IN-FLIGHT PANEL NOISE CONTRIBUTION ANALYSIS ON A HELICOPTER

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Abstract

PU sound probes offer a new and versatile solution to assess cabin interior noise during true operating conditions, allowing ultimately an in-flight panel noise contribution analysis to be made for various listeners' position in an aircraft vehicle. With the Microflown sensor, acoustic particle velocity has become a measurable quantity. Close to a vibrating surface acoustic particle velocity is a direct measure for the normal structural velocity as it is usually measured with an accelerometer. In a so called PU probe, a Microflown sensor is combined with a sound pressure transducer. Such a PU probes allows sound intensity measurements that are not hampered by the pressure/intensity index that limits the use of sheer sound pressure based sound intensity measurements. A larger number of these probes, a so called PU array, allows for relatively uncomplicated in-flight panel noise contribution analysis in a cabin that is normally governed by a high pressure/intensity index.
This was demonstrated in a PZL Swidnik helicopter in the summer of 2008 using a large PU probe array as will be explained.

1. INTRODUCTION AND AIM OF THE STUDY

There exist a number of different types of experimental approaches for sound source localisation and panel noise contribution analysis in vehicles. The aim is always to detect the acoustically weak part of the vehicles in order to introduce appropriate counter measures. Acoustically weak parts could be relevant or not depending on the specific driving condition considered. In that sense, it is of benefit to select a method for acoustical investigation that allows for a free choice of relevant driving conditions.

The most direct way for an automotive vehicle of course is driving the vehicle on the road. But reproducibility is also of major concern especially if an acoustical optimisation treatment has to be verified quantitatively. Therefore, measurements on test benches are often the best way to ensure reproducibility even though not all relevant driving conditions may be realised properly. The most appropriate measurement approach would be the one that allows for an arbitrary choice of driving condition without any restrictions to stationary excitations, indoor use, limited frequency ranges, etc.

Certain measurement techniques exhibit specific strengths and weaknesses. Commonly used methods are window-based techniques [1, 2], intensity measure-ments [3], laser-scanning-vibrometry measurements [4], beam forming [5] and holographic technologies [6] using large sensor arrays.

In addition to these widely used methods, the panel noise contribution analysis method based on Microflown PU-sensor arrays [7] might be considered as a better alternative. These sensors allow the direct measurement of the airborne noise particle-velocity. In conjunction with a pressure microphone a sound wave is then fully determined at a certain point in space. Especially for sound source localisation inside vehicles, the application of these sensors shows benefits compared to other techniques [8].

The Panel Noise Contribution Analysis method using Microflown PU-sensor arrays has been successfully applied many times since the year 2004. During that time the method has been used mainly for automotive applications. Interestingly, it has never been used for aerospace applications so far. In that sense the Panel Noise Contribution Analysis on a helicopter might be considered as a new step towards this direction and opens up a new field of application. Especially the demands on the equipment in terms of robustness and reliability are much higher compared to conventional automotive situations. Since the flight time is limited and therefore very precious it is also very important to work with measurement tools that are reliable, stable and work even under extreme conditions.

Given that the level of structural vibration and noise during flight is extremely high the measurement inside a helicopter sets new demands regarding robustness of the measurement equipment.

The aim of this project was to analyze in detail the single panel noise contributions of the interior cabin of the Swidnik W3 helicopter during flight for various flight conditions. In total 23 flight conditions have been recorded. About 180 single panel contributions have been measured for each flight condition. All measurements were taken on the testing ground of PZL Swidnik S.A. in Swidnik, Poland in June 2008.

The following sections show the experimental set up, the in-flight measurements and the gained results.

2. MEASUREMENT SET UP

2.1. Definition of the measurement grid

In total 45 PU sensors were available for testing. Since the interior cabin of the helicopter was too large in order to be covered with this amount of sensors it was necessary to split the interior surface of the helicopter compartment into four distinct areas and to run for each area an independent measurement.

The compartment was split into the bottom plate, the right side, left side and the roof panel. The sensors were spread as uniformly as possible to yield a well balanced measurement grid. The distance between each sensor position was approximately 30 cm.

