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An Investigation of Noise Reduction for the 3BB Nozzle With a Pylon Using External Flaps

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July 2008

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Summary

Flaps (or half wedges) attached to the sides of a pylon are shown to result in a small but clear noise benefit. Noise radiated towards the ground is reduced apparently through a deflection and thickening of the fan stream underneath. Based on results from the current as well as concurrent investigations at the University of California at Irvine (UCI), it is recommended that further tests in a larger facility simulating realistic engine conditions be considered.

Introduction

An experimental investigation was conducted exploring noise reduction with a separate flow nozzle fitted with a pylon. The concept follows earlier findings on noise reduction at the University of California at Irvine (UCI) by the use of fan flow deflectors in the form of wedges (ref. 1). In the latter investigation, wedges were placed on the outer surface of the primary nozzle and near the fan nozzle exit in order to deflect the fan stream sideways and downward. This resulted in a thicker fan stream underneath. Smaller velocity gradients, and hence less turbulence, occurring in the thicker stream resulted in less noise radiated downward. An aircraft engine, however, also involves a pylon structure that supports the engine from the airframe. A part of the pylon extends into the fan stream like a wedge. Thus, the exploration of the noise reduction by the technique under consideration is incomplete unless the pylon structure is also considered. This provided a motivation for the present investigation which was conducted in complement of continuing noise reduction efforts at UCI involving similar considerations and hardware (ref. 2).

Experimental Set-up

The experiments were conducted in a coannular jet facility at NASA Glenn Research Center (GRC) (ref. 3). A separate flow nozzle mimicking the geometry of the “3BB” configuration, having a nominal bypass ratio of 5, was used. Models of this nozzle were used earlier in experiments at UCI as well as GRC for studying the fan flow deflection concept (ref. 4). A picture of the facility is shown in figure 1(a) while figure 1(b) shows the contours of the nozzle. The primary (“core”) nozzle is connected directly to the 30 in. diameter main plenum chamber. Another annular plenum chamber, located just upstream of the nozzles, provides the secondary (“fan”) flow. The experiment involved cold flow, i.e., the total temperature was the same everywhere as in the ambient. All data pertain to “static test”, i.e., without any surrounding co-flow.

Figure 2 shows various nozzle components and their configurations. The nozzle fitted with the pylon is shown in figure 2(a). The pylon, designed to have minimal interference with the primary flow, [Harry Haskins, NASA Langley Research Center (LaRC), private communication], is attached to the outer surface of the core nozzle. (In the present experiment the pylon was attached underneath while the noise was measured above.) The pylon details are shown by the computer-aided design (CAD) drawing in figure 2(b). Note that a part of the pylon is the “internal wedge” that sits inside the fan duct. The internal wedge was designed according to guidelines previously followed at LaRC, also adopted in the UCI experiment (ref. 2). The top and bottom surfaces matched the contours of the nozzle walls while the side walls were such as to make the flowlines parallel at the nozzle exit. The internal wedge was detachable from the pylon so that the effect produced by it alone could be studied and compared with the net effect of the entire pylon structure.

The external flaps, also seen in figure 2(b), were detachable and simply glued to the sides of the pylon when needed. The main aim of the present study was to investigate the influence of the flaps on the noise field. Figure 2(c) shows an end view of the nozzle fitted with the pylon and the pair of flaps. Each flap has an angle of divergence of 15°. The thin upstream edge of a flap is located just downstream of the fan nozzle exit, thus, the deflection of the fan stream ensues after it has exited from the fan nozzle. The upper edges of the flaps were designed to match the contour of the core nozzle. Figure 2(d) shows a side view of the same configuration. In this picture, the abrupt ends of the flaps were smoothed with a filler material. It was found that this modification alleviated some high-frequency noise degradation otherwise occurring at locations perpendicular to the jet axis. For brevity, only data with flaps having smoothed ends are to be presented in the following.

Figure 2(e) shows four delta-tabs fitted to the fan nozzle. The tabs were used in an effort to suppress a tone during the initial checkout of the hardware (further discussed later). Subsequently, it was decided to obtain some data with the tabs since they mimic the chevron configuration in modern engine exhausts. The triangular shaped tabs protruded into the primary flow with apex leaning downstream by about 45°. The tabs (spares from an earlier experiment) were machined out of 0.005 in. stainless steel shim stock. They had precision forms so as to sit flush on the 0.030 in. thick lip of the nozzle. They had a base width of 0.16 in.; the total blockage due to all four was about 1 percent of the annular area of the fan stream. In addition, two rectangular tabs were used with the primary nozzle. These also had a base width of 0.16 in. and protruded at an angle of 45° into the primary stream; the penetration was about 0.005 in. These were also adopted during the initial checkout phase in order to suppress screech when the primary jet was run alone. The tabs in the primary stream, visible upon a close look in figure 2(e), were left in place for the rest of the investigation and pertain to all data presented in the following.

Sound pressure level spectra were acquired using two microphones held fixed at $\theta = 25°$ and $\theta = 90°$. Here, θ is the angular location relative to the downstream jet axis. All data were obtained on the thicker fan stream side (i.e., opposite to the side of the pylon and flaps). The 25° and 90° microphones were located at distances of $35.3D_{fan}$ and $26.2D_{fan}$, respectively, where the fan diameter, $D_{fan} = 2.1$ in. Data were acquired for six run conditions as listed in table 1. Two conditions involved entirely subsonic flows and four involved supersonic primary stream. All cases were chosen so that the "fully expanded" velocity ratio was 0.7, approximating typical engine conditions. "Fully expanded" velocity is the value had the flow expanded fully for a given nozzle pressure ratio.

TABLE 1.—RUN CONDITIONS

[Subscripts 1 and 2 denote primary and secondary streams at the nozzle exit. M = "fully expanded" Mach number, U = "fully expanded" velocity in m/s.]

M_1	U_1	M_2	U_2	M_2/M_1	U_2/U_1
0.820	266	0.555	186	0.677	0.7
0.955	303	0.639	212	0.669	0.7
1.190	362	0.776	253	0.653	0.7
1.313	391	0.847	273	0.645	0.7
1.503	430	0.947	301	0.630	0.7
1.620	453	1.006	316	0.621	0.7

Results

Sound pressure level (SPL) spectra for the baseline case, without pylon or the fan tabs, are shown in figure 3 for the six run conditions. In each graph spectra for 25° and 90° are shown by the red and the green lines, respectively. The legend indicates the angular measurement location, primary and secondary stream "fully expanded Mach numbers" (M_1 and M_2, respectively) and the overall sound pressure level (OASPL) in dB. The last column represents a notation for the configuration, the baseline case being denoted by "BSLN". For the supersonic cases, the spectra at 90° are found to be characterized by broadband shock-associated noise (BBSN), represented by the peak on the right. At the high Mach number conditions, a tone sometimes occurred at about 3.6 kHz. It occurred even in the presence of the pylon but required both primary and secondary streams to be on. Tabs and flaps suppressed the tone. Despite an effort to understand it, the source of the tone remained unclear. In figure 4, corresponding spectral data are shown for the pylon case. Differences from the baseline case are not readily apparent. Some direct comparisons of the spectra will be made later for a few cases. First, comparisons in OASPL values are made to elucidate the impact of the various components (pylon, tabs, flaps, etc.) on the noise field.

