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Experimental Studies on Complex Swept Rotor Blades

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Abstract

Helicopter blades on the advancing side are limited in speed because of critical Mach number occurrence. The sweep in the blades can be considered to raise the critical Mach number, thereby the speed of advancing blade can be increased to increase the lift; thus resulting in a smaller rotor disc. The blades with complex sweep are considered and tested in wind tunnel using Internal Strain gauge balance. The data is compared with the straight blades. The data on normal force and axial force is presented for different angles of attacks. The lift to drag ratio is compared. Blades with sweeps are seen to be very competitive for application to rotor blades.

Introduction

Currently the rotor blades are not seen to have such sweep effects, also there not enough literature available on these effects towards helicopter application.

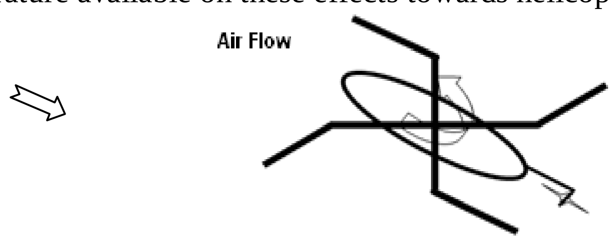

Figure 1: Possible Application of Concept.

The complex sweep means the sweep is reversed over the span. Possible application of the concept is shown below in Figure 1. The Wind Tunnel available at MVJ College of Engineering has been utilized for this purpose. The wind tunnel is open type and is shown in Figure-2.

Rotor blades for helicopter application are considered with sweep effects so that critical Mach number can be raised on the advancing blade. The increased speed of the rotor aims at smaller diameter of rotor disk, thereby resulting in lesser inertia and greater agility. Sweep of complex nature is introduced to reduce inertia effects.

Aerodynamic data is generated on complex swept rotor blades for helicopter application using internal balance. The data is compared with the straight blades.

Figure 2: Wind Tunnel at MVJ College of Engineering 6m x .6m x 2m Test Cross-section 50 m/sec Max Speed.

Description of Equipments

Following equipments are described herein:

- Internal Balance.
- Model Positioning System.
- Data Acquisition system with related software.
- Six set of blade with hub and attachment devices.

Internal Balance

This strain gauge Internal balance is shown in Figure-3. It has been procured through Hitech Engineering Equipments, Bangalore. Thel balance is calibrated through a calibration rig and has an accuracy of 0.5%.

It has two stations for measuring normal forces as N1 and N2. The total normal force is N which is sum of N1 and N2. The balance center is taken as center for pitching moment estimation. Pitching moment is multiple of (N1-N2) with the distance between the balance center and center of N1, which is 3.5 cm. The location of pitching moment is not important for our purpose, since the pitching moment at the rotor center is always zero under the static conditions of rotor.

The following are the specifications of the balance:

- Normal force = ±3Kg.
- Axial force = ±3Kg.
- Pitching Moment = ±15Kgcm.

- Angle of attack range = -100 to +300

The following are the details of the Balance:

- Length 43 mm.
- Dia 15mm.
- Accuracy 0.5%.
- Axial Force AF gms.
- Normal forces N1,N2 gms.
- Net Normal Force N=N1+N2.
- M_{bc} .
- (Moment about.
- Balance center) (N1-N2)x 3.5 gms cm.
-

Figure 3: Three Components Internal Strain Gauge Balance.

The calibration of the balance is conducted on a special calibration rig to obtain the calibration formula of the balance (the functional relationship between the loads acting on the balance and the output signals from the balance).

The balance is installed on a calibration rig in the calibration process. The calibration rig consists of a loading subsystem, an attitude modification subsystem, and a control and measurement subsystem. Static loads are applied to the balance in accordance with the force conditions in wind tunnel tests and following the defined coordinate system of the balance. The relationship between the balance output signals and the applied loads is worked out.