In total four times 45 sensors were applied which leads to a spatial resolution of 180 individual panel contributions in total. The following pictures show the four different surface areas:

FIG. 1. 45 Sensors applied on the roof

FIG. 2. 45 Sensors applied on the bottom

FIG. 3. 45 Sensors applied on left side of the helicopter compartment (same for right side)

2.2. Installation of the PU-array

The sensors were not directly mounted onto the surfaces but were kept in a special mounting device instead. The reason for this approach can be explained as follows:

Assuming the sensor would have been directly attached to the vibrating surface the element would only follow the vibration of the panel. In that sense the sensor would move in the same way as the emitted sound wave does.

Therefore the sensor would underestimate the real particle velocity. The correct way is to decouple the sensor from the vibrating surface. This is the only way to ensure that the Microflown sensor measures the right particle velocity. Figure 4 and 5 show the decoupling device in detail.

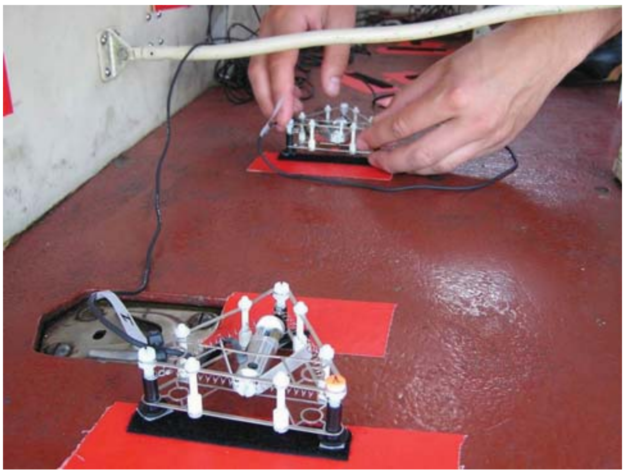

FIG. 4. Microflown PU sensors decoupled form the vibrating structure

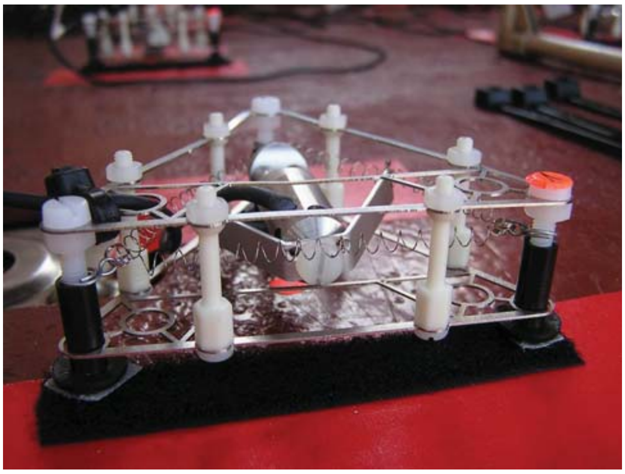

FIG. 5. Mounting device to ensure proper decoupling from the surface

2.3. Flight conditions

The following flight conditions were chosen:

Number	Flight Profile
1	Ground Idle
2	Engine Power Set to Flight
3	Hover 3-5 m
4	Level flight, Vias=20km/h, Hstd=5 m
5	Climb (max Cont Power), Vias=130 km/h
6	Descent 3m/s, Vias=130 km/h
7	Climb (Take-Off Power), Vias=130 km/h
8	Level flight, Vias=60 km/h, Hstd=1000 m
9	Level flight, Vias=80 km/h, Hstd=1000 m
10	Level flight, Vias=100 km/h, Hstd=1000 m
11	Level flight, Vias=120 km/h, Hstd=1000 m
12	Level flight, Vias=140 km/h, Hstd=1000 m
13	Level flight, Vias=160 km/h, Hstd=1000 m
14	Level flight, Vias=180 km/h, Hstd=1000 m
15	Level flight, Vias=200 km/h, Hstd=1000 m
16	Level flight, Vias=220 km/h, Hstd=1000 m
17	Level flight, Vias=240 km/h, Hstd=1000 m
18	Left turn, Vias=130 km/h, roll 30°
19	Right turn, Vias=130 km/h, roll 30°
20	Left slip 10°, Vias=130 km/h
21	Right slip 10°, Vias=130 km/h
22	Autorotation, Vias=130 km/h
23	Descent 6 m/s, Vias=130 km/h

TAB 1. Flight conditions

Unfortunately, not all of these flight conditions could have been used for analysis. Only 16 out 23 were usable. Since the storage of each flight profile measurement during flight in a separate time file would have taken too long the recording of the whole flight was taken in once and stored in only one single time file. Therefore, each flight profile had to be identified by its recording time afterwards. The recording time for each condition has been captured separately but unfortunately some time allocations could not be recovered thus some flight conditions were lost.

