ANKA-1 MICRO-HELICOPTER DESIGN AND DEVELOPMENT PROJECT

Y. K. Yillikci[1] , *ITU Turkey*, D. P. Schrage[2] *GATECH, USA*
Y. Ugur[3] and S. Yuksel[3] *ITU Turkey*

Abstract

Conceptual and initial design of a 870 lb micro-helicopter has been completed. Steady state forward flight trim equations are derived for the compound helicopter configuration with canard/tail wings and horizontal tail propulsion. Blade loads are calculated for different maneuver loading and vehicle configurations. Helicopter fuselage and rotor blade are modeled using IDEAS program. Composite rotor blades are designed and analyzed by IDEAS and blade transient responses are simulated by solving rotor blade partial differential equations by a conditionally stable explicit finite difference method.

1-INTRODUCTION

ANKA-1 Micro-helicopter project has been initiated as an university level design and development project by Istanbul Technical University, Faculty of Aeronautics and Astronautics and Georgia Institute of Technology, School of Aerospace Engineering in conjunction with ongoing unfunded cooperative basic research studies related with flap controlled rotor blade and stopped rotor concepts. Primary objective of the project is establishing basic rotary wing research-design-development capabilities at Istanbul Technical University.

As being the first stage development of a demonstrator aircraft the aim is to stimulate further research and design efforts for the development of a full prototype. Project currently has received a limited funding from State Planning Office of Turkiye and ANKA-1 Project has already started capturing nationwide interest as conceptual design studies and a full scale mockup have been completed.

Is Personal Micro-Helicopter Still a Dream?

Today's private transportation has gone about as far as it can go on the ground and micro-helicopters will answer the needs of individuals who want to travel point to point with less dependency on ground transportation infrastructures. As recently reviewed by Drees *(1)* small, low cost helicopters will be one of the new and challenging area of helicopter technology by the entry of the 21th Century. As pointed by Drees *(1)* shortly after the World War II, many of helicopter designers had a vision that it would be possible to design a helicopter for everybody, easy to fly, affordable, and safe. Helicopters with bigger sizes have found wide acceptance in the aviation world but nothing significant came out for the small ones except the two-seater Robinson R-22; world's most popular smallest certified civil helicopter. After a decade several designers have started to ask whether a small personal helicopter is still an impossible dream or can it be realized with today's know-how and technology? Growing interest for small/micro-helicopters and number of design, and prototype development studies are believed to be the evidences of the possibility of this dream today.

TABLE-1 shows the list of 1-2 seat micro-helicopter design and development studies, most of which have started during 90's. Computer aided design and advanced composite technologies are now making it possible to design, develop and manufacture small fixed wing aircraft and small helicopters even by relatively small companies and design groups. Growing need and interest for personal transportation vehicles which can give individuals the ultimate freedom of traveling from point to point is the major motivation these behind design efforts. Micro-helicopters are expected to be the motorcycles of aviation by the 21st century.

Major objectives of micro-helicopter designs can be outlined as easier and safer to fly helicopters with faster speeds and increased ranges. These capabilities are needed to make micro-helicopters more compatible with existing small fixed wing aircraft. Simplified controls are needed for these types of helicopters which are currently more difficult to fly then fixed wing airplanes and carlike controls for an easy to fly helicopter is essential where all controls are spring loaded and returned to center after forces are removed. It is believed that today's new generation of advanced micro processors can impement the control laws required to make a micro-helicopter as easy to fly as driving a car.

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[1] Asst. Prof.; Faculty of Aeronautics & Astronautics; Istanbul Technical University; Turkey
[2] Professor and Director of CERWAT & FLIGHT SIMS; School of Aerospace Engineering; Georgia Institute of Technology
[3] Graduate students; Faculty of Aeronautics & Astronautics; Istanbul Technical University; Turkey

Today's advanced and highly automated guidance and control systems have significantly eased the remote piloting of Unmanned Aerial Vehicles. It is now possible to remotely control UAV' s by simple commands as take-off ,climb, fly, turn, descend; like playing Atari games. Several guidance and control hardware and software capabilities originally developed for costly military projects are now becoming available for civilian applications with highly reduced prices. With these technical development micro helicopters are no longer a dream.

Table 1. Micro-Helicopter General Information

Design	Vmax knots	Range nm	Ceiling ft	Power shp	Wempty lb	Wgross lb	Rmr ft
CH-7 Angel	86	205	11000	65	374	682	9.5
Ultrasport 254	55	70	-	55	252	525	10.5
Prop. Kopter	60	200	8500	30	155	650	120
Homebuilt Heli.	65	200	7000	40	300	800	12
Sky Bird	50	75	12000	40	150	350	8.75
Sky Sport	74	150	12000	60	300	575	9.5
Excell 2000	100	200	10000	150	820	1420	12.5
Baby Bell	100	200	10000	150	900	1400	12.5
Commuter II	100	200	-	150	700	1300	12.5
Cobra	100	200	10000	150	750	1400	12.5
Predator	95	150	10000	95	450	900	9.5
Skylark I	95	120	12000	65	350	700	9.5
Heli-car	100	125	12000	80	300	650	7.5
Mini 500	95	225	10000	67	330	730	9.5
Exec 90	115	180	10000	150	925	1425	12.5
Lonestar	90	115	10000	66	370	680	10
Capri	110	555	-	150	705	1212	10.65
Anka-1	130	520	12000	100	450	870	8.0

One of the particular important aspects of future small rotary wing aircraft development is the need for new power plants. New developments in rotary engines, diesel powered engines and especially high performance mass produced light weight automotive engines are quite promising. New technologies opportunities and growing demands have motivated designers and several concepts for small VTOL aircraft have been introduced. As an example; the concept of a small twin engine personal helicopter as suggested by Drees is shown in Figure 1. A conventional main rotor and tail rotor configuration with very innovative and futuristic airframe design, ANEX reflects these expectations and imaginations. ANEX designed by industrial designer Peter Newmann in Germany is also shown in Figure 1.