Depending on the method of loading and data processing, the calibration can be classified into one-component or multicomponent loading. The one-component loading calibration means that only one component is loaded at a time while the other component is zero or is a constant value. On the other hand, in the multicomponent loading calibration process, every component is simultaneously loaded under different load combinations. An equation describing the relation between the loading and the balance signal can be constructed for every loading, with the unknown coefficients of the calibration formula. The calibration formula of the balance is obtained by solving the set of calibration equations.

Model Positioning System: This system is procured from Hitech Engineering Equipments, Bangalore. It is shown in Figure-4 below under Load Test. The model is supported in the test section by a tail sting. The tail support system is made up of a tail sting, drawing box, a curved plate. The sting turns around the center of the section, in this way, the angle of attack is changed. It has the following features:

- Hand operated for alpha range of -10° to +30 °.
- Model can be positioned to an accuracy of ±0.1 ° angle of attack.
- A sting made of high strength alloy steel is fitted to the balance and the other end gets fitted to the sting adapter of the model mounting system.

Figure 4: Model Positioning System under Load Test.

Data Acquisition System: This equipment is obtained from PYRODYNAMICS, Bangalore. It is shown in Figure-5 below. It has been integrated with the balance during the load test. A minimum load of 50 gms was tried and seen to read within the 0.3% accuracy. Testing is shown in Figure-6. The aerodynamic forces and moments acting on the model are obtained by acquiring and processing the voltage signals originating in the aerodynamic loads and measured by Internal Strain gauge balance.

Figure 5: Data Acquisition System.

Figure 6: Accuracy Test in Progress.

Test Model and Test Conditions

Existing Wind Tunnel at MVJ College of Engineering is used for testing of blades.

Wind Tunnel is run at 40 m/s. Its` test cross- section is 600x600 mm and length is 2000mm. The tunnel has a maximum speed of 50 m/sec.

Three sets of blades of following configurations are tested. These blades and nose body hub are shown in Figure-7 and drawing details are given in Figure-8.

Blade aspect ratio is 10. Blade 1 is straight. Blade 2 is swept back at mid span and again swept forward at ¾ th of span. Blade 3 is swept forward at mid span and again swept back at ¾ th of span. Typical Twin Blade arrangement is shown in Figure-9 below. The nose body hub is used for attachment of internal balance with nose body on to which blades are mounted. Blades are mounted through insertion plate that is held inside hub with screws.

The balance is mounted on a sting attached to model positioning system.

Blade1 Straight

Blade2 Swept back and forward

Blade3 Swept forward and back

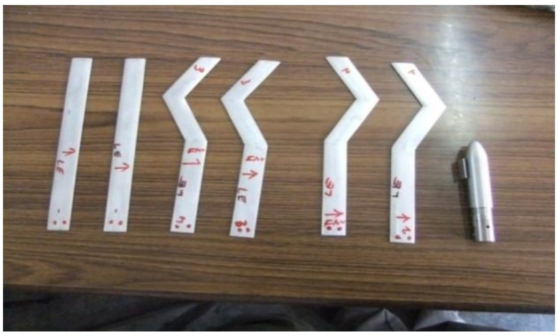

Figure 7: Three Sets of Blades and Nose Body Hub.

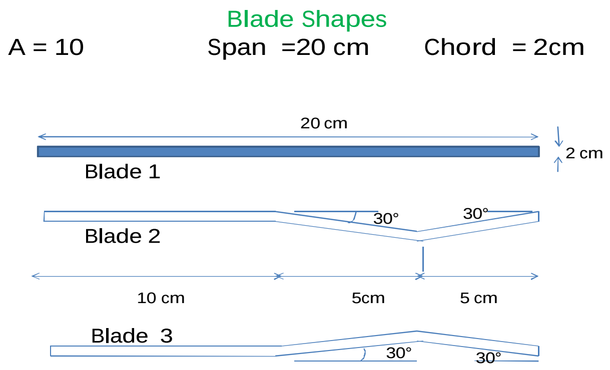

Figure 8: Blade shapes.

