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Acoustical Characterization of the F-35A Joint Strike Fighter: results and perspectives of the first experimental campaign

Aversano, Renato[1], Lt. Colonel
Italian Air Force (AMI), Servizi Supporto Comando Logistico
Viale dell'Università, 4, 00185 Roma - Italy

Bianco, Davide; De Vivo, Luciano; Sollazzo, Adolfo; Barbarino, Mattia; and Federico, Luigi[2]
Italian Aerospace Research Centre (CIRA)
Via Maiorise snc, 81043 Capua - Italy

ABSTRACT

The Italian Air Force (AMI) and the Italian Aerospace Research Centre (CIRA), have carried out an experimental campaign to evaluate the noise impact of the JSF F-35A, recently acquired by the AMI 32nd Fighter Wing based in Amendola. AMI has been the second Air Force in Europe receiving the F-35A, the Conventional Takeoff and Landing (CTOL) variant of the Lockheed Martin stealth fighter, which can fly at a maximum speed of Mach 1,6 thanks to the engine power of the Pratt&Whitney F135 turbo-fan equipped with afterburner.
Noise data have been acquired for both flyover and approach/landing flights, exploiting a wi-fi connection between noise measurement stations and a central server located in the control tower in order to allow an environmental-dependent tuning of the scheduled flight parameters. Flyover flights have been performed at different altitudes with fixed engine power (including afterburner) or fixed ground speed for several subsonic flights.
Eleven phonometric stations have been located along the airport runway in order to ensure reliability of acquired acoustical data and to build an integrated acoustical model for evaluating and reducing noise impacts in the Amendola airport surrounding area. The results of the activity will also be used to allow a sustainable integration of the F-35 fleet in the Italian airspace.
Keywords: Military aircraft noise, Noise surveys
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1. INTRODUCTION

The Italian AF and CIRA research centre has developed, within the MILNOISE program, an operational procedure for assessing the acoustic impact of air traffic at

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[1] r.aversano@aeronautica.difesa.it
[2] d.bianco@cira.it; l.devivo@cira.it; a.sollazzo@cira.it; m.barbarino@cira,it; l.federico@cira.it

military airports, based on both the use of mathematical models for the propagation of noise and on the use of experimental acoustic data. The aim is allowing the evaluation of the acoustic impact of an airport on the surrounding territory, representing it through acoustic insulation curves on geo-referenced maps, as it is routinely done in environmental evaluation practice.

In particular, having noted the characteristics of the source of each individual aircraft operating at a given airport and the current and/or future air traffic data, it is possible to evaluate the acoustic impact.

The so-called "acoustic characterization" of an aircraft includes the activities of experimentation and processing of the data necessary to obtain the characteristics of the associated noise sources in terms of Noise Power Distance (NPD). NPD plots are used to depict the noise produced by the aircraft in overflight at a certain altitude and with a specific setting of engine power (or thrust). This document describes the first acoustic characterization activity of the F-35A aircraft supplied to the Italian Armed. This activity has been carried out in close collaboration by AMI and CIRA, as part of the MILNOISE JSF program – described in the following section – launched in 2010 and aimed at assessing the acoustic impact at the airport sites of the F-35 aircraft.

2. ACOUSTIC IMPACT REGULATION AND NOISE CALCULATION PROCEDURE

Italian regulations on noise pollution (Act n. 447 of 1995 and the respective enactments) concern, at present, only with the civil airports. For the prevention and limitation of noise areas affected by military installations and activities of the Armed Forces exclusively, the above Act provides for the establishment of specific agreements, through the Regional agencies "COmitati MIsti PARitetici (CO.MI.PAR.)", that plan in a harmonized way the regional development. Since some Italian military airports are also open to civil air traffic, in these cases, to properly plan the development of the surrounding area, it is necessary to quantify the contribution of noise pollution of military activities. This allows local authorities to be fully informed about the environmental impact produced by all airport activities, and therefore to identify the procedures and mitigation measures prescribed by the regulations for the civil part.