The first objective of ANKA-1 micro-helicopter project is the development of a small commercial helicopter. Second objective is more research oriented towards the development of a proper test-in-flight helicopter for the validation of flap controlled rotor blade and tip-jet stopped rotor UAV applications. Results of several initial configuration design and fundamental research studies have indicated several overlapping (common) design futures for both configurations. Stopped rotor configuration required the utilization of auxiliary lift and forward propulsion devices such as nose canard and tail wing as well as vectorized tail propulsion for anti-torque and horizontal forward auxiliary propulsion. This design features can also be utilized to make commercial a 1-2 seat micro-helicopter fly faster to reach longer ranges. Related research studies for flap control are also promising for the achievement of advanced control mechanisms even complete replacement of conventional pitch controls primarily for a micro-helicopter weight thrust range *(2,3)*. Flap controls will also give capabilities for wide band controls which can make possible higher harmonic controls (HHC) and individual blade control (IBC). With these new technical developments and design features, it is believed that highly a stable, agile and easy to fly commercial personal helicopter can be achieved.

2-CONCEPTUAL AND INITIAL DESIGN STUDIES

Vehicle Configuration

For conceptual and initial design studies, steady flight trim formulation has been derived for a compound helicopter configuration with canards, tail wings (vertical and horizontal) and forward tail propulsion. General configuration of the vehicle has been illustrated in Figure 2. As the first step longitudinal force moment equilibrium has been derived for the compound helicopter model with auxiliary lift and propulsion utilization. Conventional trim equations given by Johnson *(4)* have been modified for new the vehicle configuration well as for the rotor system with flap controlled blades. Details of vehicle trim formulation are given in Reference *(5)*. Tail propulsion, Tpr is assumed to be acting parallel to the main rotor reference plane. For trim calculations helicopter fuselage aerodynamic drag is taken as;

$$D = \frac{1}{2}\rho v^2 f$$

where f equivalent flat plate drag area of ANKA1 helicopter is approximated as

$$f = 1.0 + 0.4\,\alpha + 10\,\alpha^2$$

Total auxiliary lift is non dimensioned as

$$\bar{C}_L = \frac{L_{can} + L_{tw}}{\rho\pi R^4\Omega^2}$$

where

$$L_{can} + L_{tw} = \frac{1}{2}\rho C_L (S_{can} + S_{tw}) V_H^{\,2}$$

Variation of auxiliary lift coefficient with respect to forward flight velocity is taken as;

$$\bar{C}_L = C_{Tcan} * V_H^2$$

for $C_L = 0.9$ and total area of canard and tail wing, $S_{TOT} = 3.2\,ft^2$, $C_{tcan} = 2{,}5.10^{-8}$. In a similar manner auxiliary tail propulsion is formulated as,

$$\overline{C}_{pr} = C_{tprop} \times V_H^2$$

and initial design value of Ctprop is taken Ctprop= $0.45x10^{-8}$. V_H is vehicle forward speed in ft/sec a series of trim calculations are performed for initial design and primary design parameters of the selected configuration are listed in Table 2.

Table 2. Baseline Design Parameters

Wg = 870 lb	σ = 0.089	Xcg = 0.125 ft	Lcan = 4.7 ft
Rmr = 8.0 ft	γ = 6	Ycg = 0.0 ft	
Cmr = 0.52 ft	θtw = -0.12 rad	h = 2.4 ft	
Number of Blades = 3	Ctcan = 2.5 E-8	Ltw = 9.5 ft	
Ωmr = 76 .rad/sec	Ctprop = 0.45 E-8	Ltr = 10.9 ft	

The effect of canard/tail wing lifts along with the utilization of tail propulsion on main rotor required power have been investigated. Figure 3 shows the variation of required rotor shaft moment versus forward speed for different maneuver loading both for the compound and standard helicopter (without auxiliary lift and propulsion) configurations. Significant reductions in power required have been obtained for the compound helicopter configuration primarily at higher speeds. Utilization of canard/tail wing lifts are also reduced the amount of collective pitch control inputs as the forward speed increased is also shown in Figure 3.

Initial design studies has indicated the advantage of using auxiliary lift and tail propulsion. Studies are currently extended towards more realistic approximation of fuselage drag particularly for different vehicle angles of attack. Since the fuselage drag has increased with the third power of angle of attack which is reduced by the use of tail propulsion less fuselage drag is expected for the final configuration. Aerodynamics of the canard fuselage combination in forward flight are being studied by Gulcat and Aslan *(6)* solving the full Navier- Stokes Equations numerically. A finite element method (FEM) with an explicit time marching scheme is developed to calculate drag lift of the Anka-1 helicopter canard fuselage combination. CFD calculations are performed around the fuselage with the grid system shown in Figure 4. The velocity vector over fuselage canard configuration about the mid span on the canard are also illustrated in Figure 4.