Figure 9: Twin Blade Arrangement.

The blades are tested in single and twin configurations.

Blades of aspect ratio of 10 are taken with the symmetrical aerofoil NACA0009 for testing.

The blades were developed & supplied by Sunrise Technology, Bangalore. The contours were developed using templates. Aluminum material was used for fabrication of blades.

Blades configurations under test

Twin blade configurations under test are shown in Figure-10 & Figures 11 and 12.

Figure 10: Blade-1 in Twin Configuration.

Figure 11: Blade-2 in Twin Configuration.

Figure 12: Blade-3 in Twin Configuration.

Results & Discussions

The wind tunnel has a provision for circular opening at the bottom of test section, through which the model support arm is inserted. The slit created is covered with a plate.

The following relationship is used between wind axis and body axis:

Lift = N cos α - AF sin α

Drag = AF cos α + N sin α

Where α is the angle of attack, N is the normal force, and AF is the Axial force measured thorough the data acquisition system. The normal force is measured at two stations as N1 and N2, and total normal force is N=N1+N2. The data acquisition procures these values in the lab top.

For the confidence level of results, estimates of single blade in configuration `1` i.e., straight blade are compared with panel method[1] and DATCOM[2]. The Reference-1 utilizes panel methods for the prediction of aerodynamic coefficients. The values are seen to match closely with this method. This gave enough confidence to proceed with testing; Table-1 below shows some comparisons.

Table 1: Comparisons of Lift Curve Slope $C_{L\alpha}$ with Different Methods.

Panel Method1	DATCOM2	Experiment
4.7	5.0	4.6

Measured Load values (N1,N2, and AF) vrs angle of attack are shown in Figures 13 (a-c) below for TWIN BLADE Configuration.

The normal force variation is of expected manner and order. The presence of strong axial force at larger angles of attack is seen to be present for all the cases.

In this case of Twin Blade configuration, the normal force is varying differently at larger angles of attack. Normal force of BLADE-3 configuration levels off at larger angles of attack (10^0 onwards). In contrast, in case of BLADE-1 and BLADE-2 configurations show linear growth of normal loads with angle of attack. Axial force follows similar trends for all these cases, which is expected. This gave a confidence to progress on testing and the well build standard of the balance.

The total normal force values are shown Figure 14. Values of all the three sets of blades are very competitive; this is because their aspect ratio is same. The pitching moment of three sets of these blades are shown in Figure15. This fallows similar trend. The pitching moment is about the balance center.

There is no evidence of presence of strong interaction between blades by way of shed vortices from one blade on another. This is concluded because of the linearity in relationships of loads with angle of attack is seen to be well maintained.

