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To Study Subsonic Flow over a Backward Facing Step

Ms.Srilaxmi
Assistant Professor,
Dept. of Aeronautical Engineering
MLRIT, Hyderbad.

Kukatla Shravan Kumar Yadav
M.Tech Student,
Dept. of Aeronautical Engineering
MLRIT, Hyderbad.

Dr. M Satyanarayana Gupta
Professor & HoD,
Dept. of Aeronautical Engineering
MLRIT, Hyderbad.

Abstract:

To study the flow over a BFS and observe the height of the steps vary the separation region corresponding to increase in expansion ratio and also change in Reynolds number where there is a significant change in the reattachment length.

INTRODUCTION

Backward facing step

The backward facing step is one of most considered models for the study of separated flows. Separated flows often occur at locations of sudden change in the surface geometry. These flows are common in several engineering applications such as aircraft wings, turbine and compressor blades, diffusers, buildings, suddenly expanding pipes, combustors, etc. The characteristics of a separated flow have been studied for decades by experimentalists to understand the physics of the separated shear layers and their instability mechanisms.

Some of the reasons for its use are:

1. It facilitates the study of the reattachment process by minimizing the effect of the separation process.
2. This separated flow geometry has a single fixed separation point and the wake dynamics unperturbed by the downstream disturbances.
3. It also has a simple geometry.

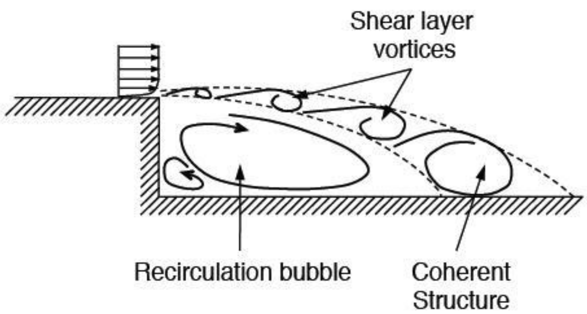

Fig 2.1: Backward facing step

The instabilities in the free shear layers are the source to distinctly visible large coherent structures. The BFS flow has been studied extensively, yet much continues to be unknown about the flow structure and dynamics of this geometrically simple, turbulent flow. Techniques such as use of hotwires, surface pressure sensors, laser Doppler anemometry (LDA), particle image velocimetry (PIV) has been ued. From the earlier studies the BFS flow can be distinguished into three main regions namely, the shear layer region, separation bubble or recirculation zone and the reattachment zone.

Features of the BFS flow

The flow behind a BFS is complex and involves various instabilities. The important flow features of the wake flow in a BFS geometry can be distinguished in three main regions.

Shear layer region

The layer of fluid with a velocity gradient subjected to viscous shearing is known as the shear layer. The free shear layer in the BFS originates at the separation pointand eventually curves down towards the wall to impinge at the reattachment point. This layer is created due to the fast moving fluid (free stream velocity) on the top and the low momentum fluid in the wake of the step

Recirculation zone

The region behind the step, which is bounded by the separating and reattaching shear layer on the top and by the wall on the bottom, is the recirculation zone. Due to the presence of vortices in the separated shear layer fluid from the recirculation zone is entrained and thus creates a low pressure triggering recirculation. This region also referred to as the separation bubble is dominated primarily by a large two-dimensional vortex (or primary vortex) that possesses a low circulation velocity.

Reattachment zone

The reattachment point of an uncontrolled separating and reattaching shear layer in a BFS is seldom fixed at a single point. This unsteadiness in the point of reattachment is associated with the low-frequency

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oscillations detected in the shear layer [31]. This unsteadiness in the shear layer trajectory is referred to as the flapping of the shear layer.

There have been several active control studies conducted on BFS ows in which the characteristics of the coherent structures are altered to achieve desired results. In active control studies the forcing on the separated shear layer is usually applied through two methods: flaps or by acoustic forcing, the latter being the most common.

Flow parameters

The parameters that significantly affect this flow are

1. Aspect ratio (w/H):

The results suggested the effect of aspect ratio (the ratio of width to height of the BFS) on the two-dimensionality of the step remained two-dimensional but not uniform along the width, when the aspect ratio was greater than or equal to 10:1

2. Expansion ratio (Y1/Y0):

The expansion ratio is defined as the ratio of downstream to upstream height of the channel at the step location, i.e. Y1/Y0

3. Free stream turbulence intensity:

The free stream turbulence intensity, which is the ratio of the turbulent fluctuation to the free stream velocity (√u'.2 + v'.2 + w.'2/Uª), has a significant effect on the reattachment of the shear layer behind the BFS .

4. Reynolds number, the boundary layer state and thickness at separation:

The reattachment length increases sharply to a peak value with the change in boundary layer state from laminar to transitional and then decreases gradually to a steady value as the boundary layer becomes turbulent. The effect of boundary layer state on BFS flows is highly nonlinear and difficult to isolate due to its dependency on Reynolds number and boundary layer thickness at separation.