CAD and Structural Modeling

Advanced computer aided design capabilities is one of the key assets for the realization of advanced rotorcraft design and development studies. CAD model of ANKA-1 helicopter is modeled with IDEAS package (7) program and initial layout out of fuselage and tail boom is shown in Figure 5. IDEAS package has been also used for static structural analysis.

Rotor loads are calculated based on rotor blade element vertical and in plane force formulation. Resultant blade distributed force Fz acting vertical to blade rotation plane and in drag plain force Fx are written by the use of two dimensional strip type aerodynamics and integrated along the blade span. Rotor thrust and required shaft moment are calculated by averaging these calculated values over one blade revolution. Rotor loads are calculated for different blade azimuth positions to find the maximum loading condition. Typical blade vertical force spanwise distribution is shown in Figure 6 for different maneuver conditions up to vertical acceleration of g=3.0 and for standard and compound helicopter with canards. As seen from Figure 6, blade loads are reduced with the use of auxiliary lift which eased main rotor thrust requirement.

A graphite-epoxy based composite blade has been designed for the calculated maximum blade loads and deflections of the designed rotor blade under maximum static loading has been shown in Figure 7.
Rotor blades designed for maximum static loading are also checked for their dynamic responses. Non dimensional blade stiffness are approximated for Anka-1 blade as;

$$\Lambda_1 = \frac{EI_y}{m_b \Omega^2 R^4} = 0.00356 \qquad \Lambda_2 = \frac{EI_z}{m_b \Omega^2 R^4} = 0.0486 \qquad \Delta = \frac{GJ}{m_b \Omega^2 R^4} = 0.006$$

Anka-1 rotor blade transient blade responses are simulated by solving nonlinear elastic blade equations with a conditionally explicit finite difference scheme introduced by Yillikci and Hanagud *(8)*. Blade required control inputs calculated by trim formulation for increasing forward flights conditions are illustrated in figure 10 where forward speed has been increased by $\Delta\mu = 0.025$ increments at every 3 blade revolutions. Figure 8 also shows ANKA-1 rotor blade lead-lag, flap and elastic twist responses respectively. Blade response simulations studies have given promising results for the initial blade configuration.

3-FINAL EVALUATION

Conceptual and initial design studies of Anka-1 micro-helicopter have been completed with above described studies. Overall weight, dimensions and performance estimations are as listed in Table 3. Future goals of Anka-1 design are set as maximum cruise speeds reaching 150 knots and maximum range around 650 nm along with highly automated pilot friendly flight controls. With current limited funding development of a demonstrator helicopter with design goals listed in Table 3 is planned. Anka-1 will be developed to be a one-seat high performance helicopter which can be also flown as a two seat helicopter for shorter range. Three view of Anka-1 helicopter is shown in Figure 8. A full scale mock-up of the helicopter has been also built by the design group which is shown in Figure 9.

Table 3. Anka-1 Micro-Helicopter General Description

Weights		**Dimensions**		**Performance**	
Max Take-Off =	870 lb	Length =	16.8 ft	Max cruise =	130 knots
Empty Weight =	440 lb	Height =	6.25 ft	Normal cruise =	120 knots
Fuel Weight =	210 lb	Width =	3.12 ft	HOGE =	7000 ft
Payload =	220 lb	Rmr =	8.0 ft	HIGE =	9000 ft
		Cmr =	0.57 ft	Service Ceiling =	12000 ft
Number of blades = 3				Range =	520 nm

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7- IDEAS, I-DEAS Solid Modeling and I-DEAS Finite Elements are trademarks of Structural Dynamics Research Corporation.
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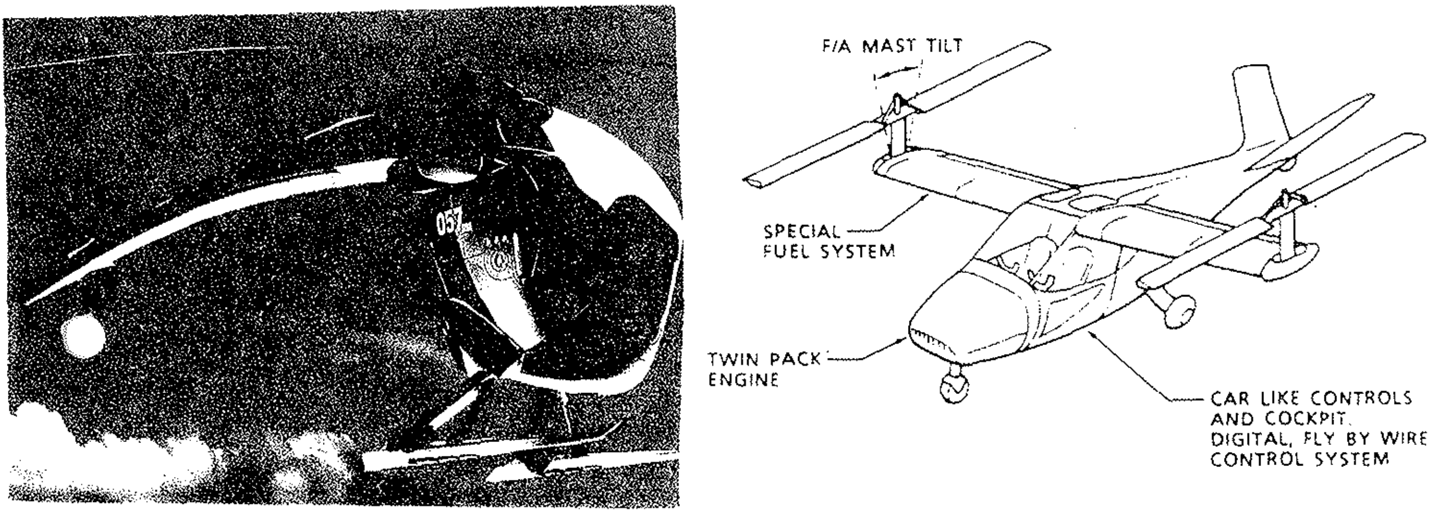