While for civil aviation the international law requires aircraft noise certification, this is not true for military aircraft. Therefore, in order to comply with environmental civil regulations and allow airlines to better manage the fleet, the aviation industry is committed to develop less and less noisy aircraft. In the military sphere, however, the aviation industry promotes the development of increasingly higher performance aircraft and therefore often more "noisy". Italian Air Force (AMI) however, within the framework of politics to protect the outdoor environment from high levels of noise around military airfields, more than ten years ago, started a complex applied research activity named "MILNOISE Project" in conjunction with Italian Aerospace Research Centre (CIRA). Such a project is aimed at identifying the strategies and operative procedures to control and reduce the noise pollution due to the aircraft training flight operations of Italian Air Force.

Noise laws, issued in Italy for civil aviation, require that aircraft noise pollution to be described in terms of a descriptor named LVA (Airport eValuation noise Level). Then, the main acoustic descriptors used in the present study are those required by the reference regulations, namely: LAmax, SEL, and LVad LVaj

The index of evaluation of airport noise in the determination of the noise contours in Italy is the "Level of Evaluation of Airport Noise" (LVA) described by the following expression:

$$L_{VA} = 10 \, \log \left[\frac{1}{N} \sum_{j=1}^{N} 10^{L_{VAj}/10} \right] dB(A) \tag{1}$$

where N is the number of days in the observation period[3] and LVAj is the daily value of airport noise assessment level as defined below:

$$L_{VAj} = 10 \, \log \left[\frac{17}{24} 10^{L_{VAd}/10} + \frac{7}{24} 10^{L_{VAn}/10} \right] dB(A) \tag{2}$$

where:

$$L_{VAd} = 10 \log \left[\frac{1}{61200} \sum_{i=1}^{N_d} 10^{SEL_i/10} \right] dB(A) \tag{3}$$

$$L_{VAn} = 10 \log \left[\left(\frac{1}{25200} \sum_{i=1}^{N_n} 10^{SEL_i/10} \right) + 10 \right] dB(A) \tag{4}$$

in which Nd and Nn are, respectively, the number of aircraft movements during the daytime (06:00–23:00) and during the night (23:00-06:00). The values of the descriptor are then used in quantifying noise exposure coming from air traffic in residential neighbourhoods, plotting them on a map that allows to subdivide the area, surrounding the airport, according the three zones defined in Table 1.

Respect Areas	LVA (dBA)	TERRITORY USE DESTINATION
A	60 - 65	No expected restriction
B	65 - 75	Agricultural activities, trading activities, industrial activities, offices
C	> 75	Exclusively activity and office for airport working

Table 1: Noise limits for respect areas of Italian airports and restrictions for territory use destination.

As seen above, the Italian Law about airport noise defines a LVA noise pollution level for each respected area; therefore the A, B and C areas extension is the basic information to perform assessments of the environmental acoustic impact due to the airport activities.

For each individual aircraft for which there is the need to estimate the noise impact, a set of Noise Power Distance (NPD) curves is built. NPD, as mentioned above,

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[3] The number of days should be twenty-one that are equal to three weeks, each of which must be chosen in the following periods:
October 1 - January 31; February 1 - May 31; June 1- September 30
Under the civil context the week within the observation period must be the one in which there are greater number of movements.

are graphs capable of mapping the noise produced by the overflying aircraft at a certain altitude and with a specific setting of engine power (or thrust). Starting from the NPD of the aircraft and the airport traffic data one can develop the forecast model of the airport impact, based on the use of the Integrated Noise Model (INM) acoustic software.

This software implements a so-called "segmentation" forecasting model. This means that the program is able to determine the contribution of each segment in which a single flight is decomposed, with respect to each individual ground receptor, as shown in Figure 1.

Given the geometry and the motor thrust associated with flight path, INM proceeds to calculate the relative noise level, in accordance with the algorithms defined in the model SAE AIR 1845. The noise data obtained in this way are corrected by INM through a series of propagation models that take into account aircraft speed, atmospheric and soil absorption and lateral attenuation due to engine installation effects, according to the methodologies referred to in SAE AIR 5662 and SAE ARP 866.
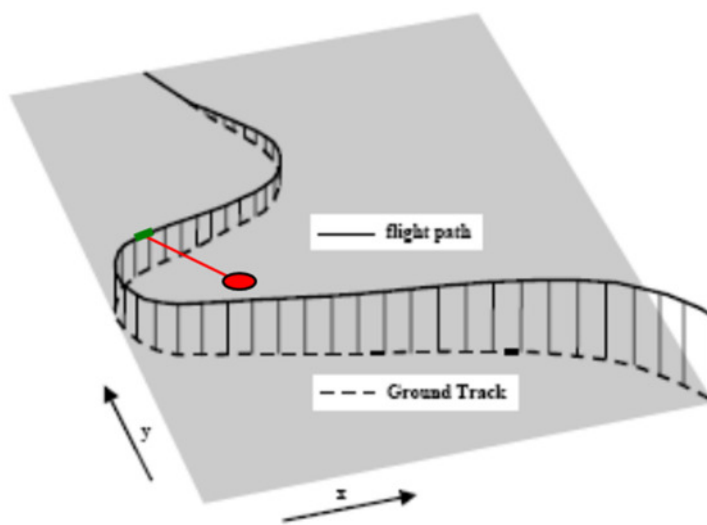

