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Flow Induced Noise Studies on a Porous Trailing Surface of a Flat Plate

Sumesh C.K.

Research Scholar, National Institute of Technology Calicut, India
email: sumesh55ck@gmail.com

T.J.S Jothi

Assistant Professor, National Institute of Technology Calicut, India,

The present study investigates the effect of porous trailing surface on flow induced noise from a flat plate at different Reynolds numbers. In general, porous surface helps in breaking of large scale eddies, delaying the separation of velocity boundary layer, vortex shedding and so on. However, the presence of porous surface largely affects the aerodynamic noise generated from a flat plate. To study these effects, a flat plate of 150 mm chord length, a span of 250 mm and plate thickness of 4.5mm (0.03 of chord) were considered. Experiments are conducted at different free stream velocities with Reynolds numbers ranging between 0.5×10^5 to 4×10^5. The noise studies have been carried out in an in-house constructed semi-anechoic chamber having wedge tip to tip distance of 2.5 m × 2.5 m × 2.6 m size. The aerodynamic noise generated from the interaction of flow over the flat plate with and without porous trailing surface was investigated. The noise characterization has been done using the directivity studies where the noise measured at different angles from the upstream of the trailing edge of flat plate to downstream. The OASPL (Overall Sound Pressure Level) of the plain trailing edge noise and the porous surface trailing edge noise from the flat plate at different polar angles and Reynolds Numbers are reported in this paper.

Keywords: Reynolds number, noise generation, porous surface, trailing edge, directivity.

1. Introduction

Low noise emission is an important challenge in the field of civil aviation transport flights. Since the flight density is increasing day by day the noise levels are much annoying to the residents near to the airport. So many aircraft manufacturing companies are open to a high need of silent aircrafts. The trailing edge noise from the lifting surface gives the major contribution to the airframe noise of a passenger aircraft. Different effort is being carried out to reduce the aircraft noise level by 10-20 dB, and it is evident that the control of trailing edge noise is critical to achieve this. Also the trailing edge noise impose barrier to wind turbines and helicopters to limit their use in thickly populated areas. Indeed, to achieve the aim of quieter aircraft the control of trailing edge scattering noise from the lifting surfaces is essential. So that reduction of noise emission from the trailing edge is subject of intense research due to this practical relevance.

The trailing edge noise is highly depends to the flow turbulence produced inside the boundary layer of a lifting surface.[1] When a turbulent flow passes a sharp trailing edge, it enhances the conversion of turbulent energy to acoustic energy. Since, in aerodynamic point of view, the trailing edge has minor importance than the LE, it can be altered to significantly reduce the noise emissions. Different studies shows that, [7,8] the geometric discontinuity is directly affecting the noise radiated from trailing edge. On its basis extensive experimental studies have been carried out in serrated trailing edge [2-4], trailing edge with bushes [5] and trailing edge with porous surfaces [6] etc. It is reported that around 2dB to 6dB noise reduction can be achieved using the passive methods and among which the serrations are showing good reductions in noise levels. Geyer *et al*.[6] experimentally stated that air resistivity and roughness of the surface of the material affect the noise generated by a porous airfoil. Oerlemans *et al*.[9] stated that at low frequencies the trailing edge serrations causes reduction of noise from the airfoil but at high frequencies the opposite effect is noticed. This is a contradiction to the Howe's theory. Graham [10] described that the silent flight of owl is achieved by the porosity and permeability of the feature of an owl's wing. Parchen *et al.* [11] investigated the effect of using a porous material in an airfoil side edge, which in turn reduced the induced drag on airframe and the noise produced due to the pressure fluctuations at the side edge.

By inserting the brushes at the trailing edge the broadband noise can be reduced. The intention behind the application of brush TE extensions is that to alleviate the sudden change in the solid TE boundary conditions, which interacts with the turbulent boundary layer flow and, thus, to reduce the generation of edge noise. Finez *et al*.[5], extensively studied the effect of trailing edge brushes on the TE broad band noise level and reduction in the noise level is achieved.

In spite of all the above methods, making the surface near to the trailing edge perforated is also affect the noise generation at the trailing edge. That is, putting holes near to the trailing edge which causes the interaction of fluid at the suction and pressure side, which influences the trailing edge noise. The present study takes a move to perceive the effect of holes near the trailing edge in the production of TE noise. The experiment is carried out with a thin flat plate with c=150mm and thickness 4.5 mm, one with plane TE and other with holes near to the TE.

