



NUMERICAL SIMULATION OF A PROPULSIVE WING

By

Eng./Hossameldin Elmoatsem Mourad

A thesis submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the degree of
MASTER OF SCIENCE
In
AEROSPACE ENGINEERING

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Summary:

In the present thesis, Chapter 1 is an introduction to the propulsive wing and literature review of related work done in this field. In Chapter 2 the numerical model and method of calculation and the grid sensitivity analysis is presented. In Chapter 3 the results is shown. In Chapter 4 the conclusion is discussed.

The propulsive wing is examined numerically to determine the benefit and efficiency of a new proposed propulsive device. In the propulsive wing concept, the fan is embedded inside the wing section and the out flow jet blows over the wing. This pushes the aerodynamic envelope of the wing by avoiding stall up to 45° and hence maintain very high lift coefficient. The numerical model is first compared with published experimental data. The comparison shows that the K- ϵ model is the optimum model for the numerical calculation; a sensitivity study is then performed to determine the flight operating points of the propulsive wing based on the numerical values for the net thrust force. The numerical results show that the operating speed of the propulsive wing increases from 3.4 to 13.5 m/s as the RPM throttle setting increases from 1020 to 4200 RPM. The lift can be high as 23 N for $\alpha = 30^\circ$, which is not attainable with conventional wings. The airstream operating velocity (velocity required to get almost zero net thrust, is proportional to the fan speed at the same angle of attack, while it is proportional inversely with the RPM at different angles of attack; at 4200 RPM, the velocity is 21.6 m/s at ($\alpha=0^\circ$) while it decreases to 13.5 m/s at ($\alpha=30^\circ$). The relation between Lift and the fan RPM's is progressively proportioned, the lift increases with RPMs in same angle of attack, and also it increases with angles of attack for same RPM.

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TABLE OF CONTENTS

Chapter	Page
ACKNOWLEDGMENTS	i
TABLE OF CONTENTS.....	ii
LIST OF TABLES	iii
LIST OF FIGURES	iv
NOMENCLATURE	vii
ABSTRACT.....	viii
CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW	1
1.1. History.....	6
1.2. Literature Review.....	6
1.3. Objective	8
1.4. Thesis Layout	8
CHAPTER 2: NUMERICAL MODEL	9
2.1. Numerical Model	9
2.2. Method of Calculation	10
2.3. Grid Sensitivity Analysis	13
CHAPTER 3: RESULTS	19
3.1. Comparison of Lift and Thrust with Experimental Data	19
3.2. Comparison of Flow for Different RPM's vs. Angle of Attack	20
3.2.1. Angle of Attack $\alpha = 0^\circ$	20
3.2.2. Angle of Attack $\alpha = 20^\circ$	26
3.2.3. Angle of Attack $\alpha = 40^\circ$	32
3.2.4. Summary of Study	37
3.3. Determination of Flight Operating Conditions.....	44
3.3.1. Angle of Attack $\alpha = 0^\circ$	45
3.3.2. Angle of Attack $\alpha = 10^\circ$	49
3.3.3. Angle of Attack $\alpha = 15^\circ$	52
3.3.4. Angle of Attack $\alpha = 20^\circ$	55
3.3.5. Angle of Attack $\alpha = 25^\circ$	61
3.3.6. Angle of Attack $\alpha = 30^\circ$	66
CHAPTER 4: CONCLUSIONS	72
REFERENCES	73
Appendix A: Experimental Data.....	75
Appendix B: Validation Data	77

LIST OF TABLES

Table	Page
Table 1 : Distributed propulsion concepts [6]	3
Table 2 : FanWing and boundary Dimensions	12
Table 3 : FanWing mesh refinement.....	13
Table 4 : Results of FanWing mesh refinement	14
Table 5 : FanWing results at (0°) angle of attack	20
Table 6 : FanWing results at (20°) angle of attack	26
Table 7 : FanWing results at (40°) angle of attack	32
Table 8 : Lift vs. AoA curves equations	39
Table 9 : Lift Coefficient vs. AoA curves equations	40
Table 10: Thrust vs. AoA curves equations.....	41
Table 11: Thrust Coefficient vs. AoA curves equations.....	42
Table 12: FanWing iteration results at (0) angle of attack	45
Table 13: FanWing iteration results at (10°) angle of attack	49
Table 14: FanWing iteration results at (15°) angle of attack	52
Table 15: FanWing iteration results at (20°) angle of attack	55
Table 16: FanWing iteration results at (25°) angle of attack	61
Table 17: FanWing iteration results at (30°) angle of attack	66
Table 18: Operational speeds for the FanWing	70
Table 19: Lift obtained according to operational speeds	70
Table 20: Operating parameters measured using a tethered wing	76
Table 21: Comparison between Numerical and Experimental lift	77
Table 22: Comparison between Numerical and Experimental Thrust.....	77