The OASPL values, shown in the 4th column of the legends of the spectral plots, are plotted as a function of the primary jet Mach number (M_1) in figure 5 for the baseline case. Two sets of data, taken on different days, are shown. Note that for all run conditions the OASPL at 90° is less than the corresponding value at 25°. At $M_1 = 1.32$, the amplitude is relatively high at 90° apparently due to an increased level of BBSN (fig. 3).

Differences in the OASPL values are now examined. In figure 6, the red data points (open symbols) represent changes in the OASPL from the baseline case when only the internal wedge was applied to the secondary (fan) stream. Positive numbers represent a reduction in the level while negative numbers represent an increase. It is apparent that the internal wedge reduced noise at $\theta = 25°$ at all run conditions. The amount of reduction is 0.5 to 1dB. At $\theta = 90°$, on the other hand, there is an increase in noise at most conditions. The increase is large at $M_1 = 1.19$. This appeared to be due to an increase in the BBSN. However, the causes for the observed effects remain far from clearly understood. The (solid) blue data points in figure 6 represent noise reduction when the full pylon structure is employed (this includes the internal wedge). Relative to the internal wedge only case, insignificant changes have taken place. This implies that the impact on the noise field came mainly from the internal wedge and the rest of the pylon structure had negligible further effect.

In figure 7, the reductions in the OASPL achieved by the flaps are shown by the red (open) data points. (Note: "P F3S" denotes pylon plus flaps with smooth end; see figure 2(d). "F3" represents flap pair #3 which was investigated in detail; two other pairs with smaller divergence angles produced less noise reduction and were not explored further). For comparison, data for the pylon only case (same as the "Pylon + Wdge1" case of figure 6; solid data points) are also shown in this figure (blue, solid data points). At subsonic conditions, there is a large noise increase by the flaps at 90°. For the supersonic conditions there is noise reduction, relative to the pylon only case, at both 25° and 90°. The improvements over the pylon only case caused by the flaps, especially at 90°, is significant since often noise reduction achieved at shallow angles is accompanied by an adverse effect at locations perpendicular to the jet axis.

The effect of the flaps in the presence of the tabs is documented in figure 8. First, the blue (solid) data points represent the effect of just the four tabs on the fan nozzle (without the pylon), relative to the baseline case. It can be seen that a significant noise reduction is achieved by the tabs practically at all run conditions and at both angular locations. In the presence of the pylon, the flaps together with the tabs produce further noise reduction at 25°. At 90°, there is a noise increase. However, the increase at the latter location is comparable to or less than that found already with the pylon plus flaps case (minus the tabs, fig. 7). The changes in OASPL values are further analyzed in the following.

Since the flaps are added to the pylon, their effect is best judged when compared with the pylon only case. This is shown in figure 9. It is clear that the flaps have produced a small but clear noise reduction at the supersonic conditions. In the two subsonic cases, there is an adverse effect at 90°. The effect of the flaps together with the tabs is similarly shown in figure 10 relative to the pylon only case. A further noise benefit is observed for all run conditions. Unfortunately, data for the pylon with the 4 tabs (without the flaps) were not taken so that the effect of adding the flaps (to the tabbed jet with pylon) could not be assessed directly. However, some data were acquired earlier during the checkout phase for 25°, with a configuration involving the internal wedge and the four tabs. Recalling that the rest of the pylon structure does not impact the noise field significantly, these data could be taken as representative for the pylon plus 4 tabs case. Relative to this case, the pylon+flaps+4tabs yielded OASPL reductions of –0.54, –0.16, 0.16, 0.10, 0.63, and 0.15 dB for the six run conditions, respectively. Thus, even in the presence of the tabs, addition of the flaps produced a small but tangible decrease in the noise at the supersonic conditions.

Detailed comparisons of spectra are made in the rest of the figures, for a few cases of interest. These comparisons provide further insight into the changes in the spectral content leading to the changes in the OASPL. In figures 11 and 12 data for the pylon only case is compared with the baseline case; for clarity the data are shown for the two angular locations separately in the two figures. Recall, once again, that the noise reduction for the pylon case is achieved by the internal wedge and the rest of the pylon structure has negligible impact. Consistent with previous observations with internal wedge (ref. 4), the noise reduction is seen to occur mainly at low frequencies, for 25°. In figure 12 for 90°, it is noted that the wedge (plus pylon) has increased noise levels at high frequencies, including the level of the BBSN. These contributed to the degradations seen in figure 6.

The effect of the pylon with the external flaps is compared to the baseline case in figures 13 and 14, in a similar fashion as in figures 11 and 12. Similar comments can be made as with figure 11 for the shallow angle data. At 90°, while there is degradation (increase in spectral levels) at the lower Mach numbers, overall noise benefit is noted over most of the frequency range at the supersonic conditions. At M_1 = 1.3 and 1.5, the BBSN peak is also reduced significantly. Finally, the effect of the pylon and flaps together with the tabs is compared with the pylon only case in figures 15 and 16. Similar overall effects are observed as already noted with the previous figures.

Conclusions

For a bypass ratio 5 separate flow nozzle together with a pylon, it is demonstrated that noise reduction can be achieved by the fan flow deflection technique. The deflection is achieved by attaching external flaps to the sides of the pylon just downstream of the fan nozzle exit. This results in a reduction in the overall sound pressure level on the side of the jet opposite to the pylon side. The noise reduction is more pronounced at higher jet Mach numbers involving supersonic core stream. At these higher Mach numbers the flaps are found to reduce some additional amount of noise over that achieved by four delta tabs placed on the fan stream. This suggests that the flaps may have the potential for further noise reduction even with chevron nozzles.

The results presented in this paper complement recent findings at UC-Irvine. Similar flap configurations used in bypass ratio 8 nozzles were shown to produce some noise reduction. Furthermore, it was shown that flaps made of fine porous material performed better than solid flaps (ref. 2). It is possible that variation of other geometrical parameters of the flap-pylon assembly may produce better noise reduction. Accumulated evidence also suggests that the technique is more effective with lower bypass ratio nozzles and for supersonic core stream conditions. Thus, it is recommended that further study involving larger-scale nozzles and realistic engine flows either at the Jet Noise Laboratory of LaRC or the Aeroacoustic Propulsion Laboratory (AAPL) of GRC, aided by computational fluid dynamics (CFD), be considered in the future.