3. PERFORMED MEASUREMENTS

3.1. In-flight measurements

The in-flight measurements on the helicopter type W3 took place on the testing ground of Swidnik S.A. in Swidnik, Poland.

As described in section 2.1 the total amount of Microflown PU sensors was not sufficient to cover the whole interior surface of the helicopter compartment in one step. According to the splitting of the surface into four separate sub-surfaces also four independent test flights had to be made. For each flight all 23 flight profiles were performed and the data recorded. The approximate time for each flight session was about 30 minutes. The overall flight time for all four flights was approximately 2 hours in total.

The crew consisted of a pilot (Swidnik), a copilot (Swidnik), a guide (Swidnik) to take care of the communication and two test engineers (Microflown) taking care of the measurements.
The picture shows the take-off of the helicopter with the testing crew on board.

FIG. 6. Helicopter take-off for in-flight measurement

3.2. Airborne noise transfer functions

During the in-flight tests the particle velocity of the radiated sound waves have been measured. These particle velocity data quantify the radiated sound from those panels where the PU sensors were attached to. Anyhow, in order to predict the sound pressure level at a certain point inside the helicopter compartment, e.g. the listener position, it is necessary to include also the path the sound wave has to travel from the noise source (panel) to the listener ear. This approach is quite common in automotive applications. Anyway, for a helicopter it does not have the same importance. Especially for helicopters having a large passenger compartment it is not really meaningful to pinpoint to only one selected single listener position. The compartment of this helicopter could carry up to 12 people and there is basically no preference listener position.

Anyway, the airborne noise transfer functions have been measured for the sake of completeness. But they have not been used for the evaluation and the display of the panel noise contributions. The principle of measuring the air borne noise transfer functions that has been used here is based on the so called reciprocity principle. This principle states that the way the sound takes from a source to a receiver point can be inverted. This means that interchanging the source and the receiver would lead to the identical transfer functions. In that sense it is possible to install a loudspeaker at the listener position and measure the sound pressure level at the panels of the compartment. The measured transfer functions that have been measured in this way are then identical to the transfer functions from the panel to the receiver ear.

The sound source to be used should have the radiation pattern of a point source. It consists of a driver and a tube. The tube contains also a Microflown sensor for calibration purposes. The Microflown sound source can be applied from appr. 200 Hz to 6 kHz (figure 7).

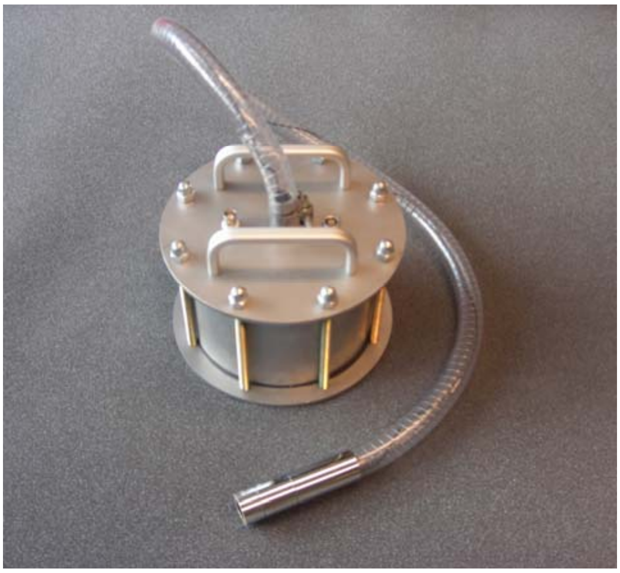

FIG. 7. Microflown reciprocal sound source

For the measurement of the airborne noise transfer functions the sound source has been installed close to the wall on the right side of the helicopter compartment as depicted in figure 8.