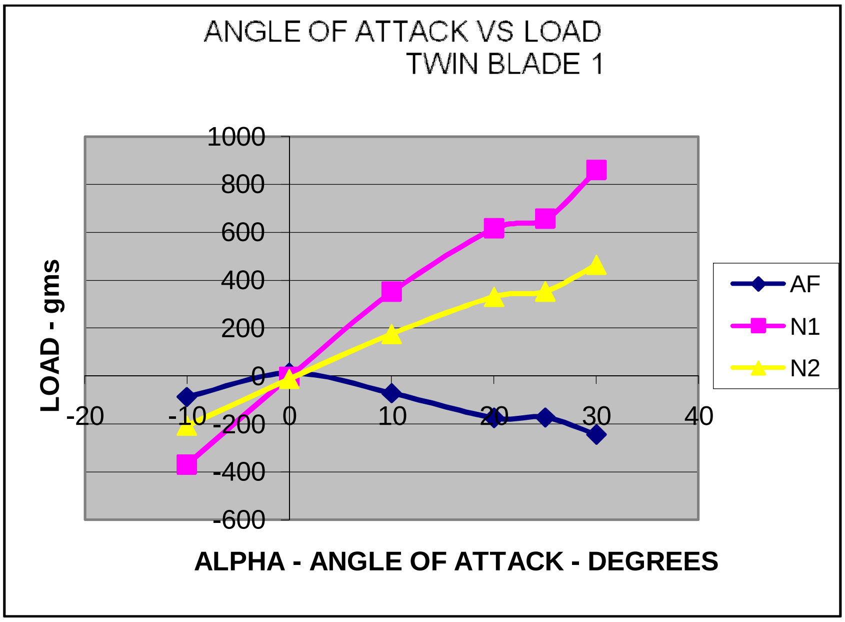

Figure 13(a): Loads on TWIN BLADE-1.

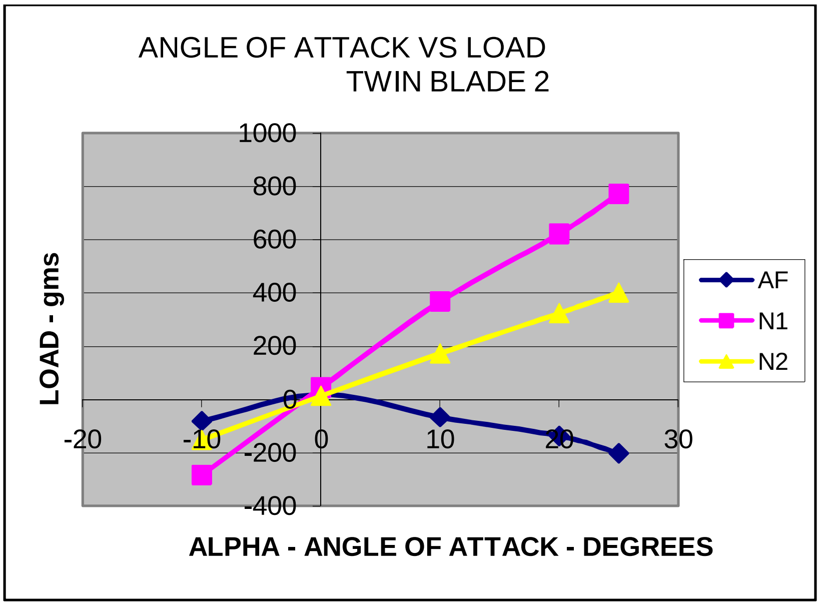

Figure 13(b): Loads on TWIN BLADE-2.

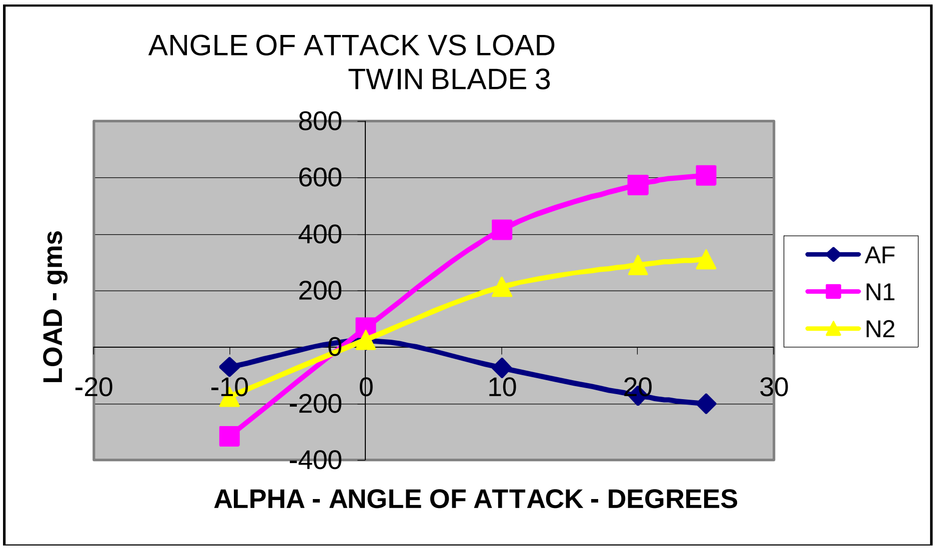

Figure 13(c): Loads on TWIN BLADE-3.