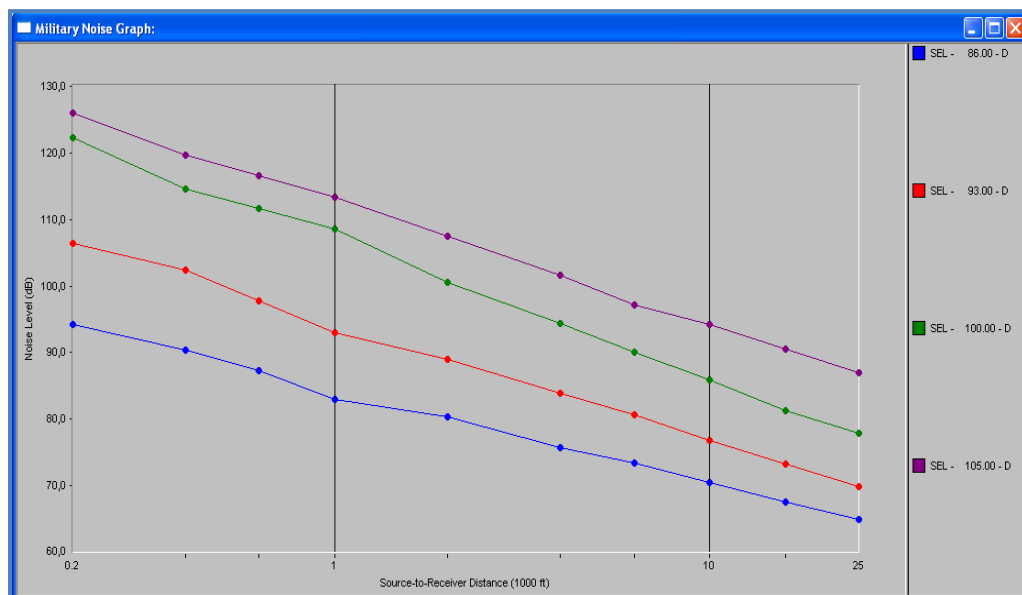Figure 1: Example of segmentation implemented in INM

Figure 2: Example of experimentally noise data for military aircraft NPD

3. EXPERIMENTAL DATA ACQUISITION

The measurements have been carried out using the phonometers and experimental set-up of both CIRA and Italian Air Force Mobile Acoustic Surveying Laboratory. The large number of measurement stations has allowed a redundancy on those stations considered of greater interest. It has been possible, then, to guarantee to a greater extent reliability and accuracy of the acquired data. The two measurement systems have been used simultaneously and completely independently. The AMI laboratory was equipped with 6 measurement stations, whose composition is described in the following table.

Detector chain			Structure		Microphone features
Device	**Maker**	**Model**		**Container**	
Phonometer	Larson Davis	831B	Height: 4 m	Watertight with backup battery	• All-weather protection • Bird dissuader
Preamplifier	PCB	PRM 2103			
Microphone	PCB	377B02			

Table 2: AMI measurements station characteristics

These stations were equipped with a class 1 phonometer compliant with IEC-61672, a back-up battery and a mass data storage. This instrumentation is housed inside a Watertight, dust-proof portable enclosure in accordance with IP54 and resistant to crashes according to the MIL-STD 810F standard. The microphone is external, mounted on a special extendable pole at the height of 2.5m, with a wind-shield and a bird dissuader. The AMI laboratory has been exploited with a continuous data acquisition mode, and the data recorded by each individual station have been stored on an external disk at the end of the entire characterization campaign. These data were subsequently transferred to CIRA servers for processing purposes.