Figure 1. ANEX futurustic helicopter study by Peter Naumann. and concept suggested by Dress *(Ref 1)*

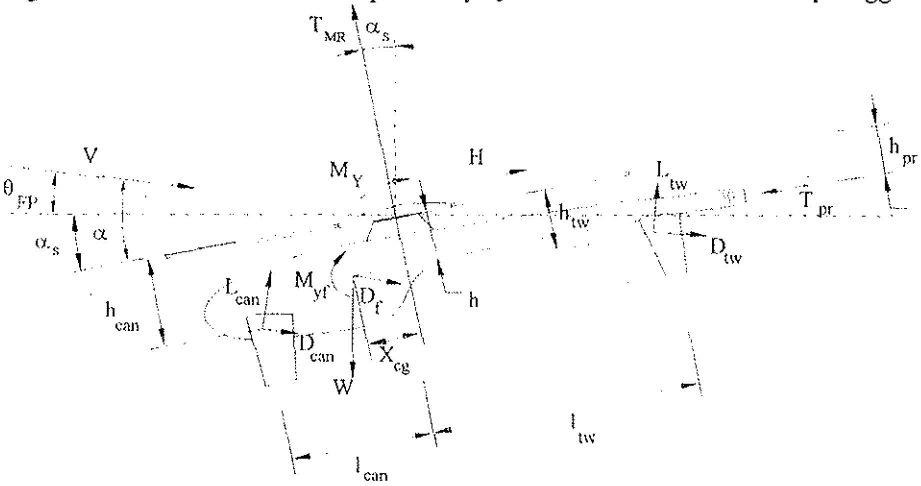

Figure 2. General concept of canard/tail propulsion helicopter.

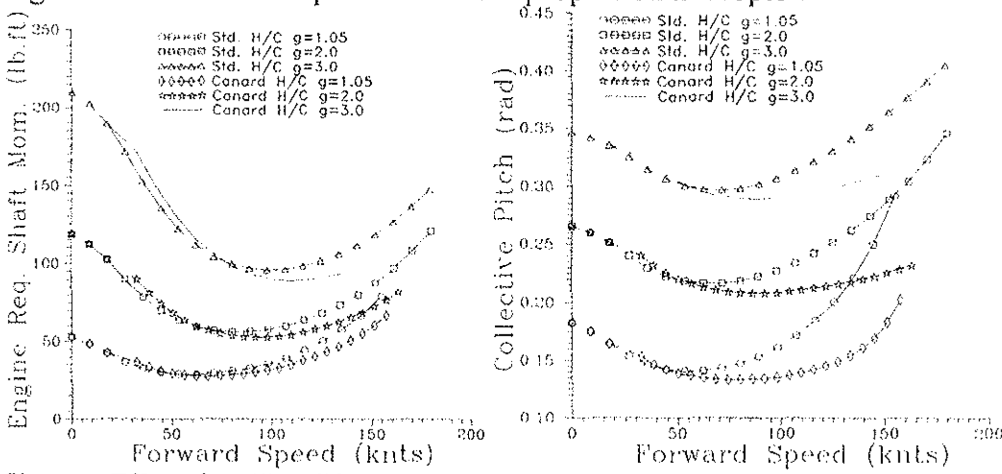

Figure 3. Effect of auxiliary lift and propulsion on rotor power and collective required.

