Simulation and Analysis of Civil Aircraft Cabin Sound Field and STI based on Wave6

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Abstract. The cabin loudspeakers of civil aircraft are very important equipment of passenger address system, and the layout scheme of cabin loudspeaker is one of the important factors affecting the audio quality of passenger address system. In the preliminary design stage of passenger address system, the simulation of sound field and STI of cabin loudspeaker by simulation tools is an important means to study, predict, demonstrate and judge the quality of cabin sound field. In this paper, we adopt an equal straight section of a civil aircraft model which is a twin-aisle wide body with a typical three classes, and simulate and compare the sound field distribution and STI of the main areas of the cabin through Wave6 simulation tool based on two different loudspeakers layout schemes, so as to give the recommended layout scheme of the cabin loudspeakers.

Keywords: Civil Aircraft; Cabin Sound Field; STI; Simulation.

1. Introduction

The cabin loudspeakers of civil aircraft are very important equipment of passenger address system, and all of the on-board passenger address audio messages are broadcasted by the cabin loudspeakers. CCAR25.1423 clearly requires that the audio of the passenger address system should be intelligible at all passenger seats, lavatories, and flight attendant seats and work station [1]. It requires the applicant to fully study, predict, demonstrate and judge the design and layout of the cabin loudspeakers when designing the passenger address system in order to ensure the audio quality of the passenger announcement system. The cabin loudspeakers need to meet the minimum performance requirements and related test conditions specified in RTCA DO-214 when designing [2], and should also meet the environmental requirements specified in RTCA DO-160G [3], and the cabin loudspeakers which meet the CTSO-C139a standard are recommended [4]. In current, the mainstream cabin loudspeakers layout scheme of twin-aisle wide-body aircraft has two solutions, one is arranged above the ceiling at the top of the cabin aisle, and the other is arranged above the PSU above the passenger seats. Simulation of the civil aircraft cabin sound field environment in the design phase is an important tool to study, predict, demonstrate and judge the quality and comfort of the aircraft cabin sound field [5]. Therefore, in this paper, we adopt an equal straight section of a civil aircraft model which is a twin-aisle wide body with a typical three classes to simulate and compare the sound field distribution and STI in the main areas of the cabin by Wave6 simulation tool based on the two cabin loudspeakers layout schemes mentioned above, in order to give the recommended cabin loudspeakers layout scheme.

2. Simulation Inputs and Constraints

2.1 Cabin Environment Model Selection

This simulation adopts an equal straight section of a civil aircraft model which is a twin-aisle wide body with a typical three classes to simulate and compare the sound field distribution and STI in the main areas of the cabin.

2.2 Loudspeakers Selection

The loudspeakers of this simulation adopt the point sound source model, and the point sound source ratio spectrum is defined according to engineering experience, as shown in Table 1.

Table 1. Loudspeakers point sound source ratio spectrum

No.	Frequency (Hz)	SPL-1(dB)	SPL-2(dB)
1	125	55	60
2	250	60	65
3	500	65	70
4	1000	75	80
5	2000	75	80
6	4000	72	77
7	8000	70	75

2.3 Preliminary Location Selection of Cabin Loudspeakers

Based on the cabin loudspeakers layout schemes of mainstream twin-aisle wide-body aircraft, two layout schemes are developed for simulation as follows.

1) Scheme 1, the loudspeakers are arranged equally spaced above the ceilings at the top of the left and right aisles, as shown in Figure 1, and there are total of 10 loudspeakers are arranged in this equal straight section of the twin-aisle wide-body aircraft, and each loudspeaker is used as a point sound source in Wave6 software, and the specific coordinates of the point sound source are shown in Table 2.

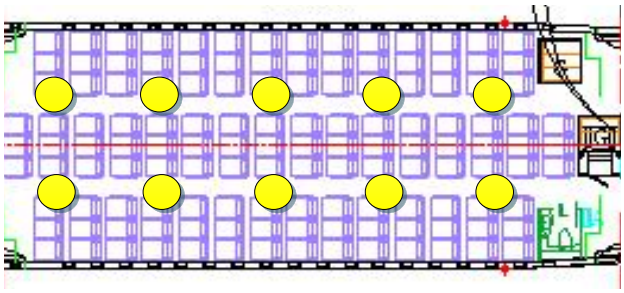


Figure 1. The Layout of the loudspeakers in scheme 1

Table 2. The coordinates of the point sound source of the loudspeakers in scheme 1