LIST OF FIGURES

Figure	Page
Figure 1 : Forces acting on airplane [1]	1
Figure 2 : Lift generation on wing [2]	1
Figure 3 : A schematic of typical airfoil [3]	2
Figure 4 : Schematic of propulsive wing cross section [4].....	2
Figure 5 : Kinematic concept solutions [7].....	4
Figure 6 : Schematic wing with enclosed cross-flow fan near its leading edge	4
Figure 7 : Example of Propulsive wing [8].....	5
Figure 8 : Cross-section trough an aircraft lifting member (wing).....	5
Figure 9 : FanWing model aircraft [11].....	6
Figure 10: Combination of FanWing and Cyclogyro aircraft [15].....	7
Figure 11: Schematic of FanWing.....	10
Figure 12: Schematic of cross flow fan for FanWing.....	11
Figure 13: Boundary Conditions.....	11
Figure 14: Geometrical parameters of the FanWing	12
Figure 15: case (A) represents the Start case of the FanWing, case (B) represents the 1 st refinement of the mesh, and case (C) represents the 2 nd refinement of the FanWing mesh.	13
Figure 16: Comparison of Thrust forces for the successive grids at different operating RPM's and $V = 5.5 \text{ m/s}$ and $\alpha = 0^\circ$	14
Figure 17: Comparison of lift forces for the successive grids at different operating RPM's and $V = 5.5 \text{ m/s}$ and $\alpha = 0^\circ$	15
Figure 18: FanWing stream function with 5.5 m/s free stream flow and (0°) angle of attack	16
Figure 19: Contours of velocity magnitude in the FanWing	17
Figure 20: Filled Contours of velocity magnitude in the FanWing.....	18
Figure 21: Lift validation chart	19
Figure 22: Thrust validation chart	19
Figure 23: Stream function at (0°) angle of attack for (0) RPM fan rotation	21
Figure 24: Stream function at (0°) angle of attack for (1020) RPM fan rotation	21
Figure 25: Stream function at (0°) angle of attack for (2500) RPM fan rotation	22
Figure 26: Stream function at (0°) angle of attack for (4200) RPM fan rotation	22
Figure 27: Lift vs. Fan RPM at (0°) angle of attack and 5.5 m/s airstream velocity	23
Figure 28: Thrust vs. Fan RPM at (0°) angle of attack and 5.5 m/s airstream velocity..	23
Figure 29: Gage Static pressure distribution at (0°) angle of attack for (0) RPM fan rotation	24
Figure 30: Gage Static pressure distribution at (0°) angle of attack for (1020) RPM fan rotation	24
Figure 31: Gage Static pressure distribution at (0°) angle of attack for (2500) RPM fan rotation	25
Figure 32: Gage Static pressure distribution at (0°) angle of attack for (4200) RPM fan rotation	25
Figure 33: Gage Static pressure distribution on the airfoil upper and bottom walls at (0°) angle of attack [17]	26
Figure 34: Stream function at (20°) angle of attack for (0) RPM fan rotation	27