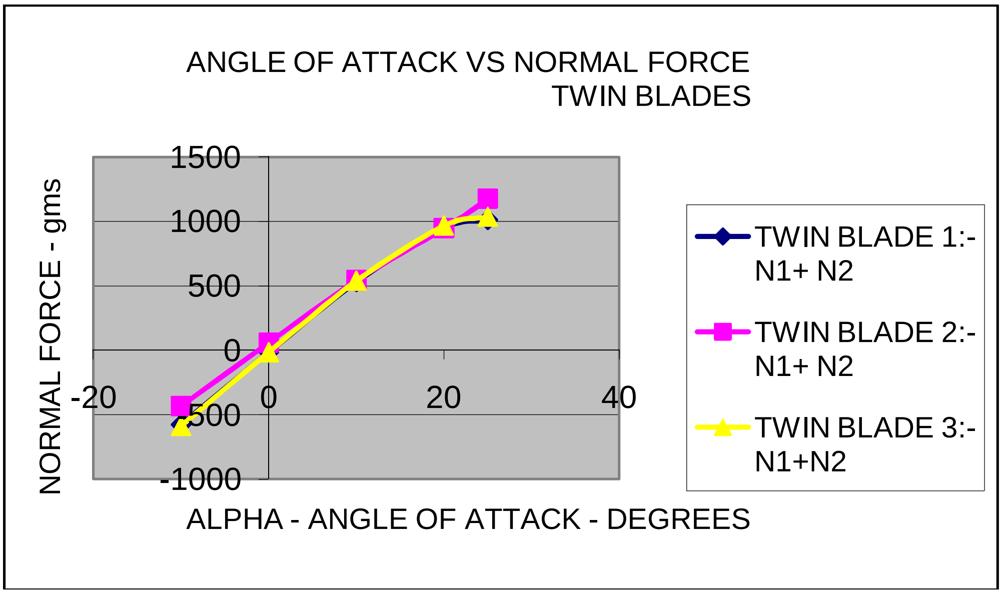

Figure 14: Total Normal Force values in Twin Blades.

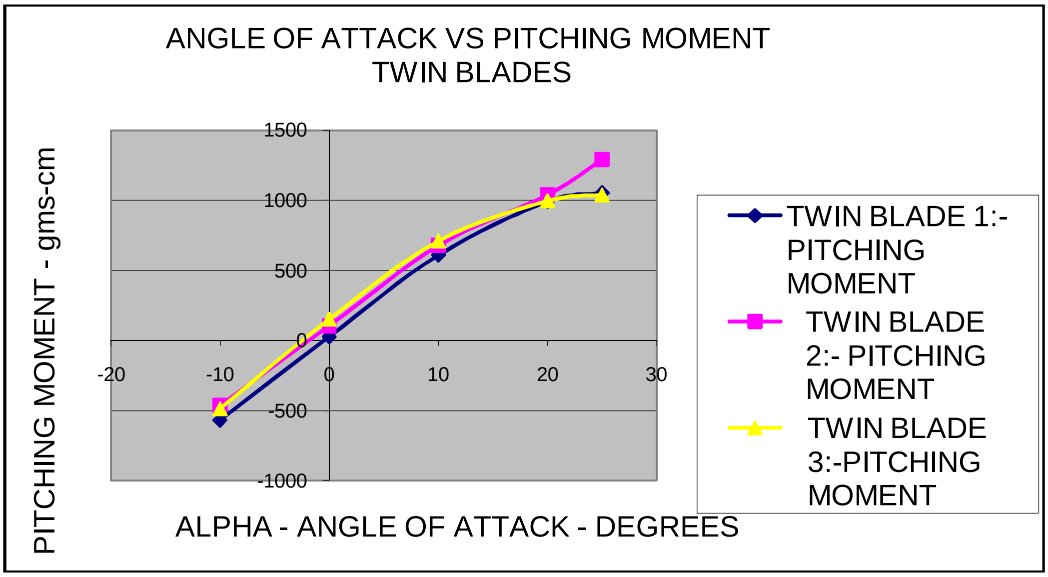

Figure 15: Values of Pitching Moment for three sets of Twin blades.