No.	X(m)	Y(m)	Z(m)	No.	X(m)	Y(m)	Z(m)
1	19.5	1.85	-1	6	19.5	1.85	1
2	22	1.85	-1	7	22	1.85	1
3	24.5	1.85	-1	8	24.5	1.85	1
4	27	1.85	-1	9	27	1.85	1
5	29.5	1.85	-1	10	29.5	1.85	1

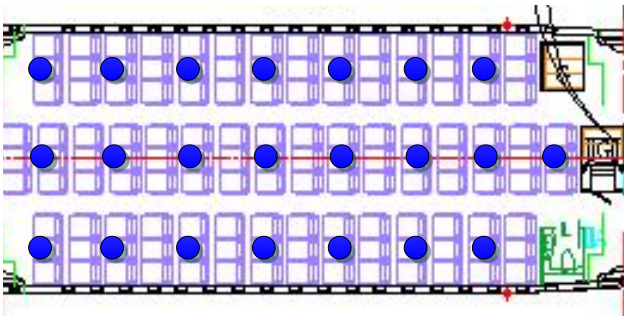


Figure 2. The Layout of the loudspeakers in scheme 2

2) Scheme 2, the loudspeakers are arranged equally spaced above the left, middle, right of the PSUs at the top of passenger seats, as shown in Figure 2, and there are total of 22 loudspeakers are arranged in this equal straight section of the twin-aisle wide-body aircraft, and each loudspeaker is used as a point sound source in Wave6 software, and the specific coordinates of the point sound source are shown in Table 3.

Table 3. The coordinates of the point sound source of the loudspeakers in scheme 2

No.	X(m)	Y(m)	Z(m)	No.	X(m)	Y(m)	Z(m)
1	19.2	1.1	-2.1	12	27.1	1.1	2.1
2	21.2	1.1	-2.1	13	29.1	1.1	2.1
3	23.2	1.1	-2.1	14	31.1	1.1	2.1
4	25.1	1.1	-2.1	15	19.2	1.3	0
5	27.1	1.1	-2.1	16	21.2	1.3	0
6	29.1	1.1	-2.1	17	23.2	1.3	0
7	31.1	1.1	-2.1	18	25.1	1.3	0
8	19.2	1.1	2.1	19	27.1	1.3	0
9	21.2	1.1	2.1	20	29.1	1.3	0
10	23.2	1.1	2.1	21	31.1	1.3	0
11	25.1	1.1	2.1	22	33.1	1.3	0

2.4 Grid Selection of Field Points

The grid of the field points for this simulation is selected on the graphic which is parallel to the floor and coinciding with the median line of the passenger windows of the aircraft.

2.5 The Cabin Noise Ratio Spectrum

The design requirements for cabin noise during the cruise phase of the aircraft are: the overall sound pressure level (OASPL) of cabin noise in the first 50% of cabin area shall not exceed 75 dBA, and the OASPL of cabin noise in the middle and rear cabin area shall not exceed 79 dBA. According to the above cabin noise design requirements, the noise ratio spectrum is constructed, as shown in Figure 3.

	ANSI standard octave bands (banc	29126 (Pa)	29127 (Pa)	29128 (Pa)	29129 (Pa)	29130 (Pa)	29131 (Pa)
1	125	0.0182601	0.0182601	0.0182601	0.0182601	0.0182601	0.0182601
2	250	0.02582368	0.02582368	0.02582368	0.02582368	0.02582368	0.02582368
3	500	0.03646886	0.03646886	0.03646886	0.03646886	0.03646886	0.03646886
4	1000	0.05157476	0.05157476	0.05157476	0.05157476	0.05157476	0.05157476
5	2000	0.07293773	0.07293773	0.07293773	0.07293773	0.07293773	0.07293773
6	4000	0.1031495	0.1031495	0.1031495	0.1031495	0.1031495	0.1031495
7	8000	0.1458755	0.1458755	0.1458755	0.1458755	0.1458755	0.1458755

Figure 3. The cabin noise ratio spectrum

3. Simulation Process

3.1 Importing Cabin Environment Data

Import the cabin environment data model and create the operation object as shown in Figure 4.

