# LMECA2323 - Aerodynamics of External Flow

# Homework - 2

## Formation Flights


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# 1. INTRODUCTION

Aircraft employs the method of formation flight to fly in close proximity to one another in unison. It entails controlling numerous aircraft in a predetermined configuration while each plane holds a precise position in relation to the others.

Training, air exhibitions, and military operations are just a few of the uses for formation flight. It enables pilots to hone their communication, precision flying, and teamwork skills. Formation flying, which enables numerous aircraft to operate as a single unit, can give military operations a tactical advantage by making a more difficult target for opposing defences. Additionally, it has various benefits for commercial airplanes, including less fuel use and increased efficiency.

# 2. OBJECTIVES

- Circulation of the leader aircraft and trailer aircraft in both trimmed and untrimmed condition.
- Wing lift slope and angle of attack of wing for leader and trailer aircraft.
- Span loading distribution as a function of si for leader and untrimmed and trimmed trailer aircraft.
- Effective angle of attack distribution for the leader and trailer aircrafts.
- Computation of induced drag coefficient for leader aircraft and trailer aircraft (trimmed and untrimmed aircraft).
- Computation of Oswald's efficiency.
- Characteristics of far wake for leading aircraft.
- Vertical velocity profile as a function of si for leader aircraft.
- Rolling moment coefficient for the untrimmed trailer aircraft.
- Aileron deflection angle for trimmed trailer aircraft.

# 3. ASSUMPTIONS

During the course of formation flight, we consider many assumptions to approach the concept better towards formation flight. The assumptions made are:

- The wing is considered as 1 dimensional.
- Wing sweep is not considered.
- Wing taper ratio is considered within the 0.2-0.3.
- Lift slope is 2π.
- Pseudo wing sections with fuselage is not twisted.

# 4. ASSUMED AIRCRAFT

Aircraft Airbus A320 is considered for the study of formation flight.

- Altitude = 12000 m
- Temperature = 216.65 K
- Pressure = $1.93304 \times 10^4$ Pa
- rho = 0.310828 kg/$m^3$
- viscosity = $1.43226 \times 10^{-5}$
- Aircraft Speed = 248 m/s
- Weight = 7,65,180 N
- Wing Span (b) = 35.8 m
- Wing Area (S) = 122.6 $m^2$

Important Assumed values:

1. Aspect ratio (AR):

$$AR = \frac{b^2}{S}$$

$$AR = \frac{35.8^2}{122.6} = 10.454$$

2. Wing taper ratio ($\wedge$):

The wing taper ratio as per the data available for the aircraft Airbus A320 is around 0.24 which we assume in our case.

3. Coefficient of lift ($C_L$):

The coefficient of lift based on weight of the aircraft we assume the aircraft in cruise and we keep the lift and weight as same and calculate the coefficient of lift which rounds as 0.653.

# 5. ANALYSIS OF RESULTS

## 5.1 CIRCULATION:

**Leader aircraft**: The circulation is calculated using the Prandtl lifting line theory and plotted along the entire span. The formula used to obtain the circulation is given by

**Trailer aircraft (Un-trimmed)**: The circulation compared to the leader aircraft is different from its formula as we will be including the even terms as well due to uneven effect of circulation induced by the leader aircraft and through formula the coefficients of Cn.

**Trailer aircraft (trimmed):** The circulation formula compared to the leader aircraft is different since we will be needing even terms as well due to uneven circulation formed by aileron deflection and through formula the coefficients of Dn and Cn both inclusive are found.

Analysing the plot for circulation in Fig. 1 and Fig. 2, we observe that for leader aircraft the circulation is symmetric and high in the centre compared to the ends of the wing. While in trailing aircraft for un-trimmed case the circulation is more towards the port side than starboard side, which is the inverse case for the trimmed case due to deflection angle by movement of ailerons.