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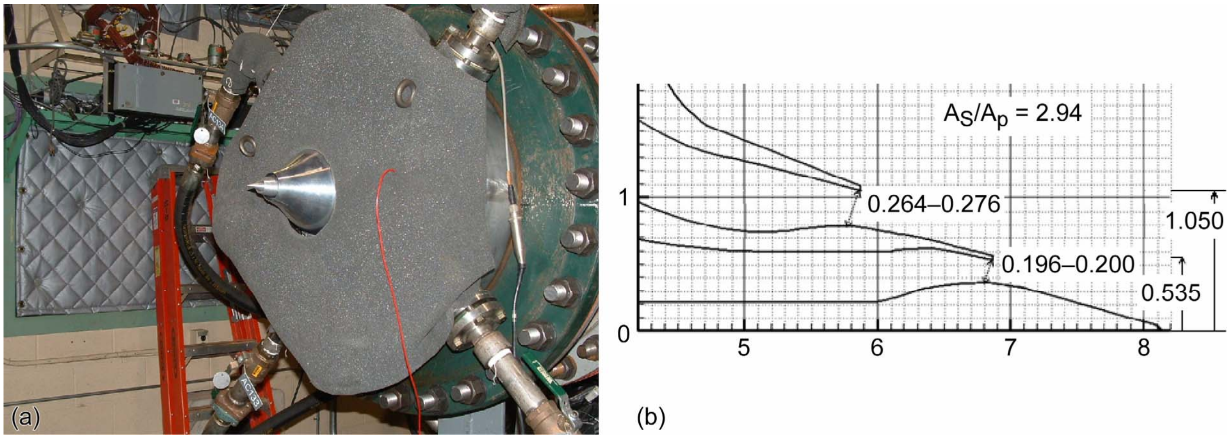

Figure 1.—(a) Picture of jet facility and nozzle; (b) schematic of 3BB nozzle.

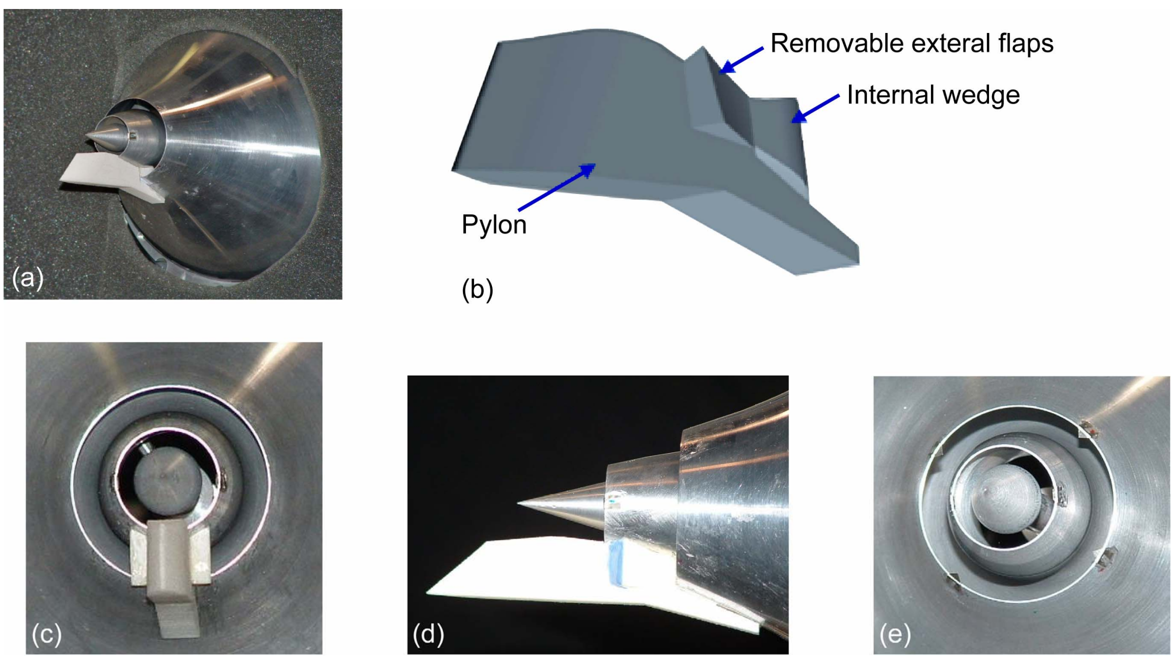

Figure 2.—Nozzle and various parts. (a) Nozzle with pylon. (b) Drawing of Pylon and flaps. (c) Front view of nozzle with pylon plus flaps. (d) Side view of nozzle with pylon plus flaps (ends of flaps smoothed by blue filler material). (e) Four delta-tabs on fan nozzle (primary nozzle has two small rectangular tabs in all cases).

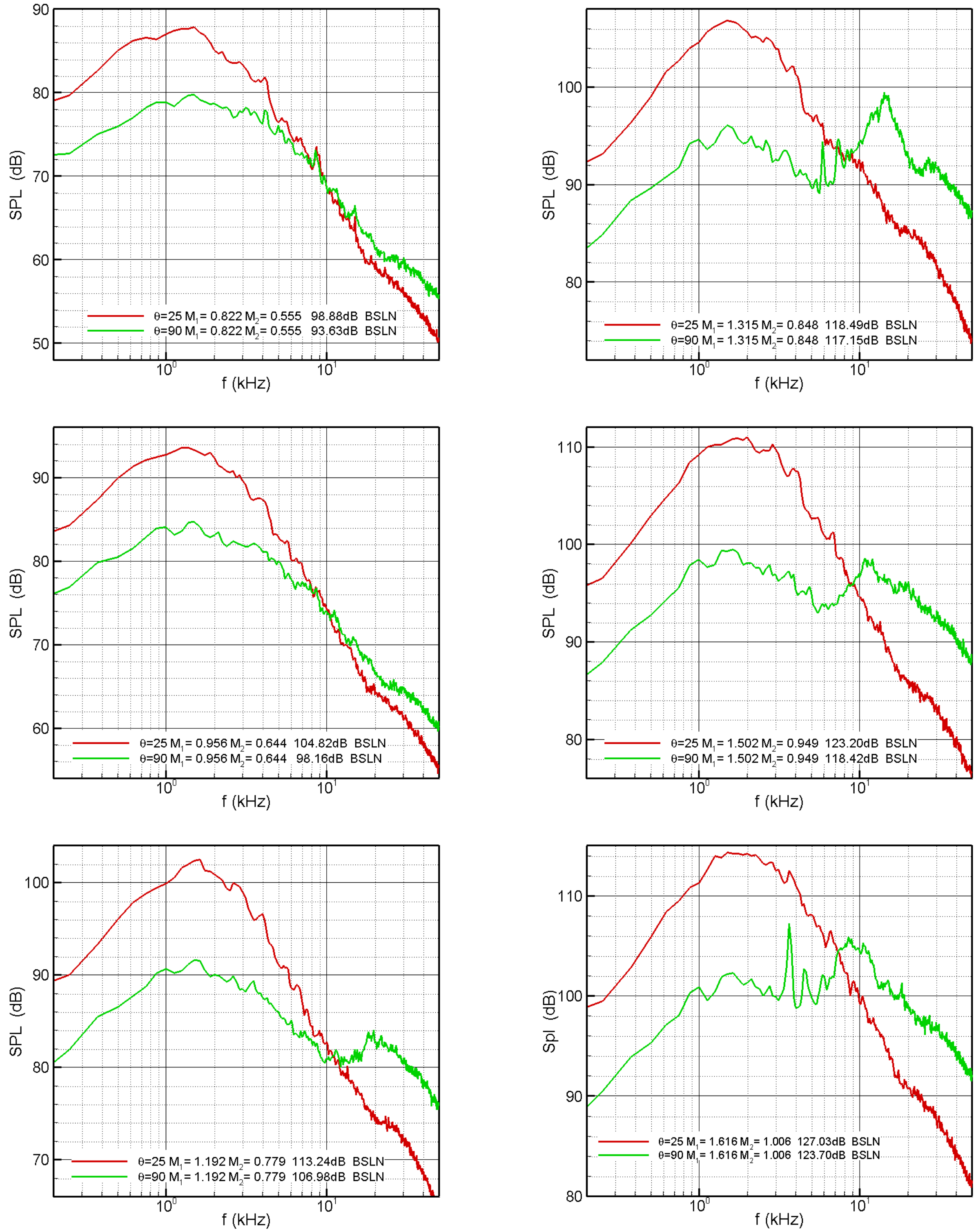

Figure 3.—Sound pressure level spectra for the baseline case at the six run conditions; Red curve: θ = 25°, green curve: θ = 90°. Fourth column in legends indicate overall sound pressure level (OASPL).

