here we present three diverse recent applications:

#### *Academic Class Work*

Helidyn+ has proven itself to be a very useful tool for a graduate level class in helicopter dynamics as it has been taught at the Middle East Technical University's Helicopter Dynamics Stability and Control class. The students were asked to build main rotor models, run and compare them in real-time simulations. Helidyn+ was configured to generate dynamic link libraries of a helicopter model without the main rotor component. The students were asked to complete the main rotor component by using various inflow models as C/C++, Fortran or Matlab/Simulink functions, integrate them with the Helidyn+ generated dynamic link library and compare results by running various simulation scenarios. The first comparison was against the verified model within Helidyn+. That way students did only spend time on modeling the main rotor, had a full nonlinear flight simulation to evaluate the helicopters total response, and a baseline to compare their results.

#### *Controller Design for Unmanned Helicopters*

Helidyn+ can be used as a design tool for controllers for unmanned helicopters. Often times, accurate models are required for controller design. Linearized models are used in developing the controller, but nonlinear higher fidelity models are used to test the controller. Helidyn+ provides a complete solution for this problem and can be used in hardware-in-the-loop and software-in-the-loop simulations.

A common way followed in our labs is the following: A helicopter model is generated using Helidyn+ using geometric, inertial and aerodynamic data. Then the model is trimmed and linearized. The linear state space model can be used to design controllers. The controller design can actually be done with tools like Matlab or Simulink. Later the model can be exported into Matlab/Simulink and the controller can be run with the full nonlinear model generated in Helidyn+ in Matlab/Simulink. Similarly, controllers written in C/C++ or Fortran can also be compiled with a dynamic model generated in Helidyn+.

#### *METU Virtual Reality Simulator*

Another application is the use of Helidyn+ models in a recently developed Virtual Reality Simulator (VRS) build in the Simulation Control and Avionics Lab (SCALAB) at the Middle East Technical University (Fig.6). The VRS uses Flightgear for visualization. In this application, the Flightgear simulation environment is integrated with data gloves, a virtual reality head-up-display. The head-up-display features stereo output. The virtual cockpit enables the pilot to interact with the interior cockpit through data gloves. The pilot can observe animated flight controls, cockpit avionics, and out-of-the window movement, such as main rotor animations, scenery, etc. [8]

Originally the simulator was developed with a custom build Uh-1h helicopter dynamic model with lower fidelity. Helidyn+ is used to increase the model fidelity and enable fast prototyping. Moreover, the model is trimmed and linearized to develop a SAS in Helidyn+. Finally, the helicopter model is exported as a model library and integrated to the real time simulation environment as a C/C++ code. As Helidyn+ allows a seamless integration with Flightgear, the model is quickly integrated into the simulator. Any change in the model can quickly be incorporated into the simulator.





Fig. 6: METU Virtual Reality Simulator.

### Model Comparisons

A thorough validation of the dynamic model libraries in Helidyn+ is performed. Here, we present some comparisons of simulation results of the Helidyn+ model with flight test data. A Helidyn+ model generated with Peters-He three state dynamic inflow and blade element main rotor calculations, Bailey's tail rotor model and aerodynamic calculations with linear coefficients of components is modeled and labeled.

The model is trimmed at a 60 knot forward flight condition and a set of simulations are performed starting from a trim condition. Some results of this effort are documented in Figs. 7-10.

First, a +1.8 degrees of longitudinal cyclic swashplate is given to the model at  $t = 1$ s. It is aimed to match the response of the helicopter model of Helidyn+ with the flight test data given in Ref.[9]. Figures 7 and 8 show a comparison of the response obtained using Helidyn+ compared with flight test data. The flight test data is depicted with the green triangle symbols.

Similarly, a +1.5 degree of lateral cyclic swashplate input is given to the helicopter from a trimmed 60 knots forward flight condition. Figures 9 and 10 show the response in the roll channel.