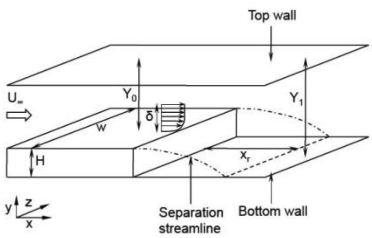

Fig 2.3: BFS Geometry

Study on subsonic wind tunnel

A low speed wind tunnel is used for studying the characteristics of the flow over the backward facing step. They are operated at very low Mach number, with speeds in the test section up to 400 km/h (~ 100 m/s, M = 0.3).

The schematic diagram of the subsonic wind tunnel:

Fig 2.4.1 schematic diagram of subsonic wind tunnel

PARTS.

1. Bellmouthed section.
2. HoneyComb.
3. Settling Chamber, and screen sections.
4. Contraction cone.
5. Test Section.
6. Transition (square to circular)
7. Diffuser.
8. Fan Duct.
9. Motor and Stand.

SPECIFICATIONS:

Test Section Size : Cross Section: 600mm×600mm.
Length : 4000mm.
Maximum Speed : 45m/sec.
Fan : Axial Flow fan of Diameter: 1.3 meter.
Maximum rpm : 1500
Number of Blades : 12
Hub Diameter : 500mm.
Spinner is provided.
Contraction Ratio : 9: 1
Contraction length : 1.8m
Settling chamber : 1.8m×1.8m
Entry section : Bell mouthed entry.
Honey Comb Size : 50mm×50mm×450mm.
Screens : Two screens 8mesh and 16mesh stainless steel.

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Provision to put smoke rake: provided in the contraction cone.
Power : 22 KW / 30HP AC motor, with speed control drive

PRECAUTIONS TO BE TAKEN WHILE RUNNING THE TUNNEL.

1.Do not allow anyone to stand behind the motor while the tunnel is being run. It is best to enclose the fan motor assembly by a strong wire/ mesh enclosure and allow only authorized personal to have access to the motor and fan area.

2.Before starting the tunnel check whether any loose parts are in the test section and remove them before start. Secure rigidly the models measuring probes, instruments etc, so that they don't fly off. Any loose parts when they fly off can damage the blades and can be dangerous to personal who could be behind the motor fan assembly.

3. Don't run the tunnel below 100 rpm continuously, this may heat up the motor and damage the windings of the motor. Intermittent running at lower speeds is allowed. But do not exceed more than a minute or two. Feel the temperature of the motor after running for short period at lower speeds. After some experience the user will get a feeling of how long the motor can be run at lower speeds.

4.At higher rpm the fan noise could be irritable. Hence personal should use ear plugs or ear mufflers while the tunnel is being run. Prolonged exposure to this noise may impair the hearing capability.

5.As far as possible do not run the tunnel for long time at higher speeds.

6.It is recommended that blade angle setting be checked regularly once in a few months.

7. The controller manual is separately given. Mains power connection must be highly secured. Sometimes electricity board might change phases without informing the customers. In that case the motor will rotate in opposite direction and then there will not be any flow through the tunnel. In that case the motor phases have to be changed appropriately for running properly.

8.There is a safety screen before the fan section. Make sure nothing is sticking to it and also make sure that it is not loose.

9.Close the top lid of the tunnel and the windows and secure it tight using C clamps before running the tunnel. If the tunnel is run with top lid and windows open loose object outside the tunnel can be sucked into the tunnel and cause damage to the tunnel.

10.Provide a cloth screen in front of the entry section of the tunnel and keep it closed whenever the tunnel is not in operation. When the tunnel is to be run the screen can be removed away from the air coming to the tunnel.

11.When the smoke visualization is not done it is advised to remove the smoke rake. After running smoke for some time it is better to blow fresh air through the smoke rake to clean the tubes.

30 PORT MANOMETERS:

Fig 2.4.2: 30 port manometer

This manometer consists of 30 different ports for measuring pressure difference at 30 different points at the same time. Range of 30 port manometer is 0mm to

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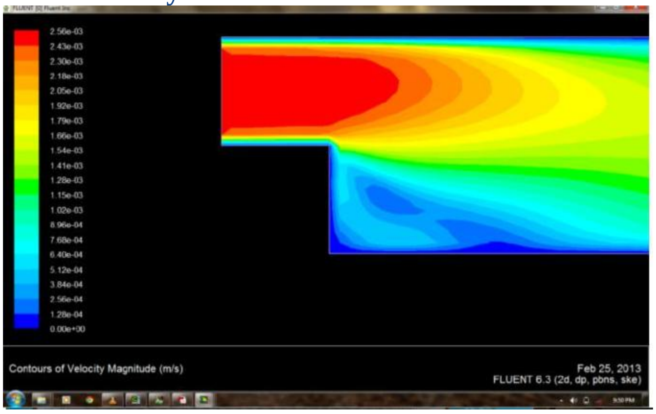
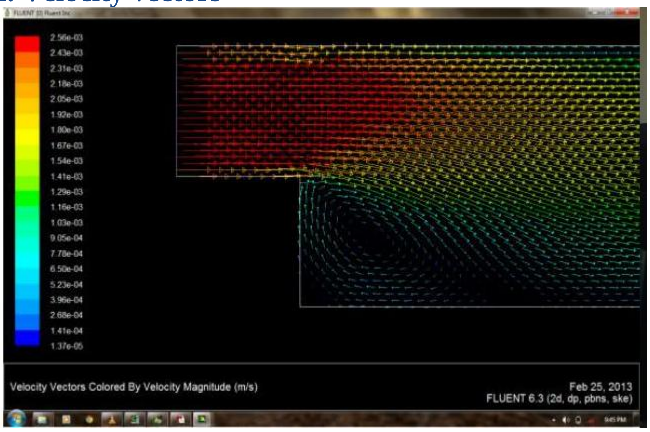
400mm. The least count of this manometer is 1mm. The liquid used for measurement is ethyl alcohol.