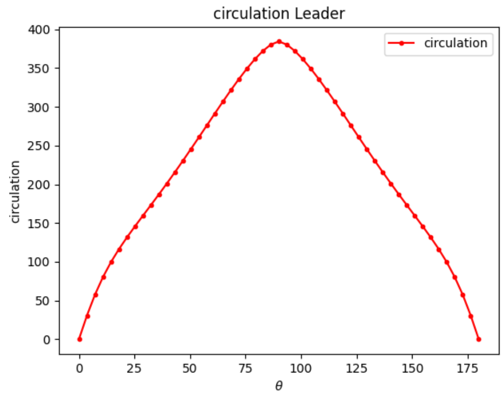


**Fig. 1: Circulation distribution over the wing span for leader aircraft**

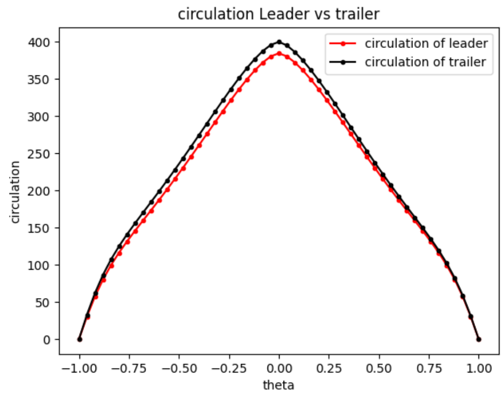


**Fig. 2: Circulation distribution over the wing span for leader aircraft and trailer aircraft**

## 5.2 WING LIFT SLOPE FOR LEADER AIRCRAFT

**Leader aircraft:** The wing lift slope for cruise case is calculated by considering the lift as weight in the lift equation to find the $C_L$ and the corresponding α. Using the equation for wing lift slope is found to be 5.27.

## 5.3 WING ANGLE OF ATTACK

**Leader aircraft:** The coefficient of lift is found which should be the same for the trailer aircraft. Using the $C_L$ we find the angle of attack of wing. For leader aircraft the angle of attack for wing is found to be 7.09 degrees.

**Trailer aircraft (Un-trimmed):** In this case the $C_L$ would be same as that of the leader aircraft but the angle of attack for the wing would change as the formula now include Cn term. For Trailer aircraft (Un-trimmed) the angle of attack for wing is found to be 6.92.

**Trailer aircraft (trimmed):** And for trimmed case the angle of attack for wing should be the same as in un-trimmed case as the formula to compute the angle is done by using the $B_n$ matrix wherein $d_n$ terms for trimmed case for odd values are zero so the wing angle of attack in same.

## 5.4 SPAN LOADING

**Leader aircraft:** The span loading for the leader aircraft is found and plotted along the si function. The leader aircraft is having more distribution at the centre than the ends of wing.

**Trailer aircraft (Un-trimmed):** As compared to the leader aircraft the trailer aircraft with un-trimmed case has more span loading towards the port side due to induced angle of attack by the leader aircraft.

**Trailer aircraft (trimmed):** For trimmed case the span loading is more towards starboard side due to aileron deflection which induces angle of deflection making it more.

Showing the span load distribution in Fig. 3, Fig. 4 and Fig. 5.