Results of aerodynamic coefficients are shown in Table -2 below for these sets of blades:

Table 2: Comparison of Aerodynamic Coefficients (C_L is Lift Coefficient and C_D is Drag Coefficient) TWIN BLADE Configurations.

α=10°	Twin blade1	Twin blade2	Twin blade3
CL	0.67	0.68	0.666
CD	0.033	0.0377	0.0305
CL /CD	20.30	18.037	21.83

From this table, the following is concluded:

Drag of Blade 2 is higher and drag of Blade 3 is lower compared to drag of Blade 1 in these Twin Blade Configurations. Lift of Blade -2 in the highest.

The ratio CL/CD is highest for Blade 3 in these Twin Blade Configurations There is no evidence of any marked phenomenon that may deter the new design applications.

Measured Forces (N1,N2,and AF) for single blade configurations are shown in Figures 16(a-c). In this case the normal force is seen to level off for all the cases between angle of attack of 100 to 200 ; and thereafter again starts rising. Axial force follows the similar trend, which is expected.

In case of Twin Blade configurations 1 and 2 this does not happen. This perhaps could be a result of some interaction of flows.

The total normal force for three sets of single blades is shown in Figure 17.

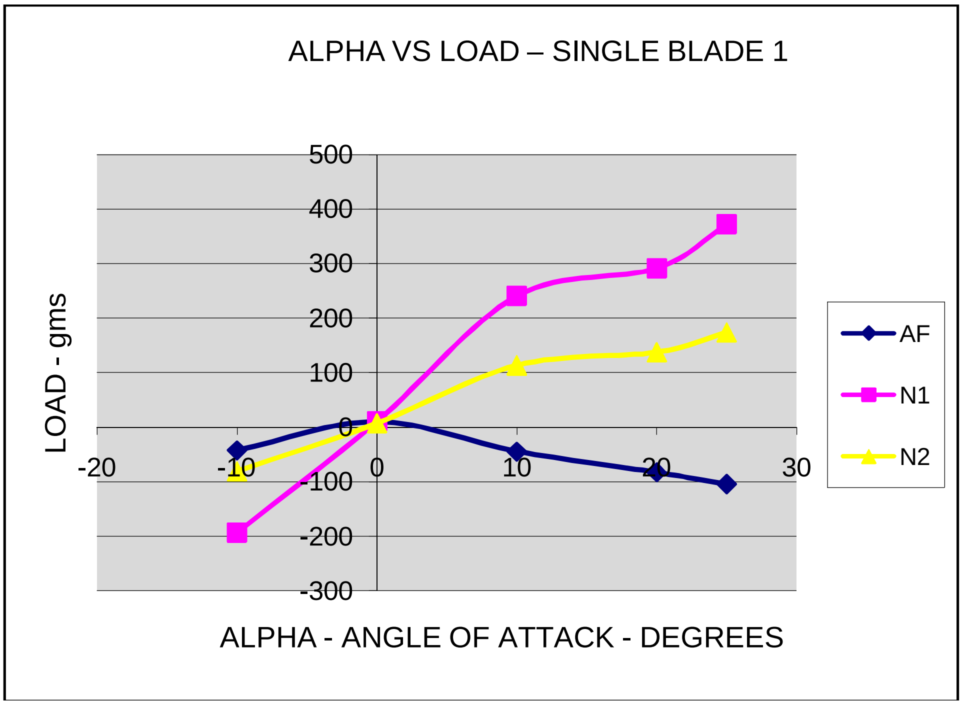

Figure 16(a): Loads on Single Blade-1.