The CIRA measurement laboratory has 5 peripheral measuring stations, each equipped with a watertight case, with a class 1 phonometer conforming to IEC-61672, a 12 VDC buffer accumulator, a Tablet unit for data collection and a network communication management system with WLAN or 4G / 3G mode. Externally, each peripheral unit has a 4-meter extendable pole to the top of which is an external microphone with an all-weather protection. This layout configuration, suitable for outdoor use, is watertight and dust-proof according to IP54 and crash-resistant according to the MIL-STD 810F standard. The CIRA data acquisition rate composition is summarized in the following table.

Device	Maker	Model
Phonometer	Larson Davis	831C
Preamplifier	PCB	PRM 2103
Microphone	PCB	377B11

The main features of the CIRA laboratory instrumentation can be summarized as follows:

• 3G/4G and wi-fi connectivity (IEEE802.11);

• Bandwidth [6.3 Hz - 20 kHz];

• Sampling period 100 ms;

• GPS data for each station.

Although each measuring station is completely autonomous, the CIRA laboratory has been used in centralized control mode by a server (laptop PC) allocated in the control tower. The server, connected to the measurement set-up in wi-fi mode, has triggered each individual station with the "start" and "stop" recording commands. The acquired data, displayed in real time on the server, have been recorded both locally and on the server. CIRA set-up has been complemented with a weather station, which has been used for verifying the eventual asymmetric features, due to the wind, of the acoustic data acquired from different stations, while the weather data used for data processing and test planning were provided from the airport staff. The field location of the experimental stations has been reported in Figure 3.

Figure 3: AMI/CIRA experimental set up deployed for the F-35A characterization.

Different, mixed flight profile of the F-35A have been used for the acoustical acquisition campaign. The flight profiles are described using the graph of the vertical profile (vertical trace), the graph of the planar profile (ground trace) and the relative descriptive tables. The different types of profiles examined included take-off (with and without afterburner), overflight performed at different heights, and approach, including both aligned approach and the loitering above the airport.

The flight profiles described above represent the actual use of the aircraft at base, and have been used to define the thrust and speed values employed for the construction of the NPDs of the aircraft. These curves correlate the altitude and power/thrust of the aircraft to the acoustic effect produced and can be determined experimentally acquiring the noise generated by the aircraft during overflights (flyover) at different altitudes. Consequently the overflight tests, performed with different thrust, altitude and speed, have been the majority of the acoustic tests performed. In particular, there have been 67 flyovers on a total of 79 tests, according with the data reported in the following tables

Test Name	Manoeuvre	Characteristics
Alfa		ETR = 85%
Bravo	Flyover	ETR = 100 %
Charlie		ETR = 40%
Delta		Constant speed and altitude
Gamma	Approach e Take-off	-
Lambda	Flyover	ETR = 150% costante (Afterburner)

Set	Maneuver	Altitude	Speed	ETR [%]	Afterburner	Test number
ALFA	Flyover	Several	-	85	-	12
BRAVO	Flyover	Several	-	100	-	25
CHARLIE	Flyover	Several	-	40	-	18
DELTA	Flyover	Constant	Several	-	-	6
GAMMA	Approach /Take-off	-	-	-	-	12
LAMBDA	Flyover	Several	-	150	On	6
					Total	79

The approach and take-off maneuvers have been used for the acoustical validation of the model.