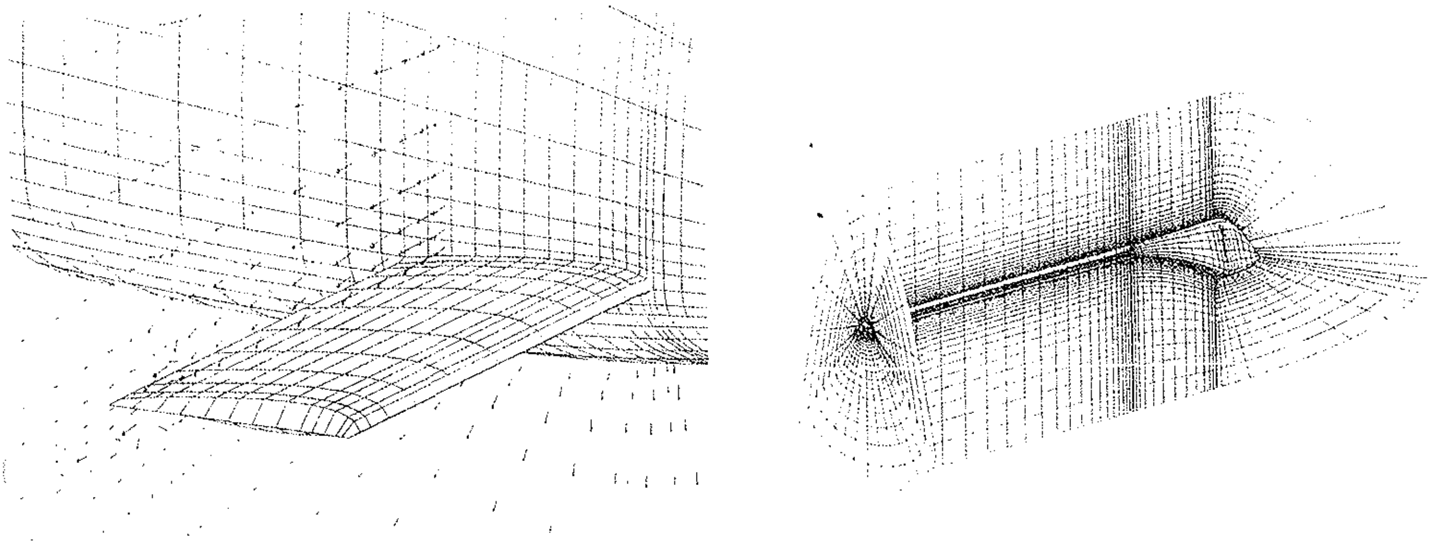

Figure 4. CFD studies of ANKA-1 micro helicopter.

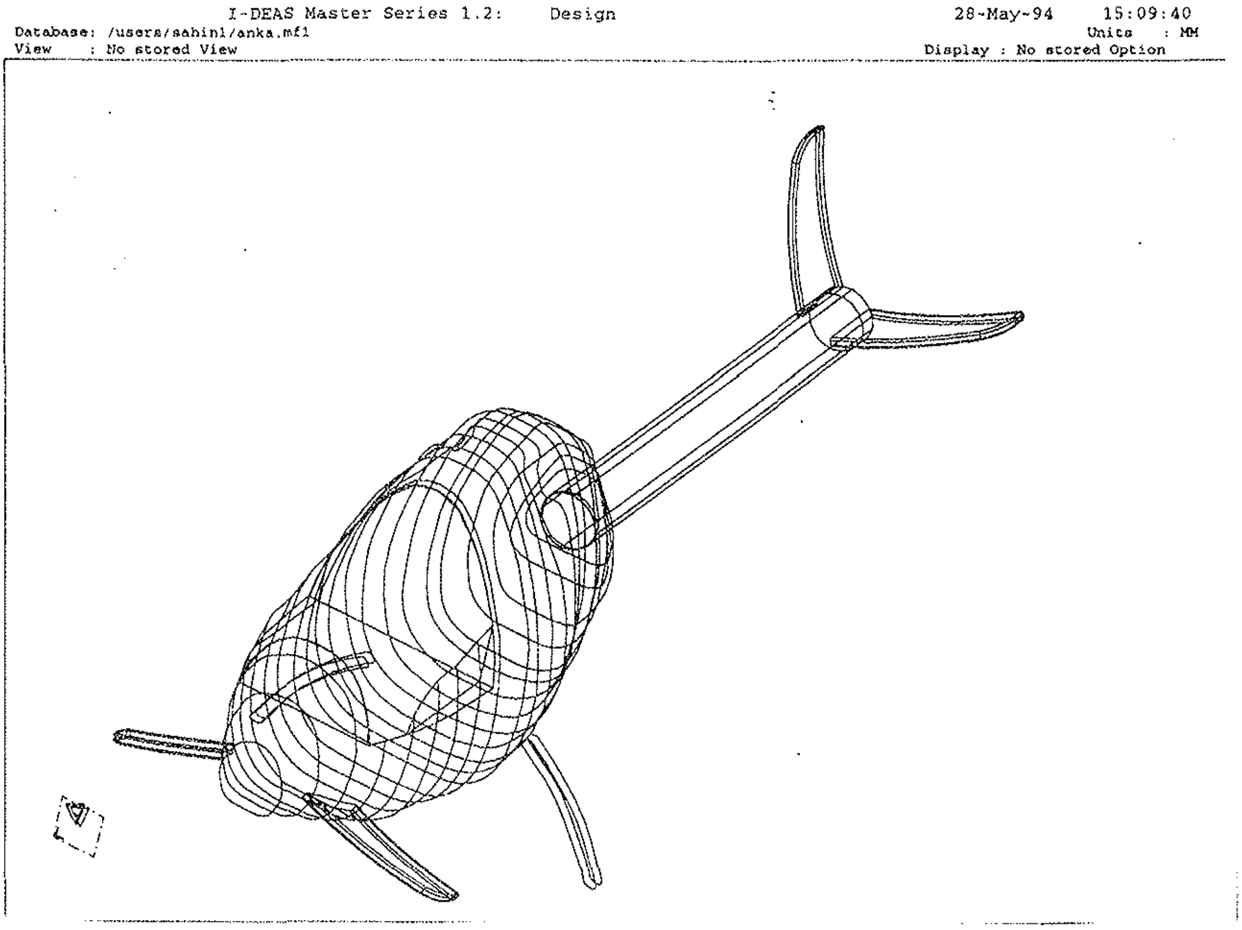

Figure 5. CAD modeling of ANKA-1 with IDEAS package program.