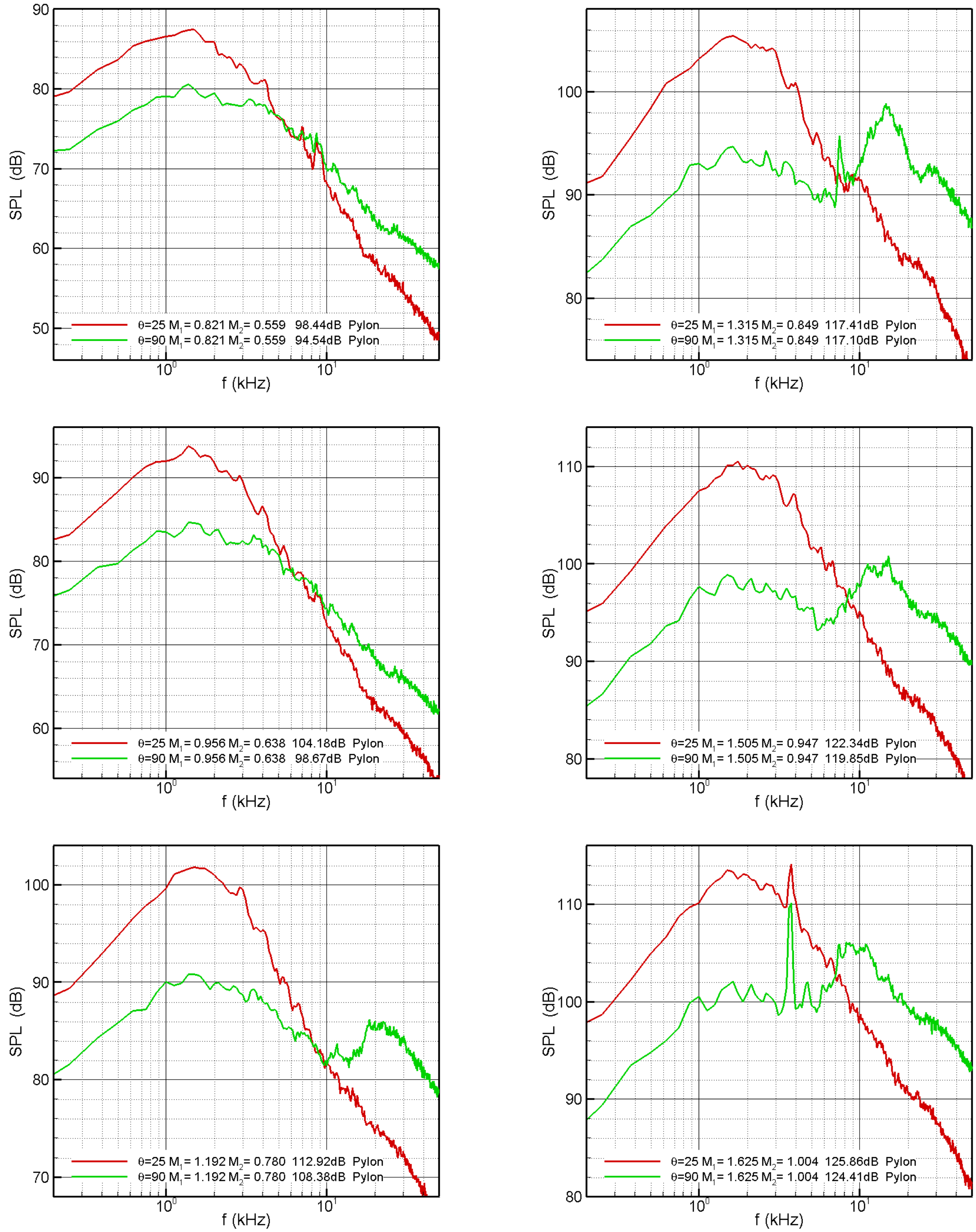

Figure 4.—Sound pressure level spectra for the nozzle with pylon only at the six run conditions, shown similarly as in figure 3; Red curve: θ = 25°, green curve: θ = 90°.

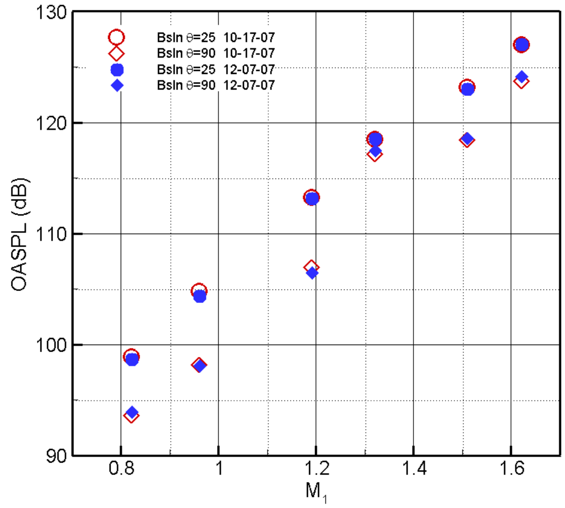

Figure 5.—Overall Sound pressure level vs. primary jet Mach number for the baseline case. Circular symbols: θ = 25°, diamond symbols: θ = 90°.

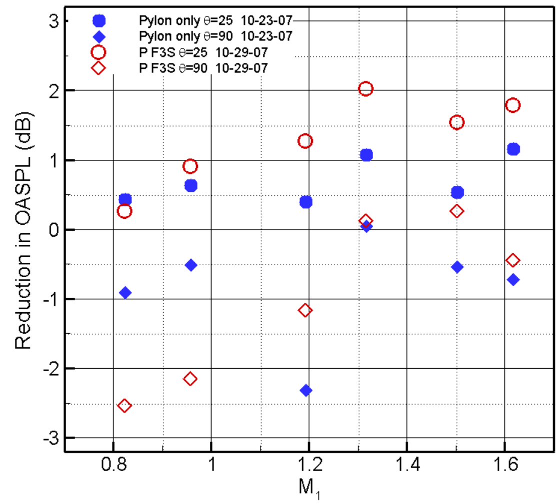

Figure 7.—Reduction in Overall Sound pressure level. Red data: pylon case relative to baseline; blue data: pylon with external flaps case relative to baseline. Circular symbols: θ = 25°, diamond symbols: θ = 90°.