Figure 35: Stream function at (20°) angle of attack for (1020) RPM fan rotation	27
Figure 36: Stream function at (20°) angle of attack for (2500) RPM fan rotation	28
Figure 37: Stream function at (20°) angle of attack for (4200) RPM fan rotation	28
Figure 38: Lift vs. Fan RPM at (20°) angle of attack and (5.5) m/s airstream velocity ..	29
Figure 39: Thrust vs. Fan RPM at (20°) angle of attack and 5.5 m/s airstream velocity	29
Figure 40: Gage Static pressure distribution at (20°) angle of attack for (0) RPM fan rotation	30
Figure 41: Gage Static pressure distribution at (20°) angle of attack for (1020) RPM fan rotation	30
Figure 42: Gage Static pressure distribution at (20°) angle of attack for (2500) RPM fan rotation	31
Figure 43: Gage Static pressure distribution at (20°) angle of attack for (4200) RPM fan rotation	31
Figure 44: Stream function at (40°) angle of attack for (0) RPM fan rotation	32
Figure 45: Stream function at (40°) angle of attack for (1020) RPM fan rotation	33
Figure 46: Stream function at (40°) angle of attack for (2500) RPM fan rotation	33
Figure 47: Stream function at (40°) angle of attack for (4200) RPM fan rotation	34
Figure 48: Lift vs. Fan RPM at 40° angle of attack and 5.5 m/s airstream velocity	34
Figure 49: Thrust vs. Fan RPM at 40° angle of attack and 5.5 m/s airstream velocity ..	35
Figure 50: Gage Static pressure distribution at (40°) angle of attack for (0) RPM fan rotation	35
Figure 51: Gage Static pressure distribution at (40°) angle of attack for (1020) RPM fan rotation	36
Figure 52: Gage Static pressure distribution at (40°) angle of attack for (2500) RPM fan rotation	36
Figure 53: Gage Static pressure distribution at (40°) angle of attack for (4200) RPM fan rotation	37
Figure 54: Lift vs. RPM at 5.5 m/s air stream velocity	38
Figure 55: Thrust vs. RPM at 5.5 m/s air stream velocity	38
Figure 56: Lift vs. AoA (α) at 5.5 m/s air stream velocity	39
Figure 57: Lift Coefficient (C_L) vs. AoA (α) at 5.5 m/s air stream velocity	40
Figure 58: Thrust vs. AoA (α) at 5.5 m/s air stream velocity	41
Figure 59: Thrust Coefficient (C_T) vs. AoA (α) at 5.5 m/s air stream velocity	42
Figure 60: Lift-Thrust chart at 5.5 m/s air stream velocity	43
Figure 61: Coefficient of Lift and Thrust chart at 5.5 m/s air stream velocity	43
Figure 62: Determination algorithm flowchart	44
Figure 63: Free stream velocity -RPM chart at (0°) angle of attack	47
Figure 64: Lift-RPM chart at (0°) angle of attack	47
Figure 65: Stream function at $\alpha=0^\circ$	48
Figure 66: Free stream Velocity - Fan RPM chart at (10°) angle of attack	50
Figure 67: Lift - Fan RPM chart at (10°) angle of attack	50
Figure 68: Stream function at $\alpha=10^\circ$	51
Figure 69: Free stream Velocity - Fan RPM chart at (15°) angle of attack	53
Figure 70: Lift – Fan RPM chart at (15°) angle of attack	53
Figure 71: Stream function at $\alpha=15^\circ$	54
Figure 72: Free stream velocity - Fan RPM Chart at (20°) angle of attack	58
Figure 73: Lift - Fan RPM Chart at (20°) angle of attack	59
Figure 74: Stream function at $\alpha=20^\circ$	60
Figure 75: Free stream velocity - Fan RPM Chart at (25°) angle of attack	64
Figure 76: Lift - Fan RPM Chart at (25°) angle of attack	64

Figure 77: Stream function at $\alpha=25^\circ$	65
Figure 78: Free stream velocity-Fan RPM Chart at (30°) angle of attack	67
Figure 79: Lift - Fan RPM Chart at (30°) angle of attack.....	68
Figure 80: Stream function at $\alpha=30^\circ$	69
Figure 81: Velocity-RPM chart at different angles of attack.....	71
Figure 82: Lift - RPM chart at different angles of attack	71
Figure 83: Top plan view of an aircraft incorporating the lifting member of Fig. 8	75
Figure 84: Graph of fan input power plotted against lift in grams force	76

NOMENCLATURE

Symbol	Nomenclature	Unit
ρ	Fluid density	Kg/m^3
V	Air stream relative velocity	m/s
P	Static pressure	N/m^2
u	x-components of velocity vector	m/s
v	y-components of velocity vector	m/s
τ	Shear stress	N/m^2
W	The input power of the fan measured in watts	Watt
k	The turbulence kinetic energy	N.m
ϵ	The rate of dissipation for the turbulence kinetic energy	$\text{J}/(\text{kg.s})=\text{m}^2/\text{s}^3$
S	Wing span	m
c	Airfoil chord	m
L	Lift force	N
T	Thrust force	N
μ	viscosity	$\text{Pa.s}=(\text{N.s})/\text{m}^2=\text{kg}/(\text{s.m})$
μ_t	The turbulent (eddy) viscosity	
V_x	Air stream relative velocity in x-direction	m/s
V_y	Air stream relative velocity in y-direction	m/s
F_x	Resultant force in x-direction	N
F_y	Resultant force in y-direction	N
α	Angle of attack	Degree ($^\circ$)
N	Fan rotation	RPM

ABSTRACT

In the present thesis, the propulsive wing is examined numerically to determine the benefit and efficiency of a new proposed propulsive device. In the propulsive wing concept, the fan is embedded inside the wing section and the outflow jet blows over the wing. This pushes the aerodynamic envelope of the wing by avoiding stall up to 45° and hence maintain very high lift coefficient.