2. Experimental Set up and procedures

2.1 Anechoic Test Facility

The free filed experiments were conducted in an in house constructed semi-anechoic test facility at NIT Calicit. Walls of the semi anechoic chamber are acoustically treated with PU wedges, having wedge tip to tip distance of 2.5 m × 2.5 m × 2.6 m size. The chamber ensures a reflection free environment for frequencies above 300Hz (cut off frequency). Air is supplied from a Variable speed

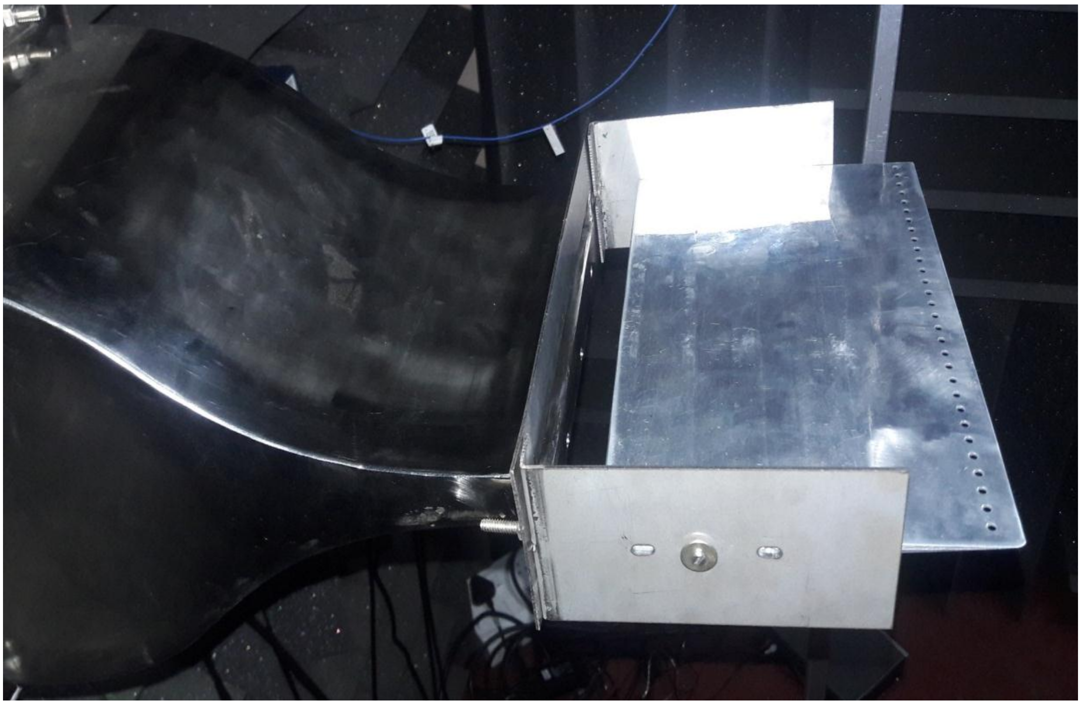


Figure 1: Experimental set-up along with the flat-plate held between two side plates.

centrifugal blower through an acoustically treated duct and a matched cubic contoured rectangular nozzle with exit cross section 20mmx 200mm is connected to supply air at test section. Side plates are attached at the exit of the nozzle to support the test plates. The maximum velocity of the jet from the nozzle is 60m/s.

2.2 Test Plates

Two flat plate models were fabricated for the study. One without holes and second is with holes near to the trailing edge. Both having a chord of c =150mm and span s =250mm and thickness t= 4.5mm(3% of chord).The schematic of the test models are shown in figure 2.The leading edge of the plates are made elliptical with a semi major axis 6 mm and minor axis 4.5 mm. The trailing edge of the plate made as symmetric wedge shaped with included angle of 5^0.A single row of 3mm diameter holes were drilled at position where the thickness of the TE is 1mm.The centre to centre distance between the holes is 8mm.The test plates where kept between two side plates attached to the contraction nozzle flange.