4. ACOUSTICAL CHARACTERIZATION

The analysis of experimental data has been necessary for correlating the acquired acoustic data with the event that generated them, according to the procedure described graphically below:
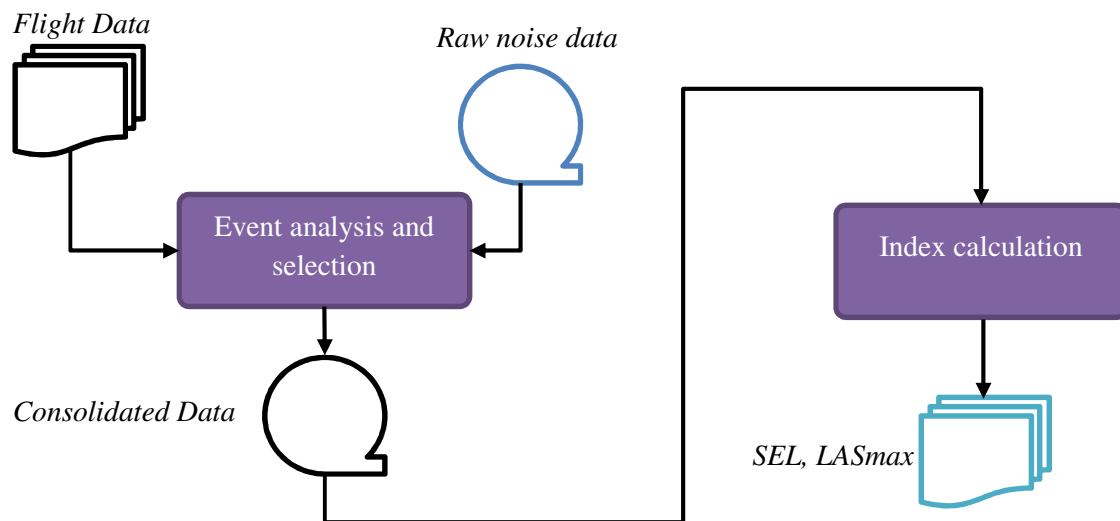

Figure 4: Experimental data analysis

The consolidated data have been processed numerically in order to obtain the index, namely LASmax and SEL, neede for the calculation of the NPDs. In Figure 5 an example of a track (time history) of the acquired acoustic data is shown. The graph shows the different noise peaks due to one of the performed flight test.
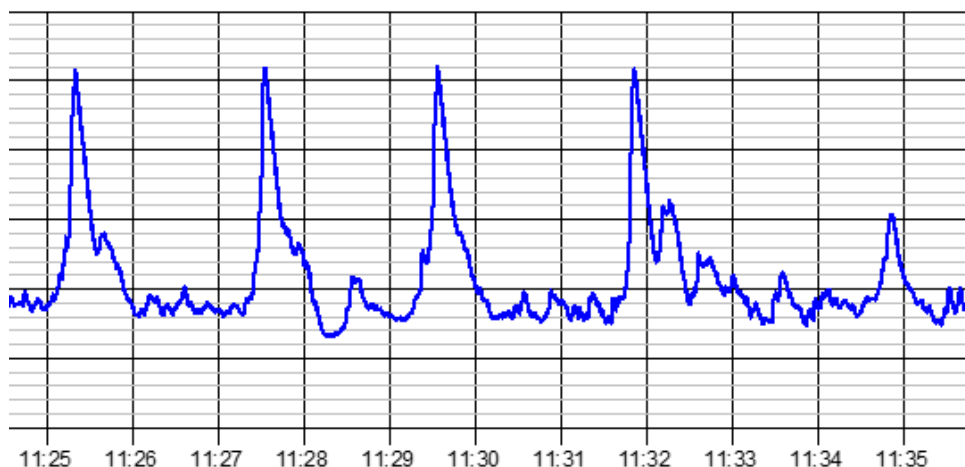
Figure 5: example of the experimental data acquired