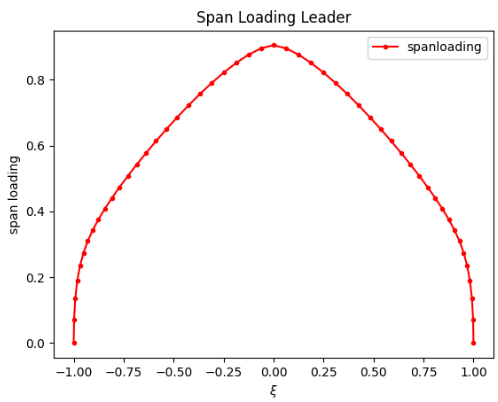


**Fig. 3: Span distribution over the wing span for leader aircraft**

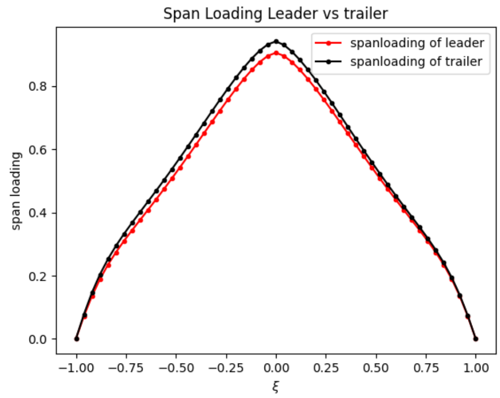


**Fig. 4: Span distribution over the wing span for leader vs trailer for untrimmed aircraft**

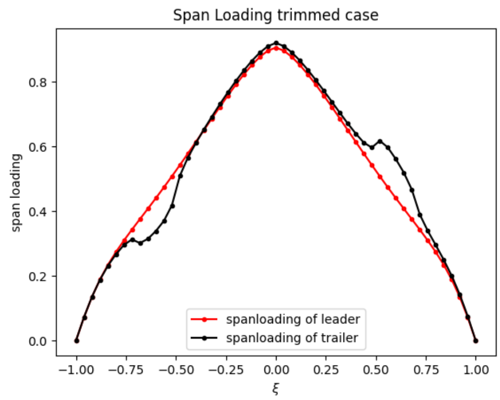


**Fig. 5: Span distribution over the wing span for leader vs trailer for trimmed aircraft**

## 5.5 EFFECTIVE ANGLE OF ATTACK

**Leader aircraft:** The angle of attack of the aircraft is not equated to effective angle of attack since the effect of downwash needs to be considered within the leader aircraft wing as a function of si which is shown in Fig. 6. The variation first increases and later decreases due to the wing tip vortices.

Near the wing tip the wing in Prandtl line is considered as an infinite number of horse-shoe vortices and for finite wing the vortices roll up and lead to push the aircraft downwards which leads to wing tip vortices and usually aircrafts use winglets to counter this. But in this case the aircraft is creating vortices creating a downwash effect.

**Trailer aircraft (Untrimmed):** The trailer aircraft along with the downwash the effect of induced angle of attack is considered which is due to the leader aircraft. The variation shown in the Fig. 8 shows more towards the port side than the starboard side.

**Trailer aircraft (trimmed):** The trimmed trailer aircraft along the aileron has increase in effective angle of attack of starboard side than the port side, as in Fig. 7.