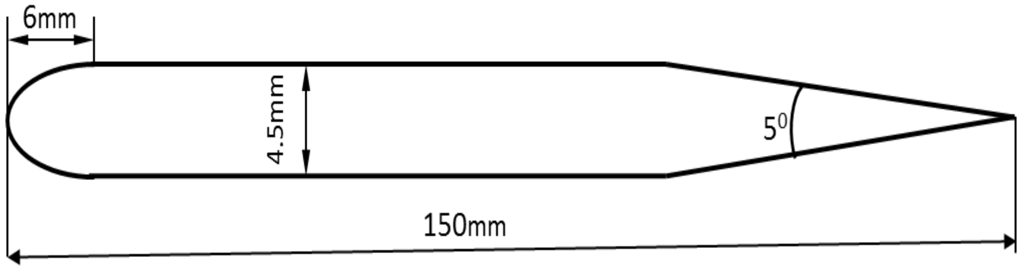


Figure 2: Schematic Diagram of Flat Plate model

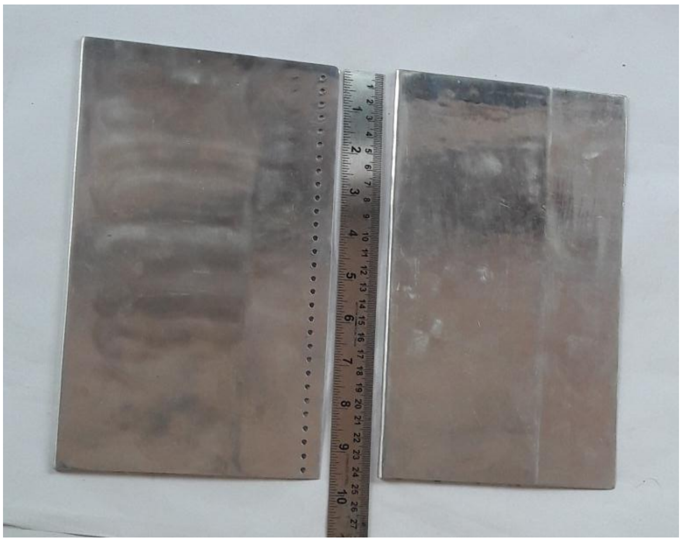


Figure 3: Flat plates with Porous TE and plain TE

2.3 Acoustic Measurements Techniques

The test plate was placed in front of the flow at distance of 25mm from the nozzle exit. Air is allowed to flow over the plate and the flow velocity is measured using a Pitot tube with digital anemometer. Acoustic measurements were taken by a PCB ¼" free field microphones (Model No. 378C01), of sensitivity 2mV/Pa. The microphone is lodged at a distance of 500mm from the centre of the railing edge of the reference plate. To plot the directivity of the trailing edge noise, acoustic data were recorded at different polar angles from 60^0 to 110^0 measured from the free stream jet axis. The acoustic measurements were estimated at zero angle of attack at low to moderate Reynolds Numbers based on chord length. ($0.5\times10^5 \leq Re_c \leq 4\times10^5$). Corresponding free stream velocity varies from 5.5 m/s to 43 m/s. The output voltage signals from the microphone were first pass on to ta PCB signal conditioner then to a National Instruments PCI- 6143 DAQ card through NI BNC-2110 Noise Rejecting, Shielded BNC Connector Block. The Microphone data were acquired at a sampling frequency of 150 kHz. The NI Lab VIEW program steers the DAQ card as per the sampling parameters. The acquired time series data were converted to Power Spectral Density (PSD) versus frequency plot using spectrum function in MATLAB.

3. Experimental Results

3.1 Acoustic Spectral Plots

Unless otherwise specified the data explained will be at Reynolds Number 3×10^5 at 90^0 polar position. Figure 3 shows the acoustic spectra of the base plate with plane TE, with perforated trailing edge and the background noise at Re 1×10^5, Re 2×10^5, Re 3×10^5, Re 4×10^5 respectively. The figure exemplifies that at low Re there is no much variation in the PSD for both base plate and porous plate. As Re increases much variation in the PSD can be observed.