FIG. 8. Measurement of the airborne noise transfer functions

3.3. 3D geometry model creation

A good way to display the measured panel noise contributions in an intuitive way is to use a 3D model of the compartment and combine the geometry data with the acoustic data. The x, y, z coordinates of the interior cabin have been measured using the Microflown 3D geometry measuring unit.

This unit consists basically of an arm with several sections and joints that ensure full rotation and maximum flexibility. The picture shows the measurement arm in action. The acquisition software leads the user through the whole procedure and captures the geometry data

FIG. 9. Microflown 3D geometry measuring unit inside helicopter compartment

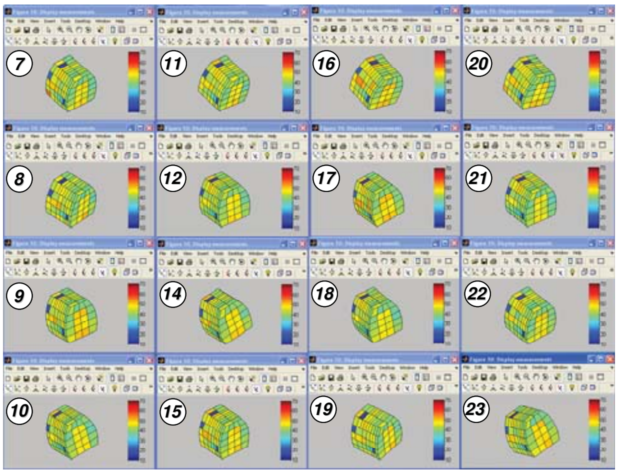

FIG. 10. Averaged spectrum back view

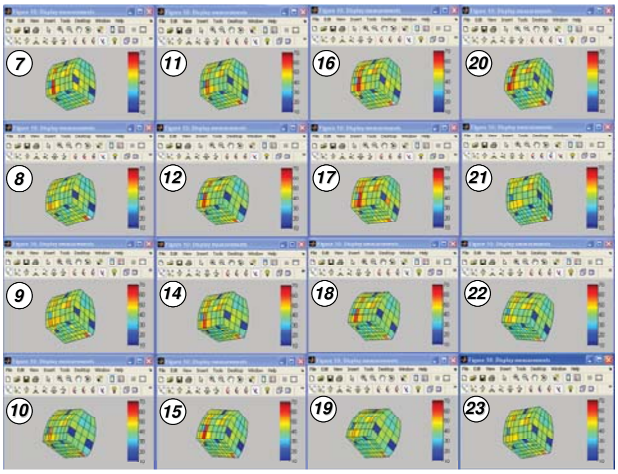

FIG. 11. Averaged spectrum front view

4. RESULTS

4.1. Average contribution overview

The following pictures show the panel contributions of the helicopter compartment in terms of overall level. Figure 10 shows the back view of the 3D model.

Back view means looking in flight direction from above (from the back side to the cockpit). Figure 11 shows the front view. This perspective is looking from underneath in opposite direction of flight (from cockpit to the passenger compartment). The numbers inside each graph represent the corresponding flight profile.

As can be seen from the figures the sound patterns for each flight condition do not differ significantly from each other. They show almost the same results.

One should keep in mind that this display only shows the averaged level over all frequencies. The dependency on flight profile is more significant for single frequency components (see 4.2). In order to find out what frequency component might contribute most only one flight conditions has been selected for further analysis.

4.2. Spectral contribution overview

The result of the comparison of flight condition with respect to frequency averaged level shows that all flight conditions behave in a similar way.

In order to indentify the most critical 3rd octave bands it is sufficient to pick one state as an example and display all 3rd octaves for the front and back view. In this case state number 9 has been selected for further analysis.