The numerical model is first compared with published experimental data. The comparison shows that the K- ϵ model is the optimum model for the numerical calculation; a sensitivity study is then performed to determine the flight operating points of the propulsive wing based on the numerical values for the net thrust force.

The numerical results show that the operating speed of the propulsive wing increases from 3.4 to 13.5 m/s as the RPM throttle setting increases from 1020 to 4200 RPM. The lift can be high as 23 N for $\alpha = 30^\circ$, which is not attainable with conventional wings.

The airstream operating velocity (velocity required to get almost zero net thrust, is proportional to the fan speed at the same angle of attack, while it is proportional inversely with the RPM at different angles of attack; at 4200 RPM, the velocity is 21.6 m/s at ($\alpha=0^\circ$) while it decreases to 13.5 m/s at ($\alpha=30^\circ$).

The lift is found to also increase as the RPM increases at the same angle of attack. Since it is possible to delay stall, the lift increases as the angle of attack is increased as long as the RPM is sufficiently high to keep the flow attached on the upper surface.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Moving an airfoil (wing) relative to the air produces aerodynamic forces of **drag** and **lift**. The **thrust force** is created by a propeller or a jet engine. There are three vectors representing the aerodynamic forces on a powered airplane: lift, drag and thrust. The other force acting on an aircraft during flight is the **weight force**.

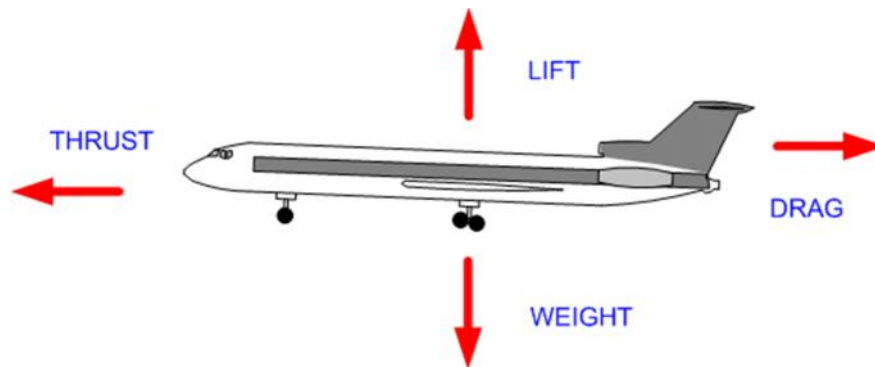


Figure 1 : Forces acting on airplane [1]

In conventional airfoil or wing, lift is generated by static pressure difference between upper and lower surface of the wing as shown in Fig. 2.

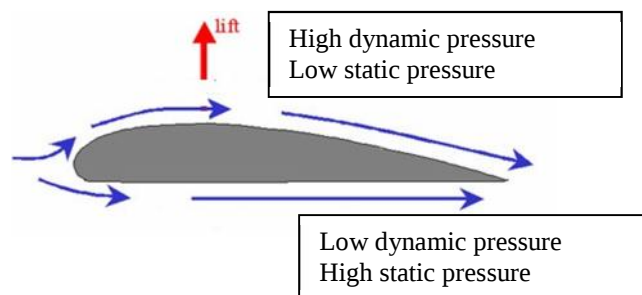


Figure 2 : Lift generation on wing [2]

There are general methods that aim to accelerate the air stream over the upper surface of the wing such as increasing the angle of attack or increasing camber of wing as shown in Fig. 3.