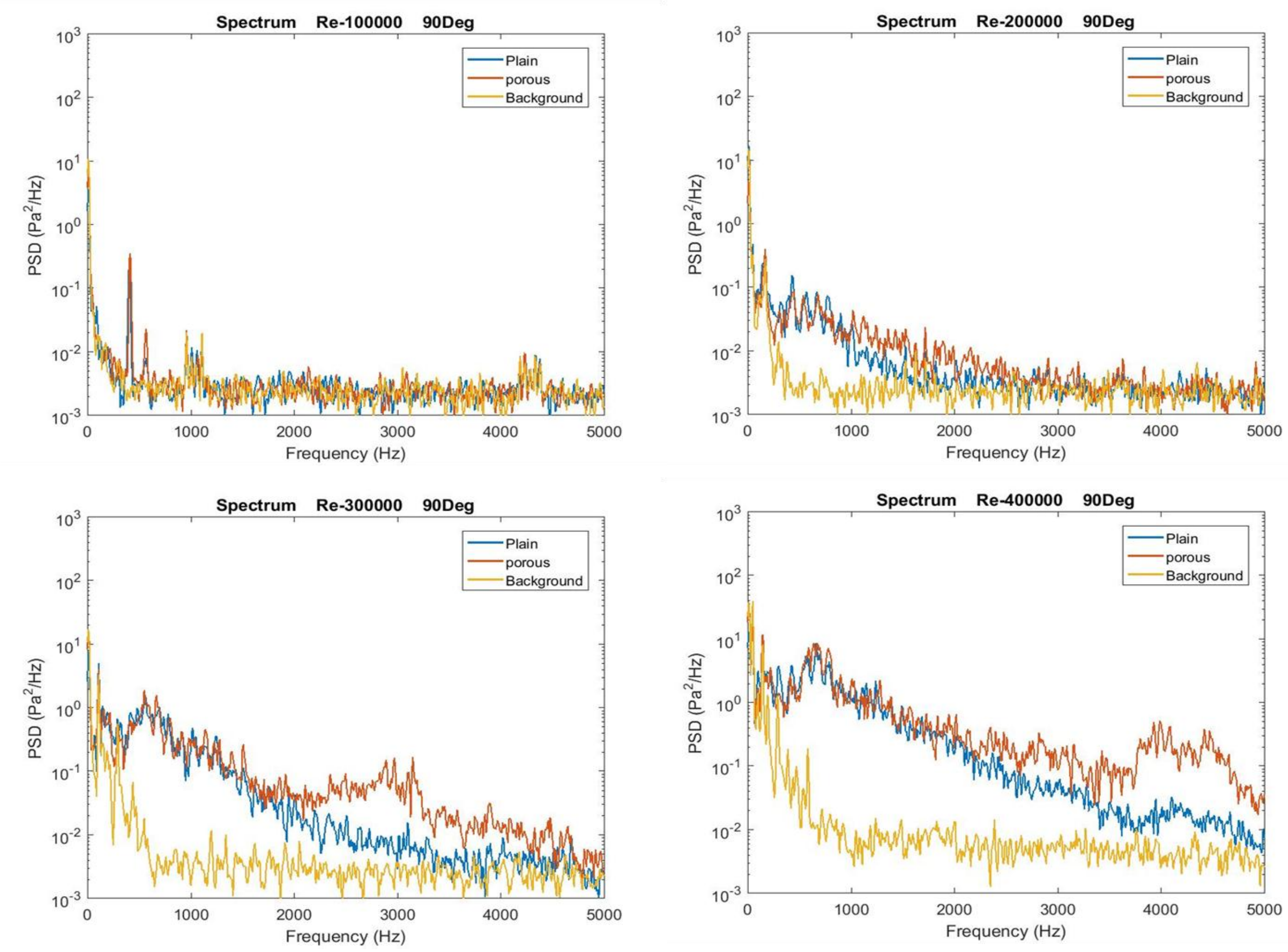


Figure 4: PSD Plots of the plain TE and Porous TE at 90 Degree polar position at Different Reynolds Numbers

In figure 4, sharp tonal noises can be observed at 410Hz and 570 Hz at Re $1x10^5$. This is due the vortex shedding occurs at the sharp trailing edge due to the laminar flow. As Re increases the tonal noise disappears and it is shifted to broadband noise. At high Reynolds Numbers the porous trailing edge produces more high frequency (*f* >2000Hz) noise as compared to the plain TE. The PSD of the noise with frequencies less than 2000Hz are more or less same. From the same figure, it is also evident that, while considering Reynolds Numbers $3x10^5$ and $4x10^{5,}$ The dominating range of frequencies of noise from the porous trailing edge is shifted to high frequency range when Reynolds Number increases.