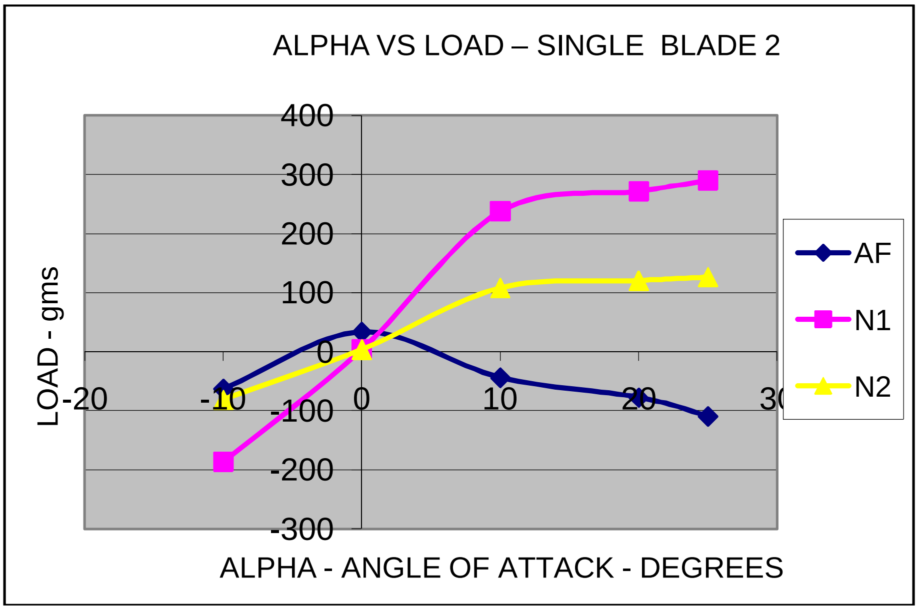

Figure 16 (b): Loads on Single Blade-2.

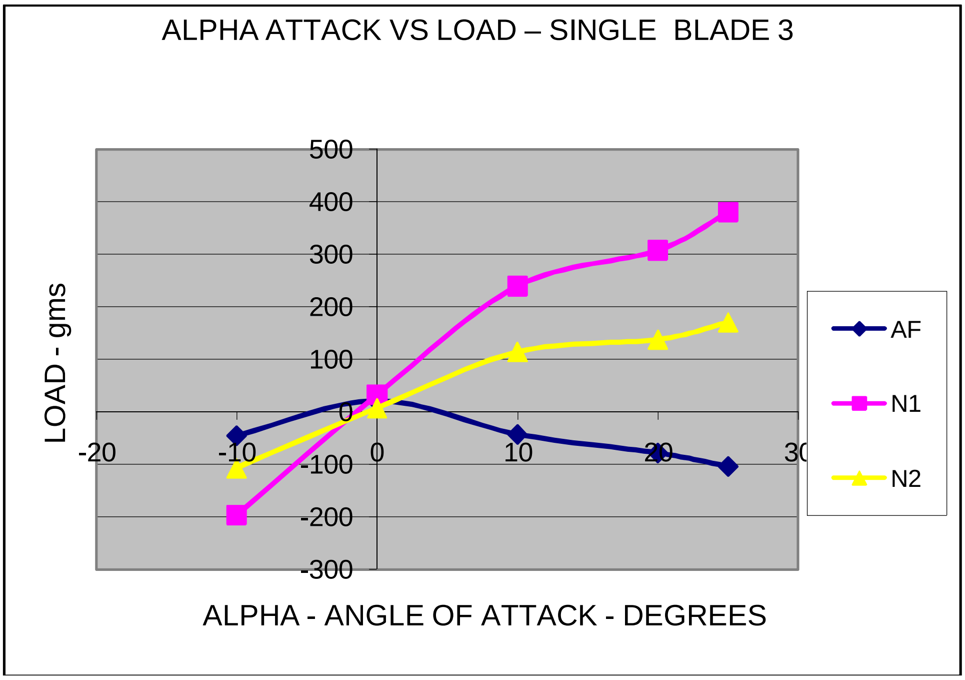

Figure 16(c): Loads on SINGLE BLADE-3.