RESULTS

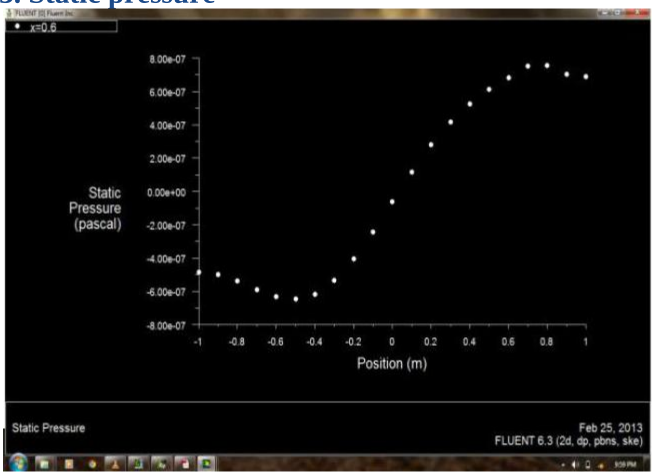
1. The velocity contour obtained is:



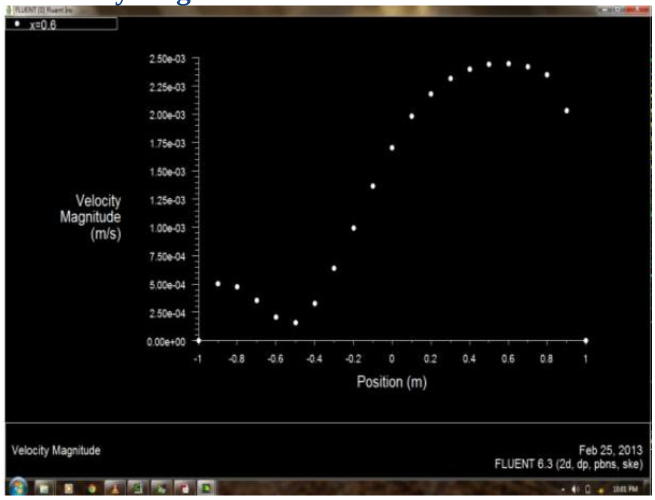
2. Velocity vectors



3. Static pressure



4. Velocity magnitude:



Pathlines

Fig 3.2.2: obtained results for validation

Mass flow rate is calculated as:
Mass Flow Rate (kg/s)
Inlet 0.0029828751
Outlet -0.0029837638
Net -8.887e-07

Thus the flow has been simulated for already available results and compared. Both the results obtained are almost similar. Therefore this procedure will be used for further analysis.

OBJECTIVES:

1. To familiarize with the simulation of flow
2. To study the measurement techniques
3. Data acquisition and interpretation.

METHODOLOGY:

1. Simulation of backward facing step model in the test section of subsonic wind tunnel

2. Study on Measurement of steady and unsteady pressures in the region of interest
3. Flow visualization using smoke and tufts
4. Simulation of flow over BFS computationally using fluent 2.3.16 and Gambit 6.3.26
5. Data interpretation and documentation

Conclusion

The flow over a BFS has been simulated in gambit 2.3.16 and fluent 6.3.26. It has been observed that as the height of the steps vary the separation region is increasing, therefore corresponding to the study that the increase in expansion ratio increases the separation region. It is also seen that as the Reynolds number or the velocity increases there is a significant change in the reattachment length i.e., firstly for the change in the velocity from lower Reynolds number there is large increase in the reattachment length. When the velocities with which the wind tunnel can be run are applied in the simulation (at high velocities, there is only a very slight variation in the reattachment length, or otherwise it is almost the same. One of the important features that have been observed is that as the velocity is being increased or the step height is being increased, there is a formation of many regions in the BFS flow.

This observation and the literature survey confirms that there is mainly three important regions shear layer region, recirculation region and reattachment zone. It is also observed that the recirculation has primary and secondary regions, where the turbulent intensity is high in all cases and thereby the region has higher adverse pressure gradients. This phenomenon thereby helps in reattachment of the flow. The region from the separation to the reattachment can form a smooth surface because of shear layer region. It is also seen that the top surface of the domain also has variations in the velocity, which almost reaches zero towards the wall.

Suggestions for further research

1. Experimental work can be done for the BFS.
2. Methods to reduce the turbulence occurring can be studied and found.

Further the studies can be extended by studying the characteristics and its reasons for the BFS flow.

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