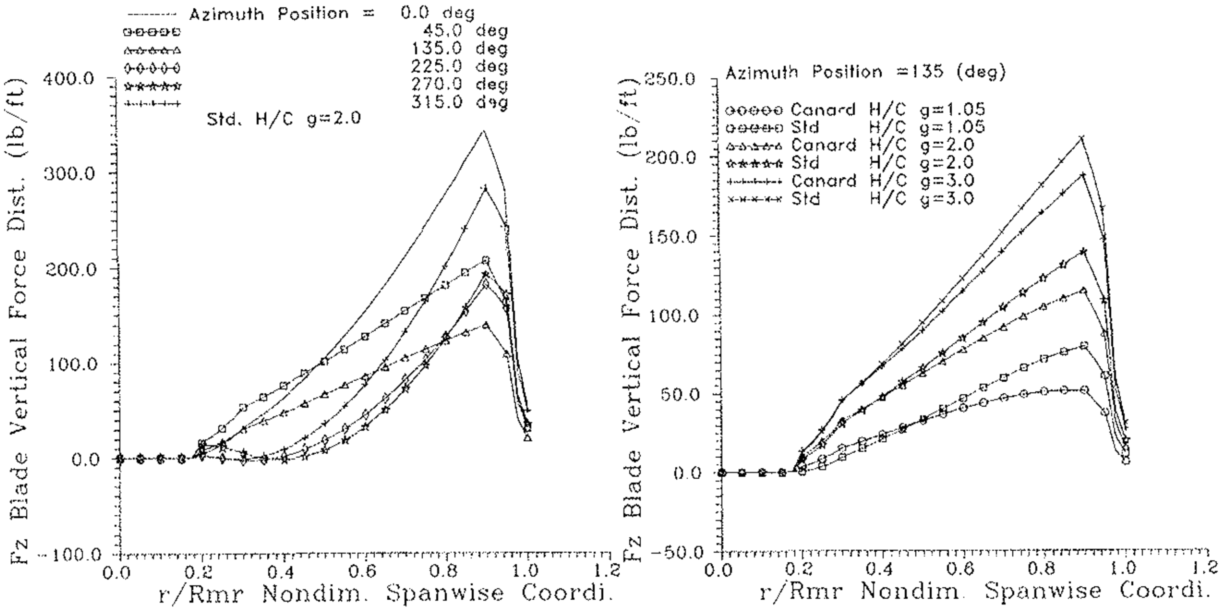

Figure 6. Blade loads calculation for standart and compound ANKA-1 configuration.