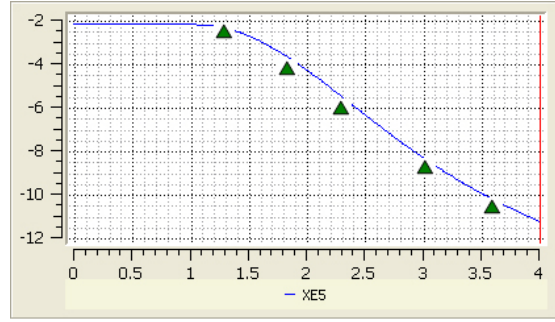


Fig. 7 Euler pitch angle (deg) vs time (s)

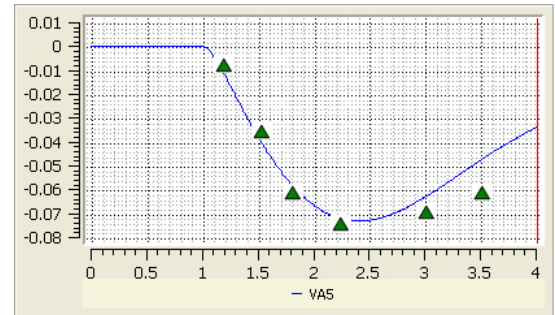


Fig. 8 Body pitch rate (rad/sec) vs. time (s)

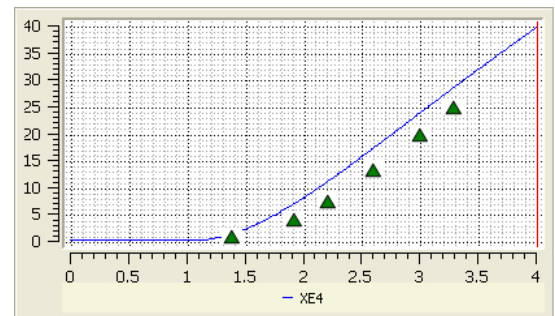


Fig. 9 Euler roll angle (deg) vs. time (s)

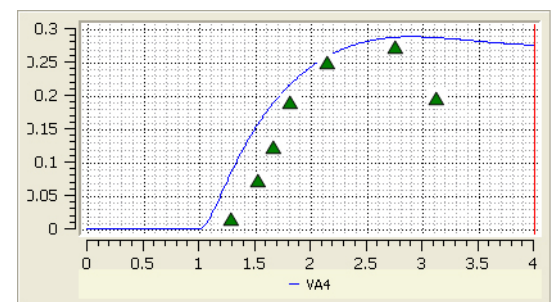


Fig. 10 Body roll rate (rad/sec) vs. time (s)

### Conclusion

A new comprehensive simulation software, called Helidyn+ is developed for helicopter

design and dynamic analysis and is used in various simulation applications. The component build-up approach enables the user to build helicopter models of various fidelities and export them in desired combinations. Moreover, direct integration to real time simulation environments such as Flightgear enables the user to conduct fast and reliable pilot-in-the-loop flight simulator tests. Helidyn+ also provides helicopter model blocks to be used with computer languages such as Matlab, Simulink, Fortran and C/C++.

Overall, any application development using Helidyn+ is easier and faster as the focus will be more on the application, rather than on developing and verifying helicopter math models. Changes in the models are easy and straightforward. The software requires basic modeling information most of which could either be measured on a helicopter or estimated.

## References

- [1] Padfield, G. D., "Helicopter Flight Dynamics: The Theory and Application of Flying Qualities and Simulation Modeling," AIAA Education Series, 1996.
- [2] Chen, R.T.N., "A simplified rotor system mathematical model for piloted flight dynamics simulation," NASA Report TM 78 575, 1979.
- [3] <http://www.flightlab.com/flightlab.html>.
- [4] <http://www.flightgear.org>.
- [5] <http://www.mathworks.com>
- [6] Hefley, R. K., Mnich, M. A., "Minimum-Complexity Helicopter Simulation Math Model," NASA Contractor Report 177476 USAVSCOM Technical Report, 87-A-7, (1988).
- [7] Peters, D. A., He, C. J., "Finite-State Induced-Flow Model for Rotors in Hover and Forward Flight," 43rd Annual National Forum of the American Helicopter Society, 1987.
- [8] Yavrucuk, I., Kubalı , E., Tarımcı ,O., Yılmaz, D. , "A Low Cost Flight Simulator Using Virtual Reality Tools," American Institute of Aeronautics and Astronautics, Modelling and Simulation Technologies Conference, Chicago, Illinois, August, 2009
- [9] Yılmaz, D., Yavrucuk, I., "Development of A Flight Dynamics Model For A UH-1H Helicopter Simulator," Ankara International Aerospace Conference, Ankara, September, 2007.