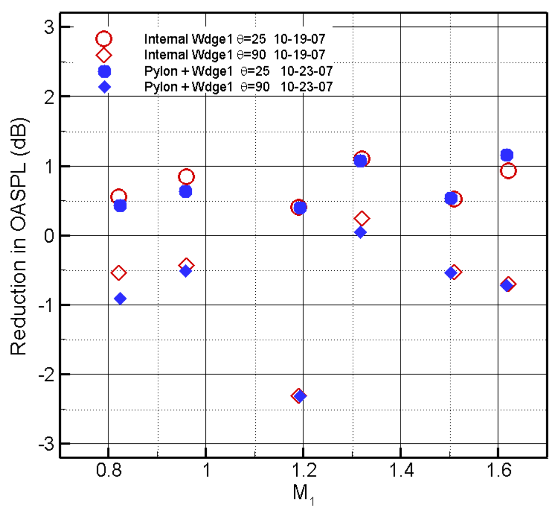

Figure 6.—Reduction in Overall Sound pressure level. Red data: for internal wedge only relative to baseline; blue data: pylon case relative to baseline. (Note: wedge inside the fan duct is integral part of the pylon case). Circular symbols: θ = 25°, diamond symbols: θ = 90°.

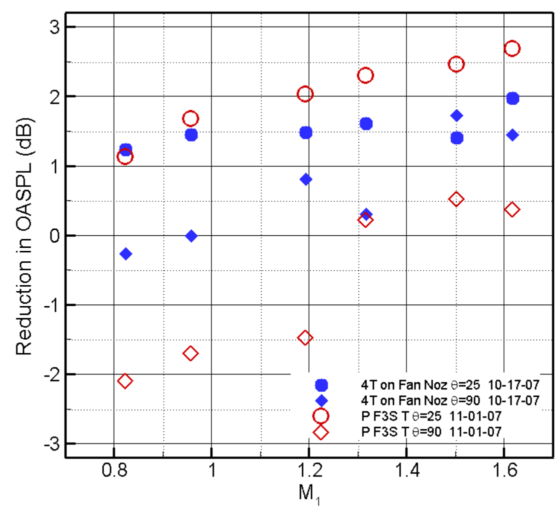

Figure 8.—Reduction in Overall Sound pressure level. Red data: pylon with external flaps plus 4 tabs on fan nozzle case, relative to baseline; blue data: 4 tabs on fan nozzle only case, relative to baseline. Circular symbols: θ = 25°, diamond symbols: θ = 90°.

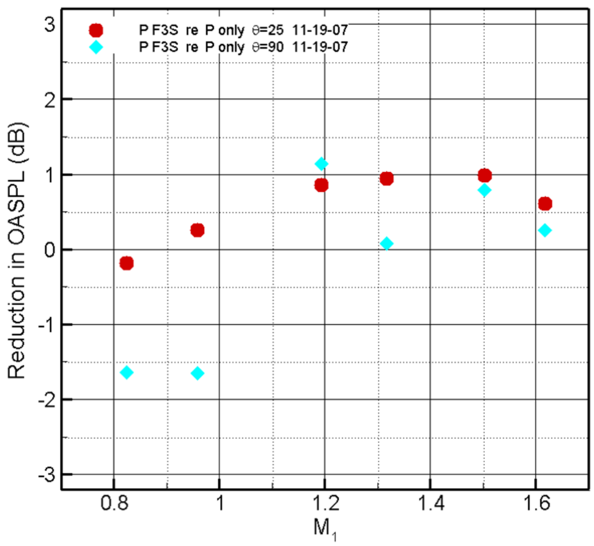

Figure 9.—Reduction in Overall Sound pressure level for pylon case with external flaps, relative to pylon case only. Circular symbols: θ = 25°, diamond symbols: θ = 90°.

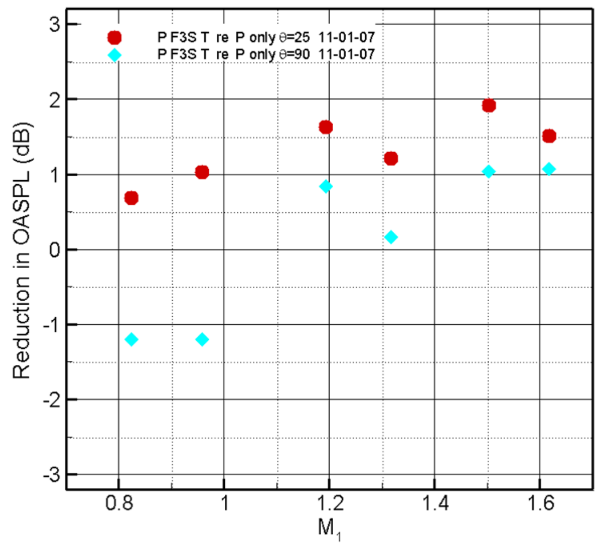

Figure 10.—Reduction in Overall Sound pressure level for pylon case with external flaps plus 4 tabs on fan nozzle, relative to pylon case only. Circular symbols: θ = 25°, diamond symbols: θ = 90°.