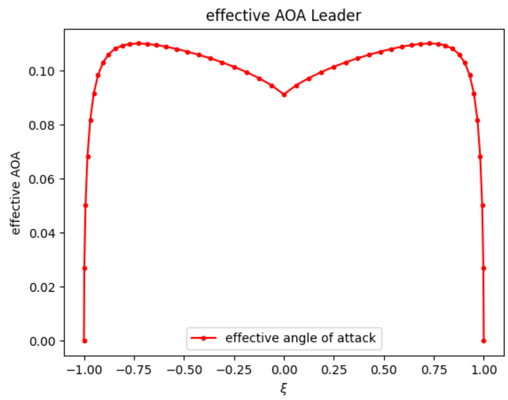


**Fig. 6: Effective angle of attack of leader**

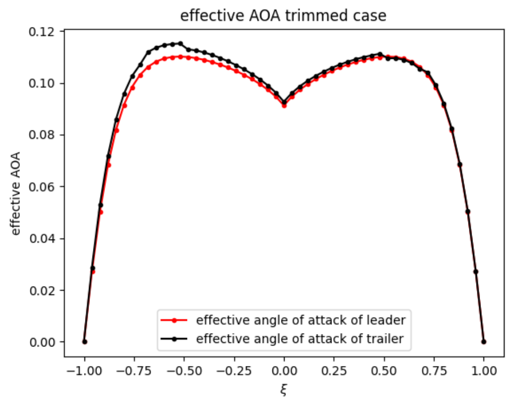


**Fig. 7: Effective angle of attack of leader vs trailer in trimmed case**

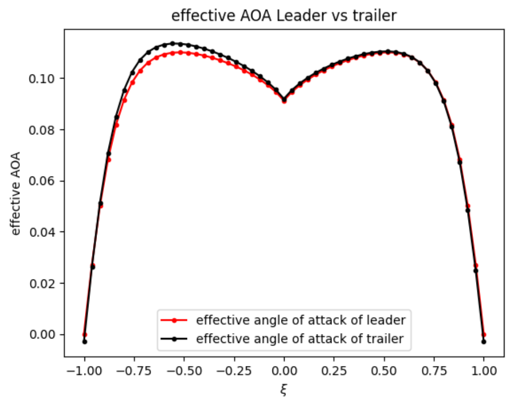


**Fig. 8: Effective angle of attack of leader vs trailer in untrimmed case**

## 5.6 INDUCED DRAG COEFFICIENT AND OSWALD'S EFFICIENCY

The induced drag coefficient is the drag coefficient occurred as a result of lift produced by the aircraft.

**Leader aircraft:** The induced drag coefficient for the leader aircraft is found to be 0.013.

**Trailer aircraft (Un-trimmed):** While for trailer aircraft with untrimmed condition is found to be 0.011

**Trailer aircraft (trimmed):** For the trimmed trailer aircraft is found to be 0.0107 .

Seeing these results, we can comment that the Induced drag has decreased as we compare with leader and trailer aircraft.

The Oswald's efficiency is found through drag polar equation and obtained as 0.97.

## 5.7 FAR WAKE

The leader aircraft creates a wake within the region which will lead to stall any aircraft under this region. So, the region where far wake is found is computed and found to be 0.043. bo/b=s=0.708 and rc/b=0.055.

## 5.8 VERTICAL VELOCITY PROFILE

The leader aircraft from energy equations the induced wake is calculated and then as function si from -2 to 2 the wake distribution is computed having vortices, at the same altitude the trailer aircraft is flying. The induced vertical velocity first increase near the wing tips of the leader aircraft and gradually decreases, as shown in Fig. 9.

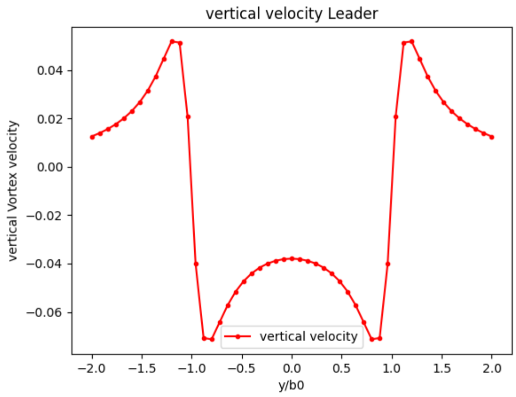


**Fig. 9: Vertical velocity distribution of leader aircraft**

## 5.9 ROLLING MOMENT IN TRAILER AIRCRAFT

The trailer aircraft (Untrimmed) has an induced angle of attack which creates a moment forming it to rotate in clockwise direction. And using moment equation with dynamic pressure is considered and the coefficient of moment is calculated which corresponds to 0.0014.

## 5.10 AILERON DEFLECTION

**Trailer aircraft (Trimmed):** To counter this rolling moment in the aircraft due to induced angle of attack we use the control surface ailerons which gives a deflection and allows the aircraft to roll up in opposite direction and bring the aircraft to stable condition and we find it to be 57.29 (degrees).

# 6. CONCLUSION

We have considered formation flight in this project where we have computed different factors based on the effect of leader aircraft on the trailer aircraft. We have used Prandtl lifting line theory to calculate the circulations on the leader aircraft which is in symmetry and later on the effect of the vortices induced by this on the trailer one. On the basis of this we can say that the formation flight has advantages as lift produced on the trailer aircraft will also have a positive impact by the leader one.The figure achieved is smaller than the zero lift drag coefficient, which will result in less drag for the same lift of the aircraft and also aid to reduce fuel consumption and extend the range of the aircraft which indirectly increases efficiency.