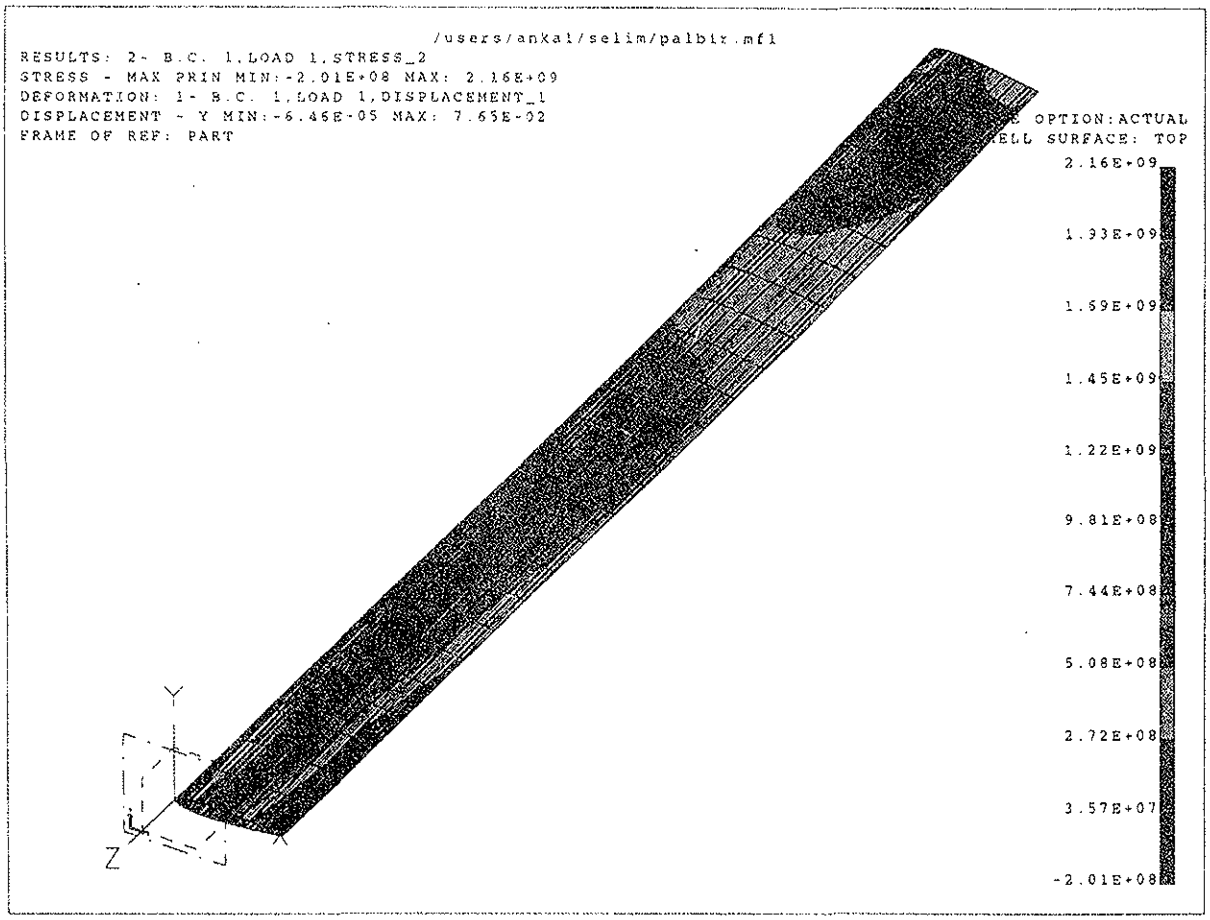

Figure 7. Composite blade static deflection analysis.

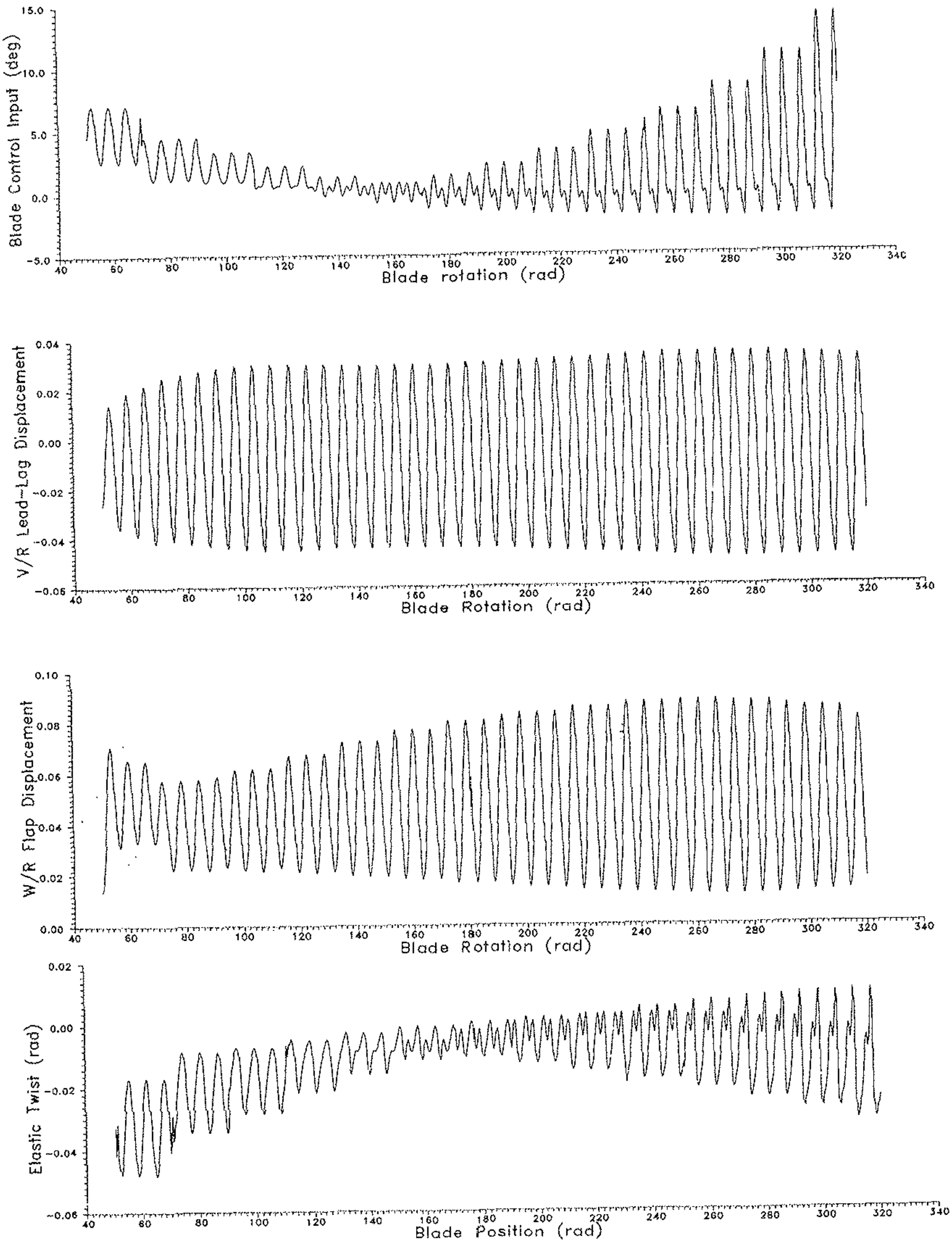

Figure 8. Transient blade tip responses of ANKA-1 helikopter during forward speed accelation