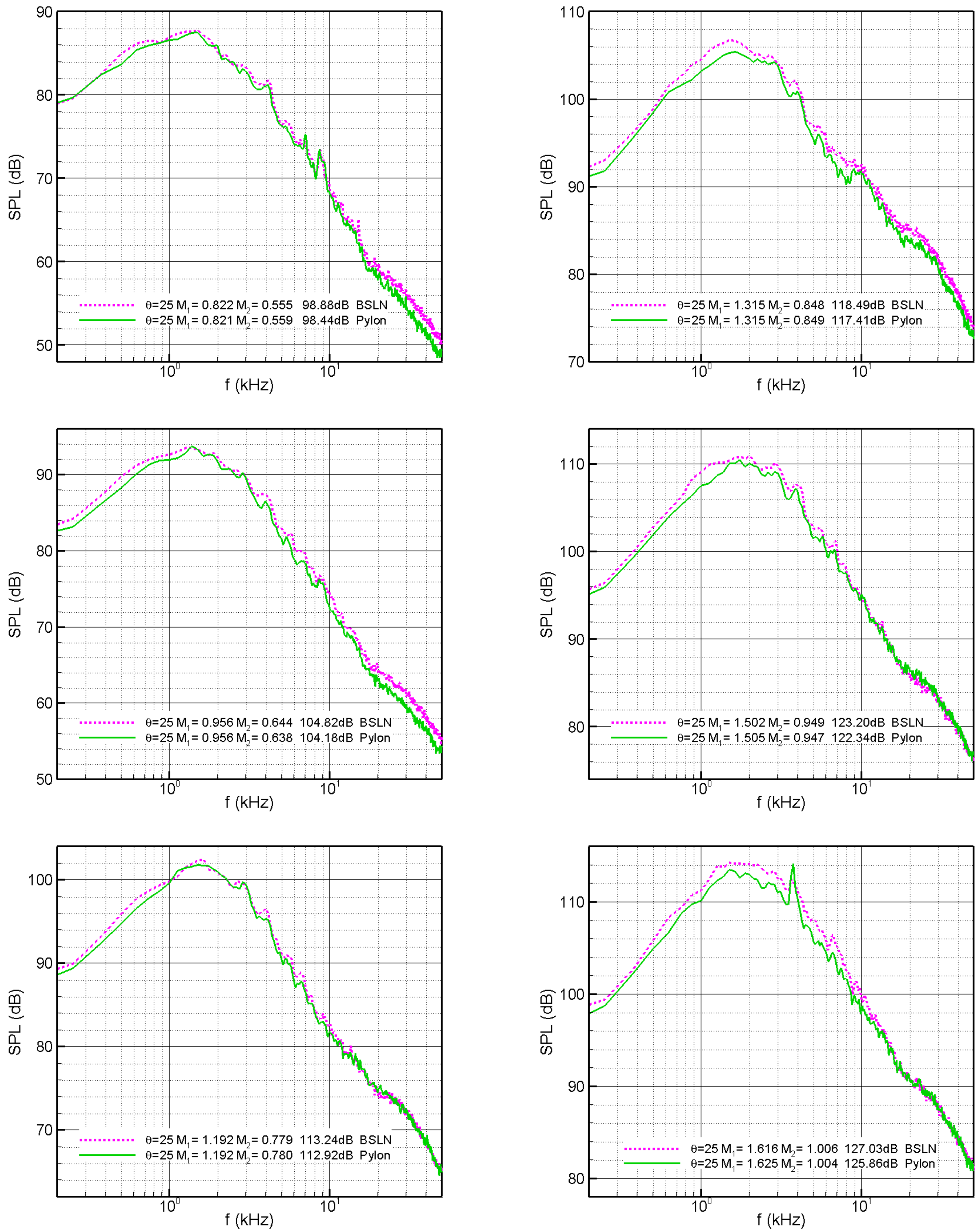

Figure 11.—Comparison of Sound pressure level spectra for the pylon and baseline cases at the six run conditions; θ = 25°.

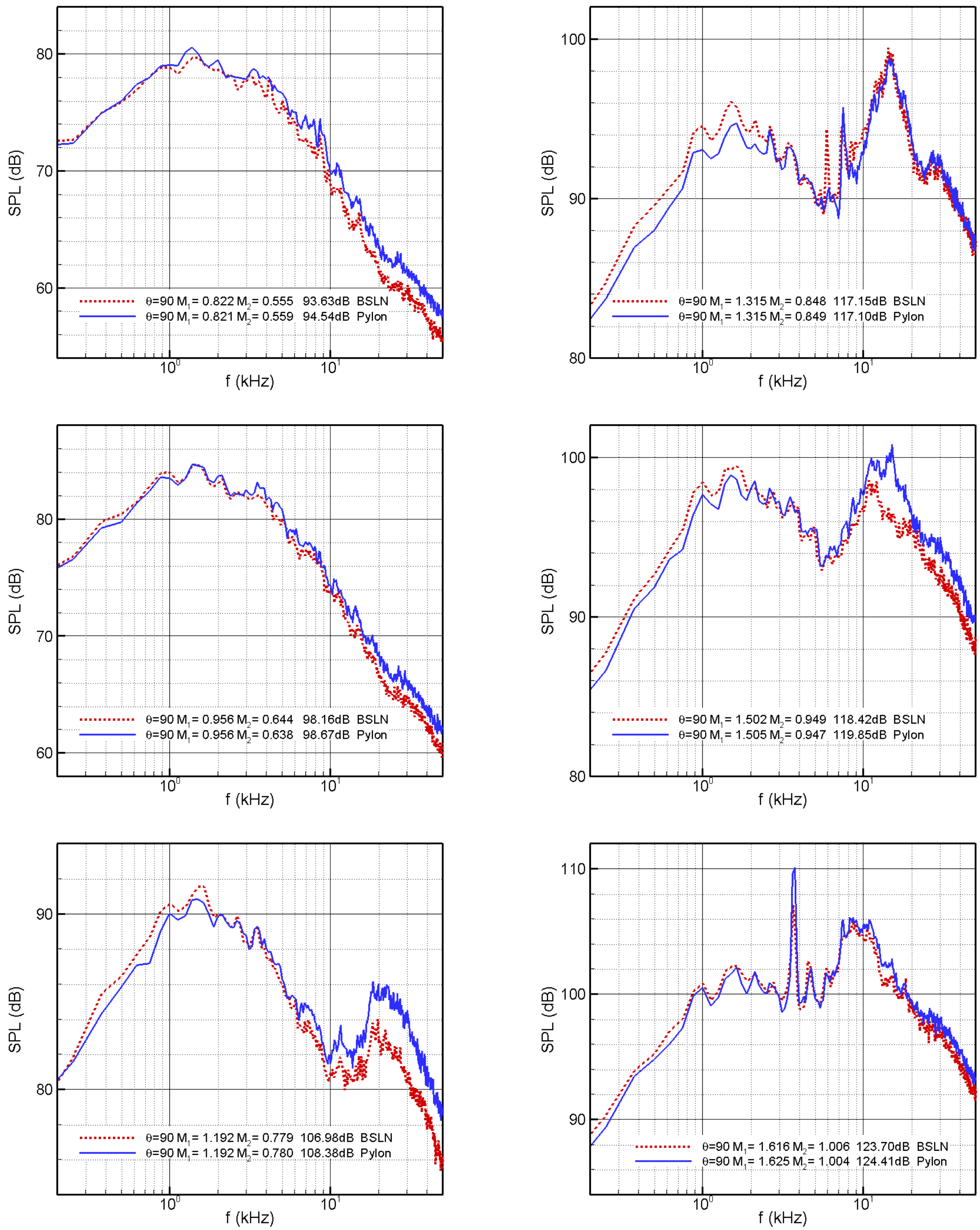

Figure 12.—Comparison of Sound pressure level spectra for the pylon and baseline cases at the six run conditions; θ = 90°.