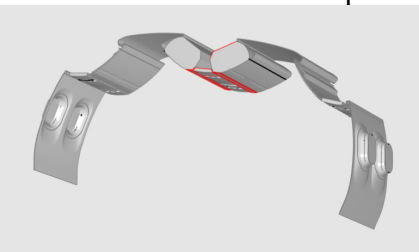


Figure 4. The cabin environment data model

3.2 Define 3D SEA Subsystem

The process of defining the 3D SEA subsystem is as follows.
1) Create the passenger cabin volume.
2) Create the mesh control points and create the mesh (surface mesh from volume).
3) Create the 3D SEA subsystem and define the attributes.
4) Define the field point mesh and add it to the subsystem.
The defined cabin environment mesh is shown in Figure 5.

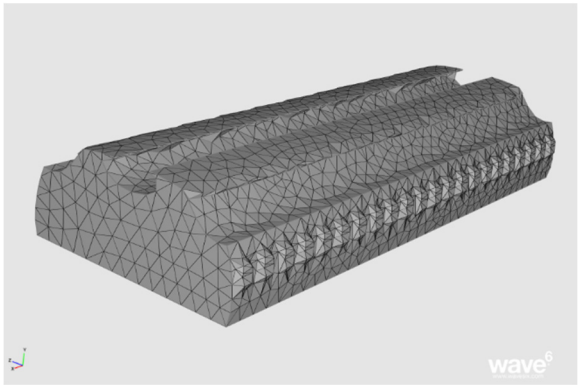


Figure 5. The defined cabin environment mesh

3.3 Define 2D SEA Subsystem

The process of 2D SEA subsystem definition is as follows.
1) Extracting the interior surfaces.
2) Define the sound absorption ratio spectrum.
3) Create the 2D SEA subsystem and define the attributes.

3.4 Define the Loudspeaker Point Sound Source

The process of define the loudspeaker point sound source is as follows.
1) Create the point geometry in the Parts module based on the location coordinates of the loudspeaker.
2) Select three points in a graphic and create the coordinate system.
3) Create the loudspeaker point sound source.
4) Create the grid of the loudspeaker point sound source.

3.5 Defining Load Cases

The Load Cases definition process is as follows.
1) Define the excitation of the loudspeaker sound field cases (point load, Ft, frequency domain).
2) Define the excitation of the transient decay cases (point load, Ft, time domain).

3.6 Define the Connections between Subsystems, Load Cases and Each Other

The process of define the connections between subsystems, load cases and each other is as follows.
1) Define the connection between the cabin environment and the interior.
2) Define the connections between point load cases and point sound sources.
3) Define the connection areas between the point sound sources and the cabin environment.
4) Define the links between the point sound sources and the link area of the cabin environment.

3.7 Solution Calculation

1) Define the 3D SEA output parameters.
2) Define the load cases output parameters.
3) Run the loudspeaker sound field distribution simulation (Stationary, frequency domain).

4) Run the loudspeaker sound field transient decay distribution simulation (Time_Shock, time domain).

5) Run the STI simulation.

4. Data Analysis

4.1 Scheme 1 Data Analysis

With the point sound source ratio spectrum SPL-1 in Table 1 as input, the sound field simulation results and the STI simulation results of scheme 1 are shown in Figure 6 and the data analysis is as follows.

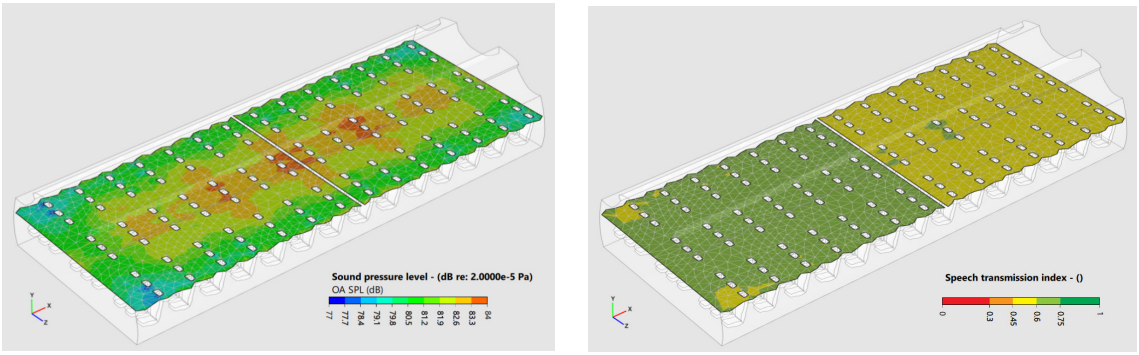
1) The SPL at the aisle where the loudspeakers are installed is significantly high, about 82dB, and the SPL difference between the front row seats and the rear row seats is about 2dB due to one loudspeaker for every three rows of seats.