Figure 5 describes the variation of overall sound pressure level with Reynolds Number. At high Reynolds Numbers the Overall Sound Pressure level (OASPL) of the Porous TE edge slightly more than that of the plain Trailing edge. But for Reynolds Number between (Re $1.5x10^5$- $2.8X10^5$) OASPL of the porous plate is less than that of base plate. The minute increase in the OASPL in the porous trailing edge noise at low Reynolds number less than $1.5x10^5$ is also observed.

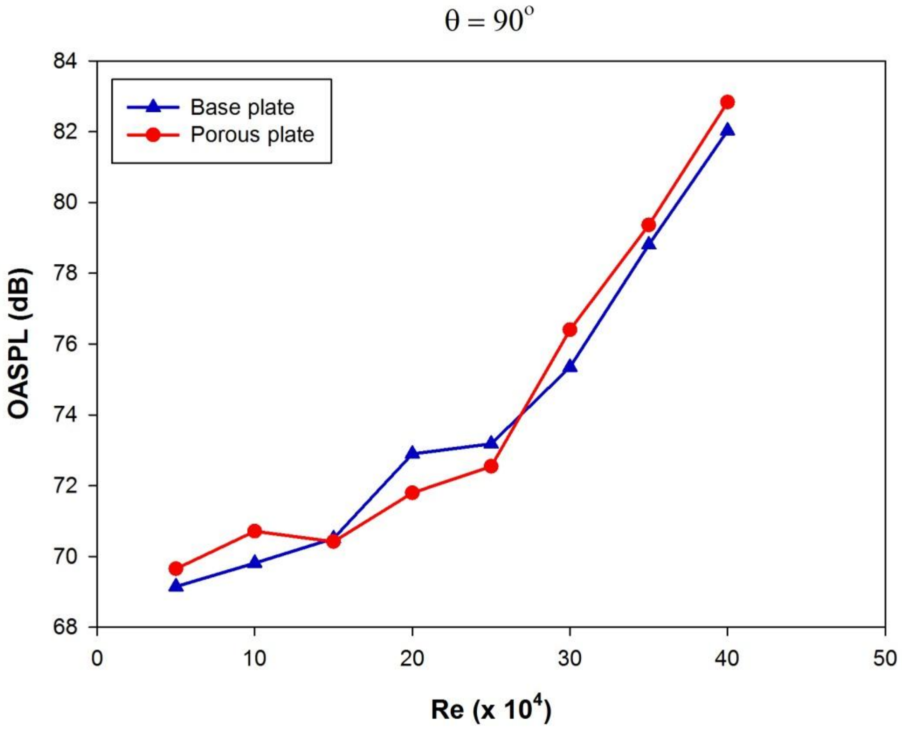
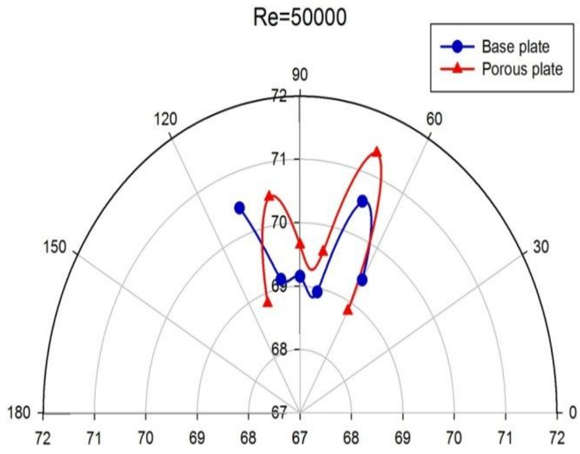