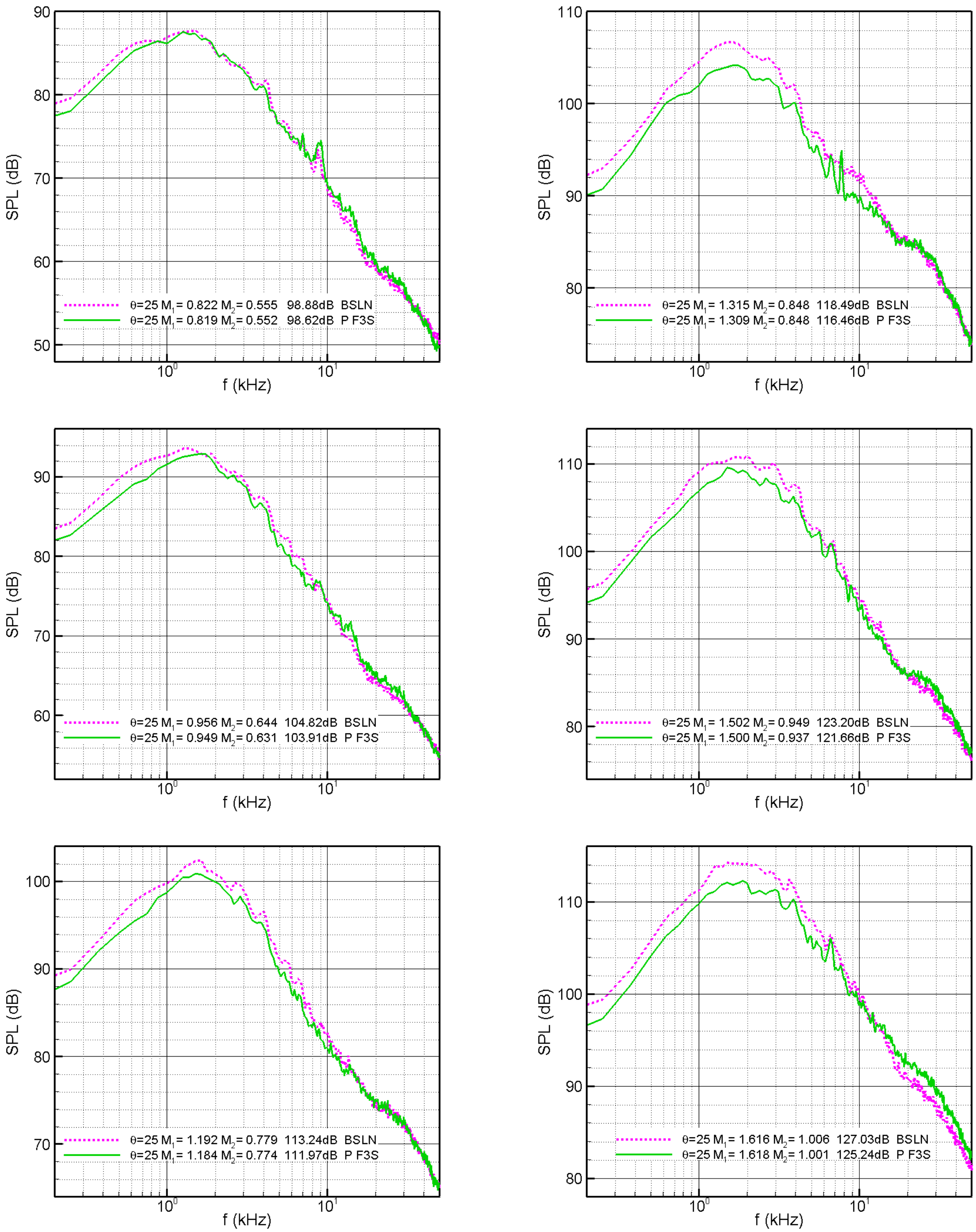

Figure 13.—Comparison of Sound pressure level spectra for the pylon and flaps case with baseline case at the six run conditions; θ = 25°.

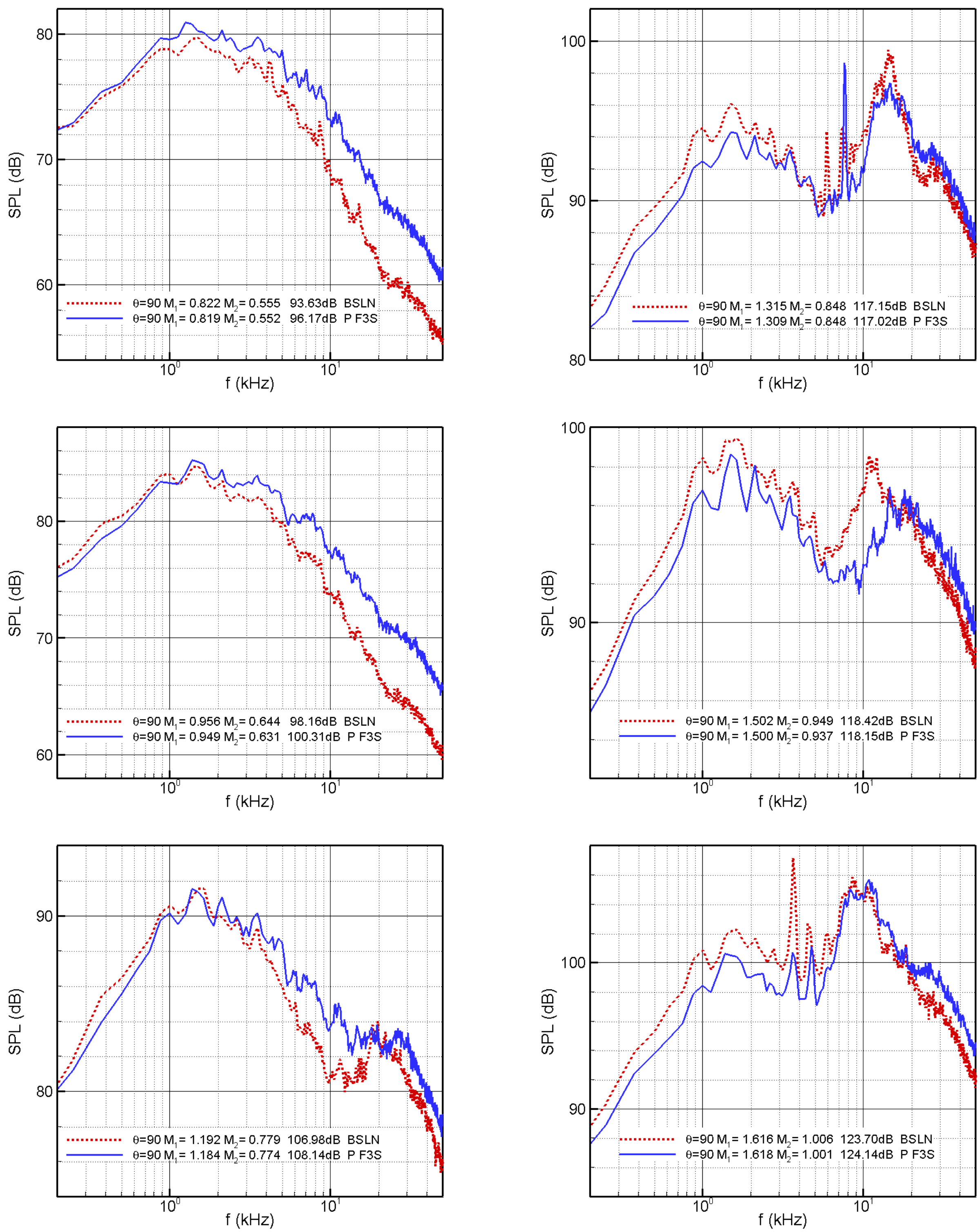

Figure 14.—Comparison of Sound pressure level spectra for the pylon and flaps case with baseline case at the six run conditions; θ = 90°.