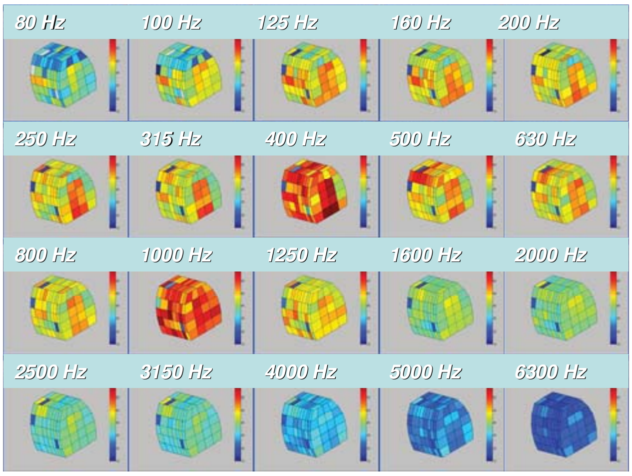

FIG. 12. Spectral contribution back view

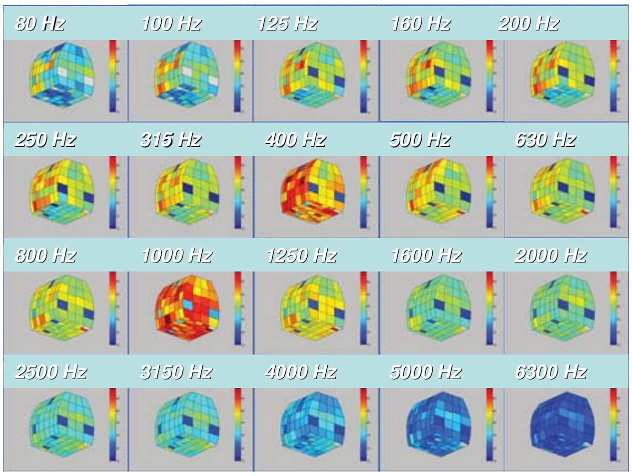

FIG. 13. Spectral contribution front view

Both views show a strong dependence of panel noise contribution on frequency. This overview shows that the most contributing 3rd octave bands are around 400 Hz and 1000 Hz. The rectangular pattern for the back view that shows up especially from 125 Hz to 800 Hz can be identified as the service door in the rear of the compartment. This seems to be an acoustically weak part.

The following detailed view shows now again all flight conditions for the most important 3rd octave bands which are 400 Hz and 1000 Hz.

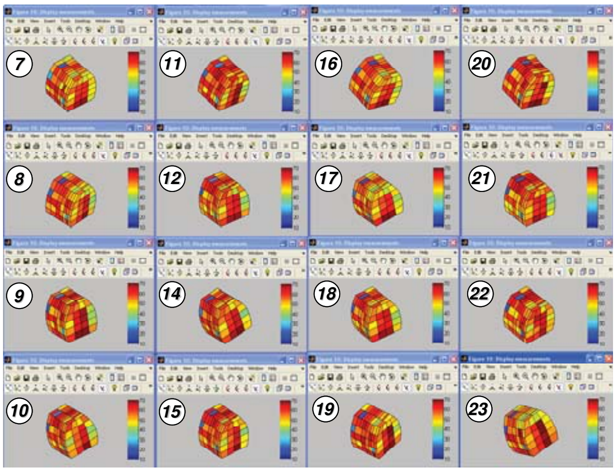

FIG. 14. 400 Hz back view

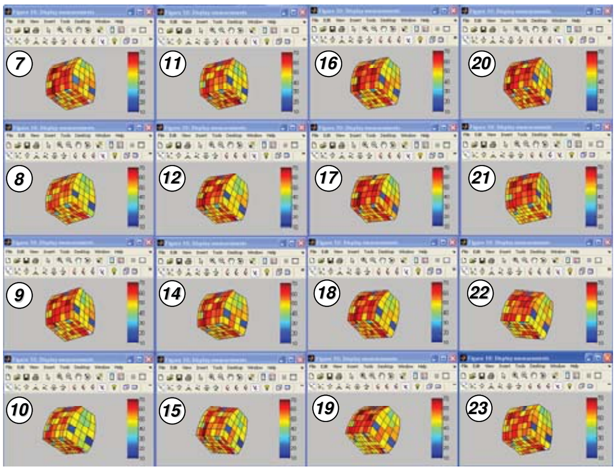

FIG. 15. 400 Hz front view

It is striking that at 400 Hz the back surface (service door) seems to contribute more than the front surface (pathway to the cockpit) no matter what flight condition is applied.

The roof seems to contribute less than the back surface. This is not naturally expected since the engine is supposed to excite the roof rather than the back surface. The floor contributes less than the side surfaces. The front surface contributes less than the floor.