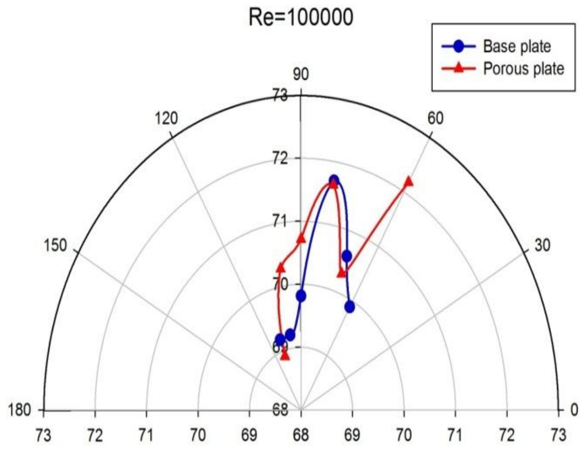
Figure 5:Variation of OASPL with Raynolds Number at 90^0 polar angle.

3.2 Directivity Plots

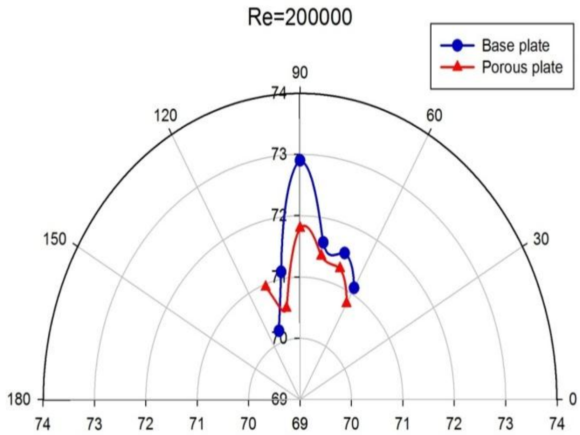
The directivity of the noise radiated from the trailing edge were plotted. The OASPL at different polar angles from 60^0 to 110^0 upstream of the trailing edge, at different Reynolds Numbers are shown in the figure 6 (a)-(d). At low Reynolds Numbers the number of lobes in the directivity patterns is more and as Reynolds number increases the number of lobes is reduced. Since the acoustic sources are distributed as elementary acoustic sources in the flat plate with pores, which gives more lobes in the directivity pattern. But at high Reynolds Numbers the number of lobes is reduced and the radiation pattern resembles to a single dipole source. In the range of Reynolds Numbers $0.5x10^5$ to $1x10^5$ OASPL is located towards the downstream side and at Re $2x10^5$ the more noise is radiated in the direction perpendicular to the TE. At Re $4x10^5$ it is observed that more noise is radiated in the upstream direction than in the downstream direction.



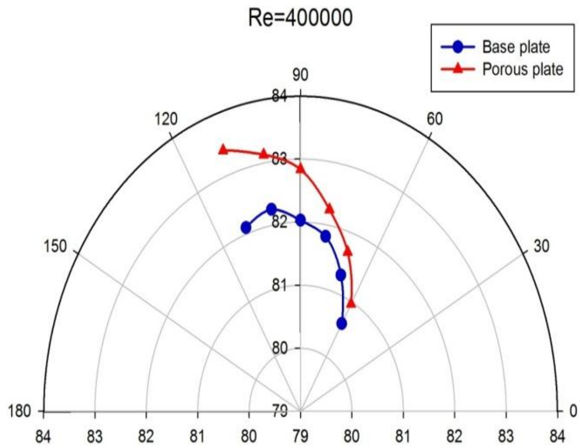
(a)



(b)



(c)



(d)

Figure 6: Polar directivity Plots at (a) Re $0.5x10^5$ (b) Re $1x10^5$ (c) Re $2x10^5$ (d) $4x10^5$

4. Conclusion

This paper has presented the experimental investigations of noise radiated from a sharp trailing edge with pores and without pores at low to moderate Reynolds numbers (based on chord), ranging from $0.5x10^5$ to $4x10^5$ and at zero angle of attack. It is shown that the 3mm diameter pores provided near to the trailing edge is not advisable in the acoustic point of view at high Reynolds Number. For Reynolds Numbers between $1.5x10^5$ to $2.8x10^5$ slight reductions in OASPL is observed. By changing the pore diameter and position with TE, better acoustic characterisation can be expected. This work can also be extended to examine the effect of holes in the aero acoustic performance of flat plate aerofoil at different angle of attack.

Acknowledgements

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