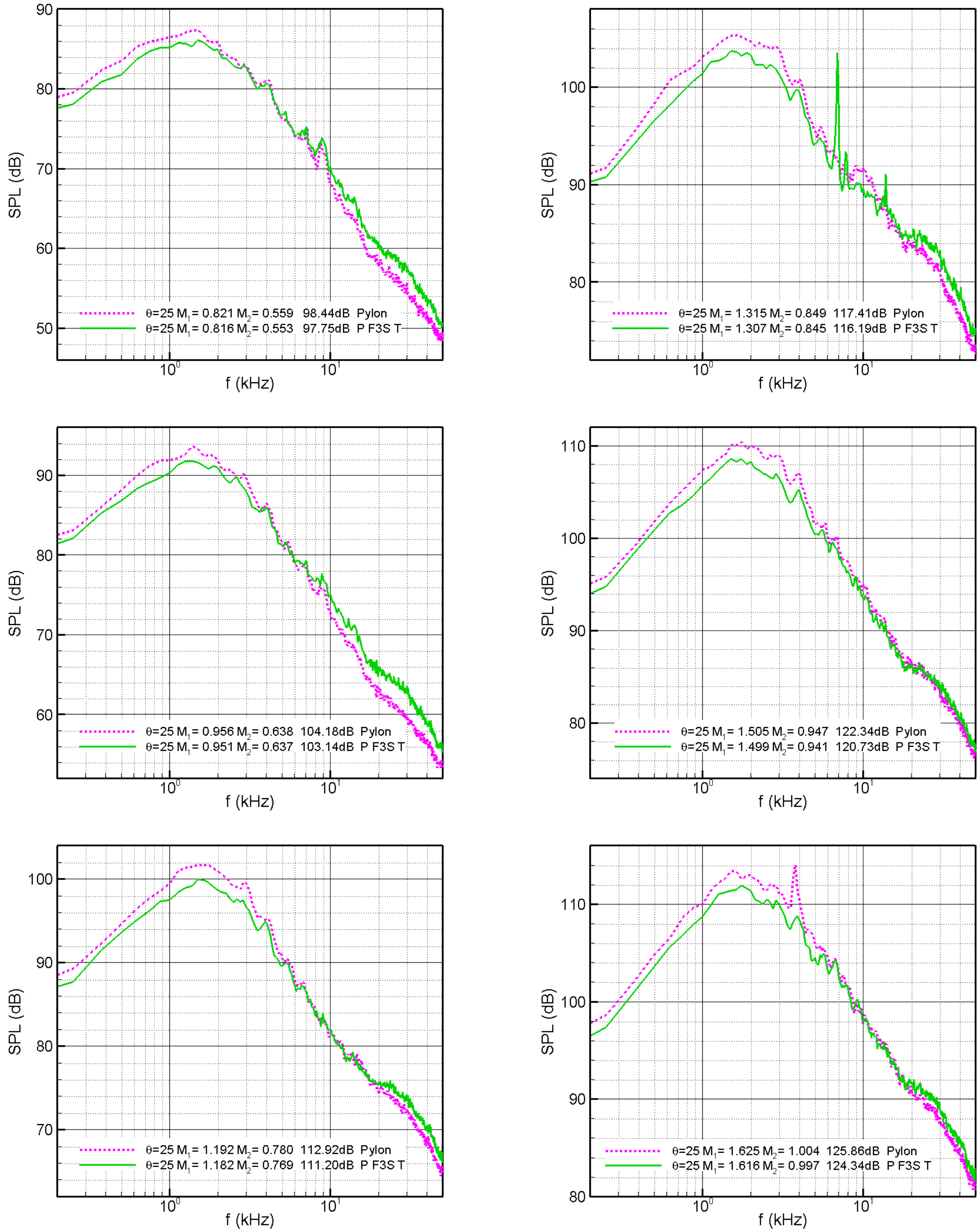

Figure 15.—Comparison of Sound pressure level spectra for the pylon and flaps plus tabs case with pylon only case at the six run conditions; θ = 25°.

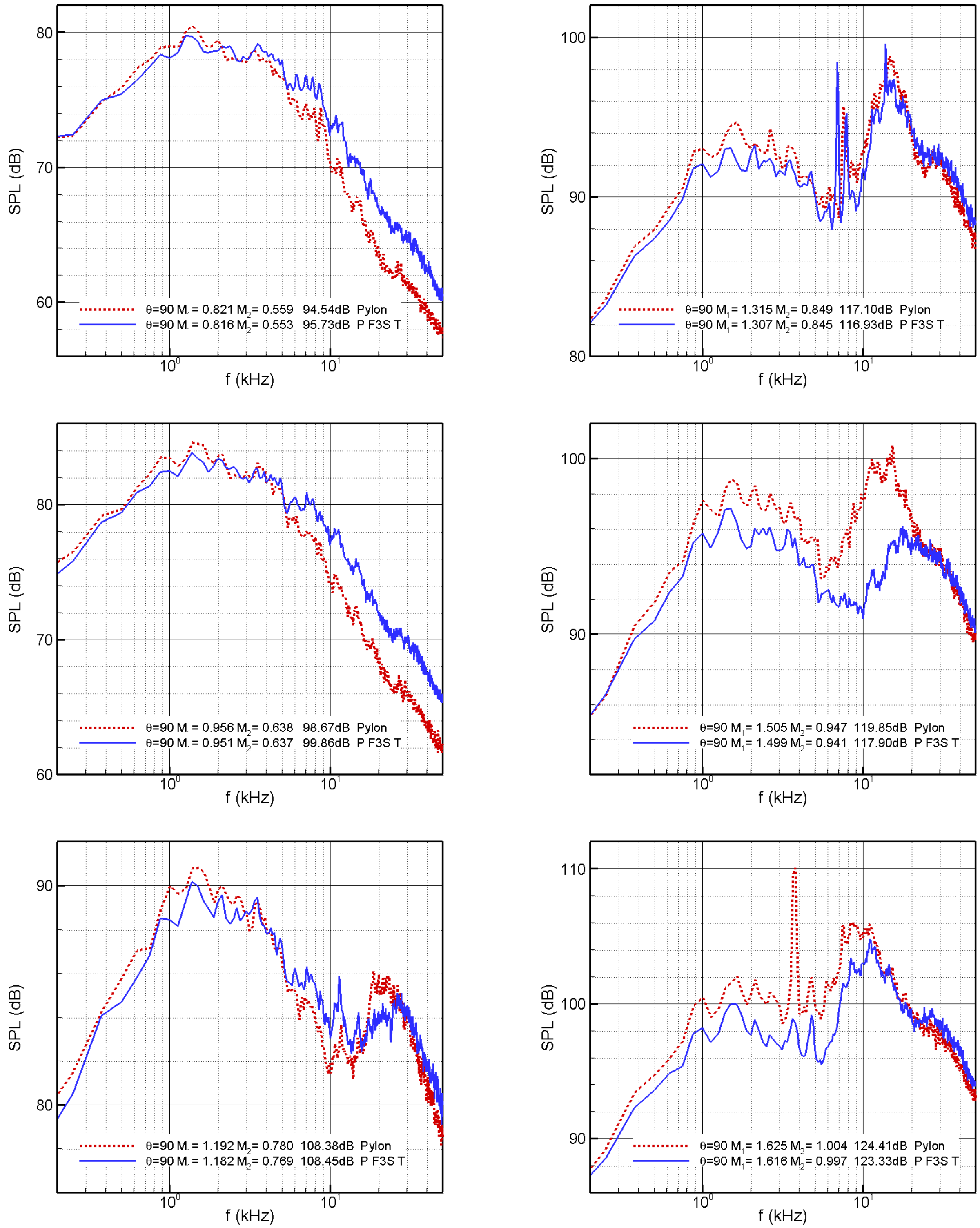

Figure 16.—Comparison of Sound pressure level spectra for the pylon and flaps plus tabs case with pylon only case at the six run conditions; θ = 90°.

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