2) The SPL at the seats on the left and right sides, the head row and tail row of the cabin is significantly lower than the SPL near the aisle where the loudspeakers are installed, with a difference of about 2dB.

3) The STI of the front section of the cabin is significantly higher than the STI of the aft section of the cabin, which is considered to be caused by the different noise.

4) The STI of the front section of the cabin is mostly between 0.6 and 0.75, with good sound field distribution.

5) The STI of the aft section of the cabin is mostly between 0.45 and 0.6, with poor sound field distribution.



(a)Sound field simulation results-(SPL-1) (b)STI simulation results-(SPL-1)

Figure 6. The simulation results of scheme 1 with SPL-1 as input

With the point sound source ratio spectrum SPL-2 in Table 1 as input, the sound field simulation results and the STI simulation results of scheme 1 are shown in Figure 7 and the data analysis is as follows.

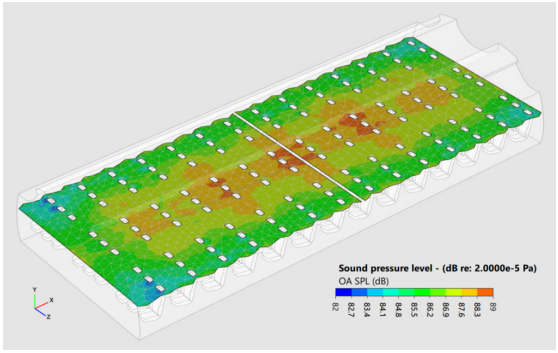
1) The SPL at the aisle where the loudspeakers are installed is significantly high, about 86dB, and the SPL difference between the front row seats and the rear row seats is about 2dB due to one loudspeaker for every three rows of seats.

2) The SPL at the seats on the left and right sides, the head row and tail row of the cabin is significantly lower than the SPL near the aisle where the loudspeakers are installed, with a difference of about 2dB.

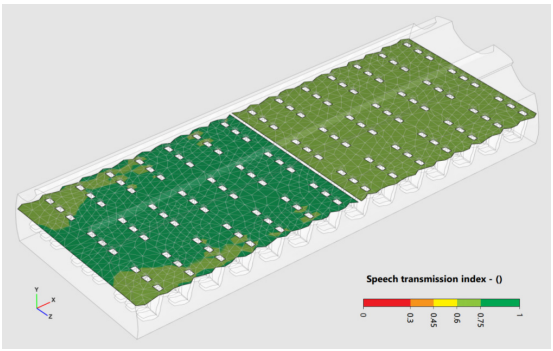
3) The STI of the front section of the cabin is significantly higher than the STI of the aft section of the cabin, which is considered to be caused by the different noise.

4) The STI of the front section of the cabin is mostly between 0.75 and 1, with excellent sound field distribution.

5) The STI of the aft section of the cabin is mostly between 0.6 and 0.75, with good sound field distribution.



(a)Sound field simulation results-(SPL-2)



(b)STI simulation results-(SPL-2)

Figure 7. The simulation results of scheme 1 with SPL-2 as input

4.2 Scheme 2 Data Analysis

With the point sound source ratio spectrum SPL-1 in Table 1 as input, the sound field simulation results and the STI simulation results of scheme 2 are shown in Figure 8 and the data analysis is as follows.

1) The SPL at the seats where the loudspeakers are installed nearby is significantly high, about 88dB, and the difference SPL between the front row seats and the rear row seats is about 3dB due to one loudspeaker per two rows seats.

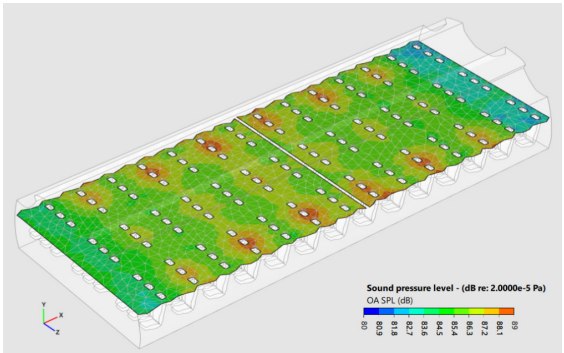
2) The SPL at the aisle of the cabin is significantly lower than the SPL at the seats, with a difference of about 3dB.

3) The SPL at the first and last rows of seats in the cabin is significantly lower than other places, with a difference of about 5dB, which is considered to be due to the distance from the nearest loudspeakers and no sound field superposition.