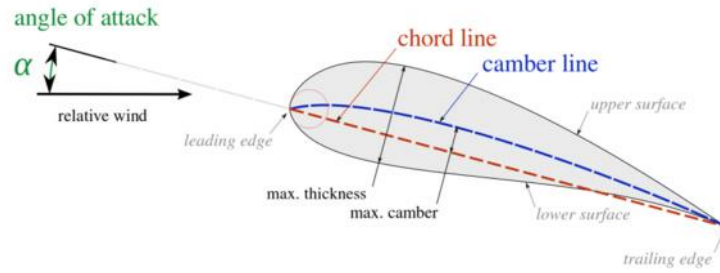


Figure 3 : A schematic of typical airfoil [3]

For the propulsive wing, an embedded radial fan at the leading edge of wing (with its axis parallel to the leading edge) permits blowing of the air towards the trailing edge. Lift is generated from two sources; the circulation at the fan which pulls the air stream from leading edge toward the trailing edge of the wing with airflow adjacent to the upper surface of the wing which increases dynamic pressure and decreases static pressure on the upper surface of the wing. There is no influence from fan circulation on the bottom surface of the wing. The second source of lift is the vertical component of the reaction force on the wing resulting from the inclined velocity vector of the exiting airstream flow at the trailing edge. The horizontal component of the reaction force on the wing represents the thrust force, this results in a direct proportional relation between the speed of rotation of the fan (or throttle setting) and the lift acting on the wing, which is a feature rarely found in fixed wing aircraft as shown in Fig.4.

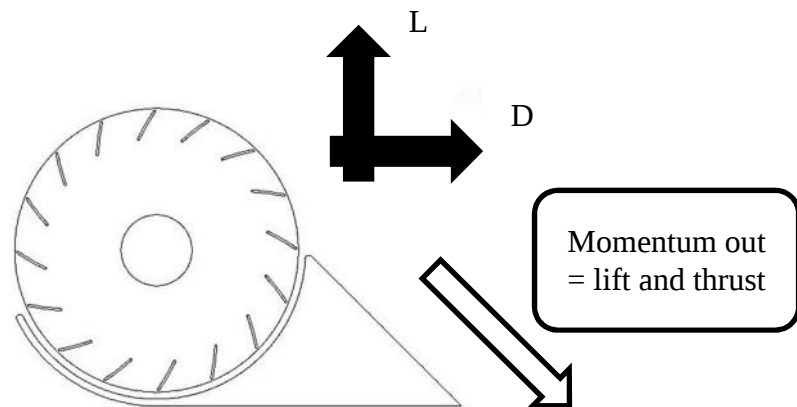


Figure 4 : Schematic of propulsive wing cross section [4]

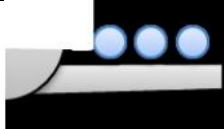
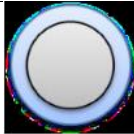
The concept of the propulsion wing is classified as one of the techniques of the embedded distributed systems. A full investigation by (Kim, 2010) [5] shows:

- Jet flaps (blowing engine exhaust out of the wing trailing edge).
- Cross-flow fan (two dimensional propulsor integrated within the wing trailing edge).

- Multiple discrete gas turbine engines (driven by their own power source).
- Distributed multi-fans driven by a limited number of gas turbine engine cores; which can be driven by conventional or electrical motors.

An investigation to study the advantages of distributed propulsion for future aircraft concepts was evaluated for six different integration approaches in order to down-select the best configuration as shown in Table 1 (Steiner, 2012) [6] . Categories included the integration of power system, the aspects of operation, weight, noise and efficiency. The evaluation is based on the boundary layer ingestion, which has the ability to increase aircraft efficiency by increasing the propulsive efficiency of the fans and shifting the optimum fan pressure ratio to higher values, hence permitting the use of a smaller propulsor size, which results in lower weight and drag of the propulsion system. The results show that the CROSS configuration is the best case and gives the highest efficiency for all embedded distributed systems.

Table 1 : Distributed propulsion concepts [6]

Concept	Description and Abbreviation
	Aft-mounted fans covering the upper part of a cylindrical fuselage (REVOLVE)
	Blended Wing Bodies (BWB) with embedded fans on top of the lifting body trailing edge (BWB)
	Tube and wing configuration with fans integrated within a split-wing (SPLIT)
	Tube and wing concept with fans mounted on the upper wing side (WING)
	Cylindrical fuselage with circumferential fan at the aft section (PROPFUS)
	Cross-flow fan embedded into the trailing edge of the wing (CROSS)

An analysis of propulsive wing configurations according to the potentials of cross-flow fan for the application to commercial aircraft featuring extreme short takeoff and landing capabilities has been done by evaluating the kinematic mechanisms for three cross-flow fan propulsive airfoil concept solutions with a preliminary assessment enabling a low-speed operation as well as high-speed operation mode as shown in Fig.5. By using a thin supercritical airfoil in performing a two-dimensional simulation for concept (2) at a free stream velocity of 35 m/s for 15° angle of attack and a 12,000 RPM fan rotational speed, representing a potential take-off condition, the lift coefficient