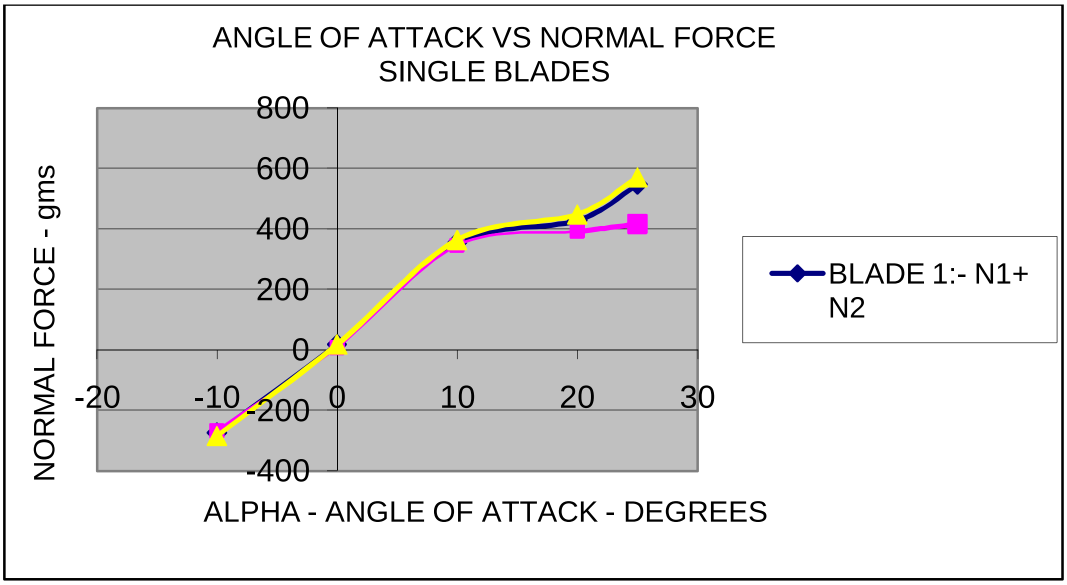

Figure 17: Total Normal Force values in Single Blades.

Aerodynamic coefficients of these configurations are shown in Table -4 below:

Table-4 Comparison of Aerodynamic Coefficients SINGLE BLADE Configurations

α=10°	Single blade1	Single blade2	Single blade3
CL	0.81	0.79	0.83
CD	0.038	0.036	0.0395
CL /CD	21.30	21.9	21.0

From this table, the following is concluded:
Single Blade Configuration data is very competitive
Single Blade 3 has highest lift coefficient

Conclusion

From the discussions above, following conclusions are drawn:

1. Normal forces are of Comparable Magnitudes in Three Configurations of Blades.
2. Drag of Blade 2 is higher and drag of Blade 3 is lower compared to drag of Blade 1 in Twin Blade Configuration.
3. The ratio C_L/C_D is highest for Blade 3 in Twin Blade Configuration.
4. Single Blade Configuration data is very competitive.
5. Single Blade 3 has highest lift coefficient.
6. Blade3 Configuration has the potential future for helicopter application.
7. Blade2 Configuration is also considered competitive.
8. There is no evidence of any marked phenomenon that may deter the new design applications.

Recommended New Design for Helicopters

Considering the high C_L/C_D for the Twin Blade 3 configuration, the Blade3 configuration is recommended for helicopter application. Since there is no marked phenomenon in Blade 2 configuration, this configuration is considered competitive.

Acknowledgment

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[2] DATCOM, `US Air force Stability & Control ,Wright-Patterson AFB, Ohio, Air Force Flight Dynamics Laboratory`, 1963.