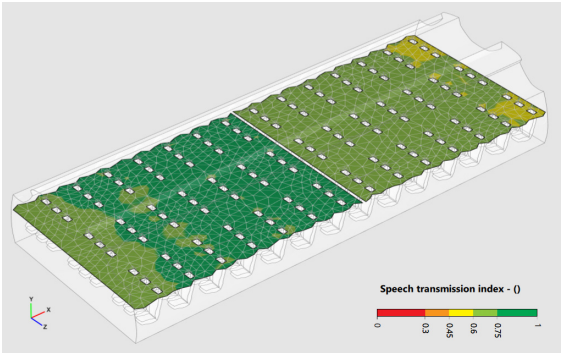
4) The STI of the front section of the cabin is significantly higher than the STI of the aft section of the cabin, which is considered to be caused by the different noise.

5) the STI of the front section of the cabin is mostly between 0.75 and 1, with a excellent sound field distribution.

6) The STI of the aft section of the cabin is mostly between 0.6 and 0.75, with a good sound field distribution.



(a)Sound field simulation results-(SPL-1)



(b)STI simulation results-(SPL-2)

Figure 8. The simulation results of scheme 2 with SPL-1 as input

With the point sound source ratio spectrum SPL-2 in Table 1 as input, the sound field simulation results and the STI simulation results of scheme 2 are shown in Figure 9 and the data analysis is as follows.

1) The SPL at the seats where the loudspeakers are installed nearby is significantly high, about 93dB, and the difference SPL between the front row seats and the rear row seats is about 3dB due to one loudspeaker per two rows seats.

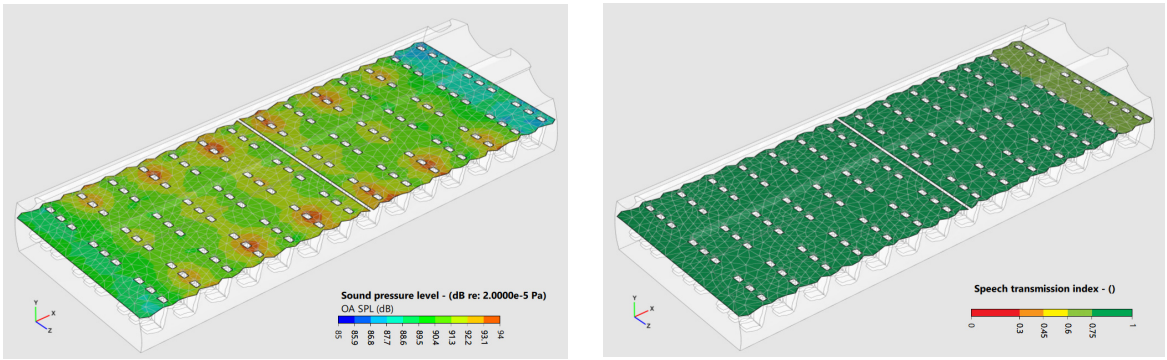
2) The SPL at the aisle of the cabin is significantly lower than the SPL at the seats, with a difference of about 3dB.

3) The SPL at the first and last rows of seats in the cabin is significantly lower than other places, with a difference of about 5dB, which is considered to be due to the distance from the nearest loudspeakers and no sound field superposition.

4) The STI of the front section of the cabin is significantly higher than the STI of the aft section of the cabin, which is considered to be caused by the different noise.

5) the STI of the front section of the cabin is mostly between 0.75 and 1, with an excellent sound field distribution.

6) The STI of the aft section of the cabin is mostly between 0.6 and 0.75, with a good sound field distribution.



(a) Sound field simulation results-(SPL-2) (b)STI simulation results-(SPL-2)

Figure 9. The simulation results of scheme 2 with SPL-2 as input

5. Conclusion

The simulation analysis of the sound field distribution and STI of the two loudspeakers layout schemes was carried out, and according to the simulation analysis, it is recommended to choose scheme 2 as the loudspeaker's layout scheme. If scheme 1 is chosen, in order to achieve the sound field distribution and STI results basically consistent with scheme 2, the average SPL of the loudspeakers in scheme1 shall be significantly higher than that of scheme 2.

The simulation results of sound field distribution and STI can be made more accurate by optimizing the point source ratio spectrum, grid model granularity, interior absorption ratio spectrum and noise ratio spectrum later.

Meanwhile, it is suggested to verify the accuracy of this simulation method by comparing the simulation data with the actual measurement data on board later.

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