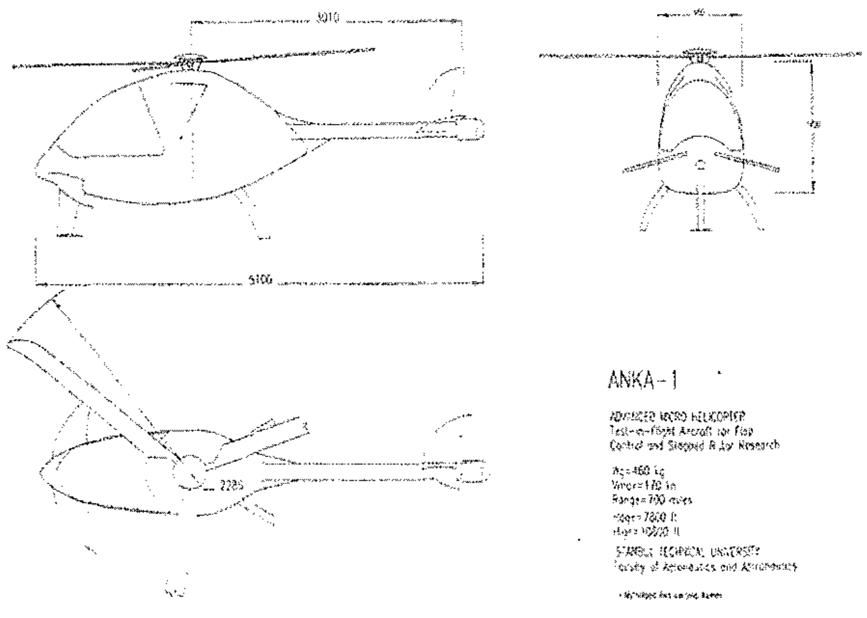

Figure 9. 3 view of ANKA-1 micro helicopter configuration.

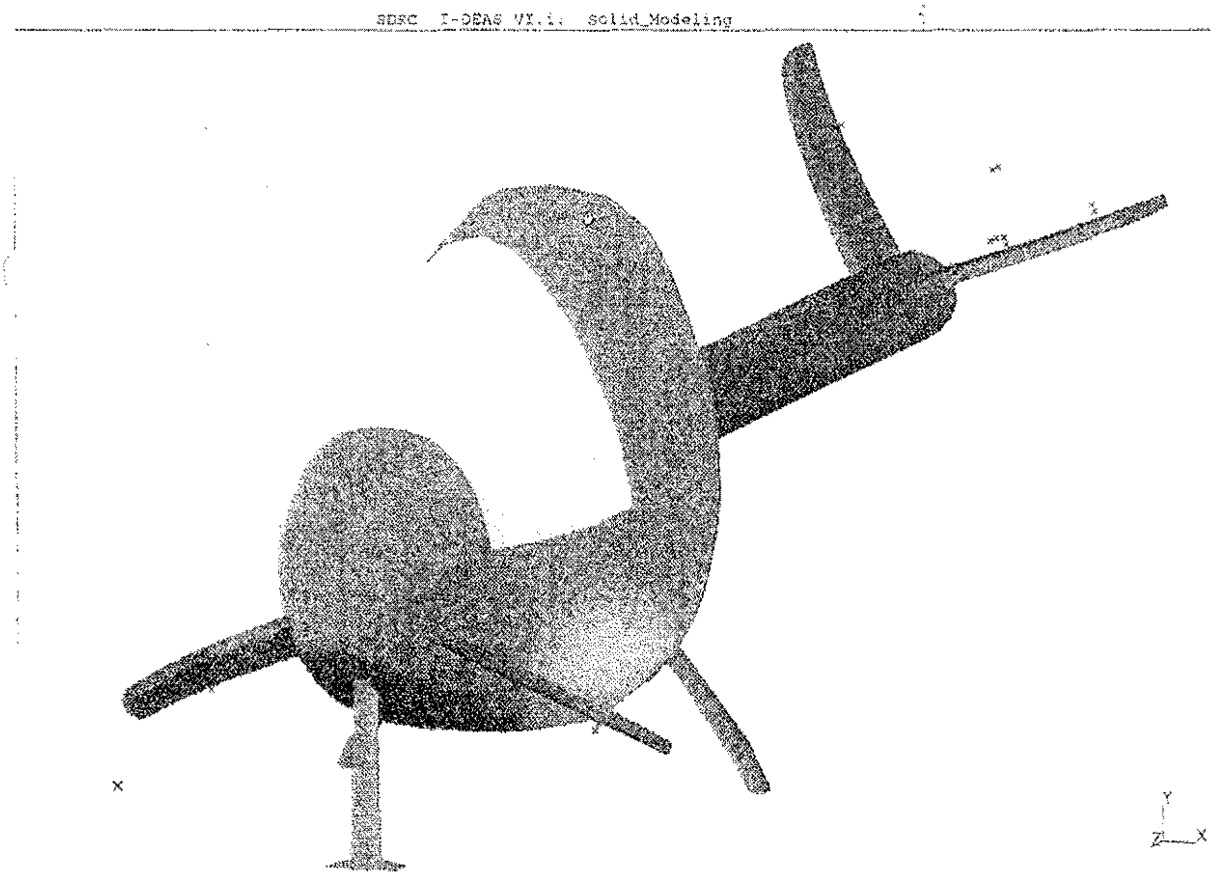

Figure 9.Full scale mock-up of ANKA-1 micro helicopter.