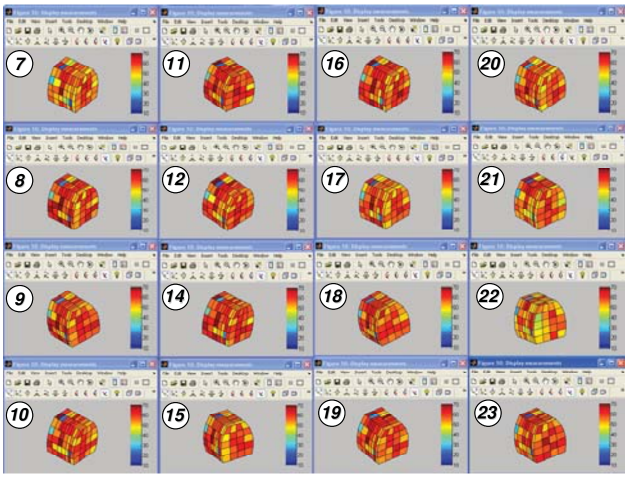

FIG. 16. 1000 Hz back view

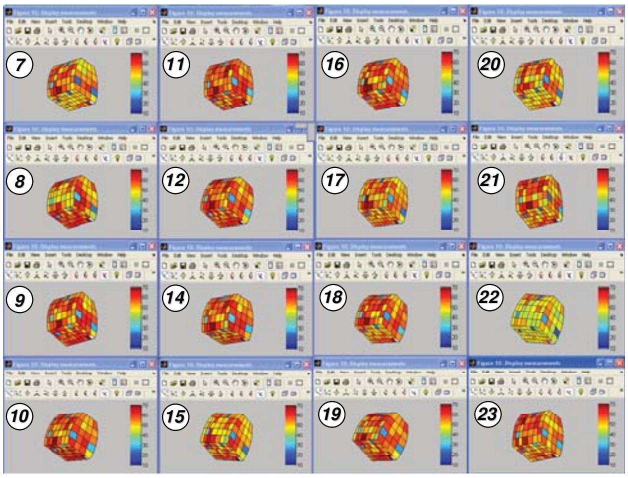

FIG. 17. 1000 Hz back view

At 1000 Hz the highest contribution can be found for all surfaces. Anyway, a clearly defined pattern of the service door like in the previous cases cannot be seen here. The back surface yields a similar contribution like all other surfaces. The contributions seem to be more or less equally spread all over the entire cabin surfaces.

A main difference compared to other 3rd octave bands is especially the strong dependency on the flight condition. The highest influence can be found for the flight state 22. The front view shows a much lower contribution than the back view. The whole cabin seems to be non-symmetrically excited.

It is also interesting to look at the state 8. The front view shows a low contribution for the lower part of the side surface. The opposite side shows a much higher contribution instead. Also here we have a non-symmetrical contribution pattern. Similar behavior can be noticed for state 9 and 15 as well.

Each state 7, 20 and 22 has a lower contribution on the floor panel compared to other surfaces.

5. CONCLUSIONS

A full panel noise contribution analysis has been carried out for the first time on a helicopter during flight. The high noise and vibration level of the helicopter compared to conventional automotive vehicles has proven the robustness of the testing equipment. Altogether 23 different flight conditions have been measured but only 16 of them could be used for analysis.

Anyway, the analysis has shown that the patterns of the panel contributions do not always depend strongly on the selected flight profile. Significant dependencies were only seen for the 1 kHz octave case. In that sense the overall results and graphs might be more or less valid also for those conditions that could not be evaluated within this study.

The main outcome of the study is the result that the helicopter compartment shows high level contributions especially for the 400 Hz and 1 kHz third octave. It could also be seen that especially at 1 kHz the whole cabin seems to contribute to the noise and it does not matter if the panels are close or far away from the helicopter engine on top of the roof (main sound source). This result was not expected at the beginning.

Between 125 Hz to 800 Hz the service door on the rear side of the compartment seems to be a strong contributor to the interior noise. Acoustic counter measures could probably be effective here.

Hereby, we would like to thank Swidnik S.A. and especially Andrzej Niewiadomski and his team for the opportunity to carry out this study, the very good support, the nice working atmosphere and the very pleasant time we could spend together at Swidnik.

FIG. 18. Testing crew (from left to right): Oliver Wolff, Hans-Elias deBree, Jordy deBoer, Wilfred Hake

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