Moreover, Figure 6 shows a further processing of the data related to the acoustical flight data acquired. In particular, the A-weighted sound pressure level in time and frequency domain have been obtained and the synthetic acoustic parameters, namely LAeq, LAmax and SEL, have been calculated.
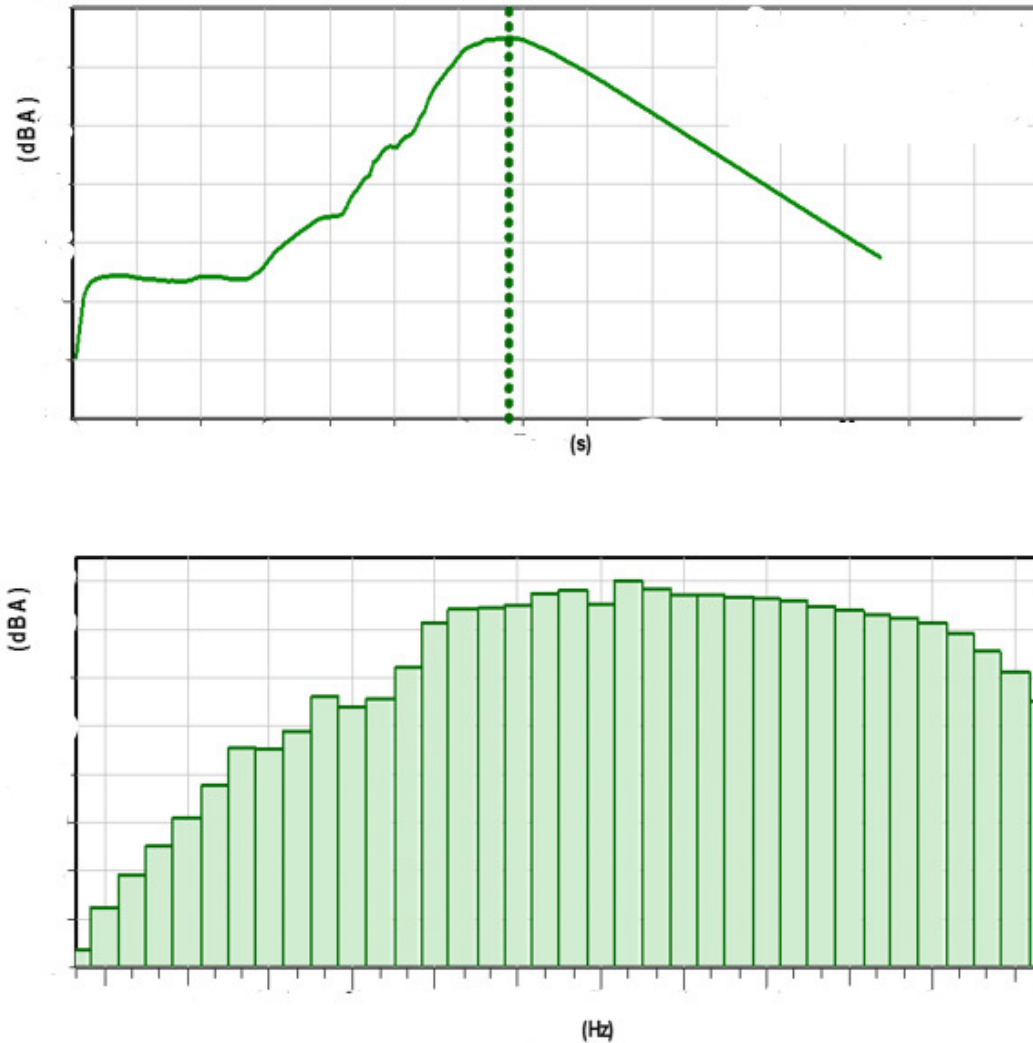

Figure 6: SPL in time and frequency domain

As mentioned in the introduction, the thrust and velocity values of the flights selected for the acoustic tests have been defined on the basis of the flight profiles of the F-35A aircraft, in order to generate a set of NPD curves most adhering to the actual operating conditions of the aircraft.

The INM SW requires input NPDs for the following 10 distances, selected to be equidistant on a logarithmic scale:

- 200 ft = 61.0 m
- 400 ft = 121.9 m
- 630 ft = 192.0 m
- 1000 ft = 304.8 m

- 2000 ft   =   609.6 m
- 4000 ft   =   1219.2 m
- 6300 ft   =   1920.2 m
- 10000 ft =   3048.0 m
- 16000 ft =   4876.8 m
- 25000 ft =   7620.0 m

Since it has not been possible to perform an experimental test for each of the altitudes listed above, the missing values were estimated using the following formula:

$$L_2 = L_1 + 20 \cdot \log\left(\frac{r_1}{r_2}\right)$$

in which L2 is the equivalent level of noise to be estimated at the distance r2 from the source and L1 is the noise level measured at the distance r1. It should be noted that this method does not take into account different contributions such as atmospheric absorption, the temperature gradient and the wind and assumes that the front propagates along a spherical surface.

For the aircraft under examination, there has been also the opportunity to integrate the missing data of the NPD with those provided by USAF (through the Ministry of Defense) in the previous phases of the MILNOISE-JSF. With this aim, we examined the degree of correlation between the NPDs calculated from the data acquired during the present characterization campaign with those provided by the USAF, both in terms of LASmax and SEL. In particular, the Pearson correlation index obtained for the two different series of NPD, defined as the relationship between their covariance and the product of the respective standard deviations, returns - for the points plotted in Figure 7 - the values reported in the following table.

PEARSON INDEX		
	SEL	Lamax
NPD series 1	0,995	0,996
NPD series 2	0,999	1,000

Table 3: pearson index comparison

In the comparison the value of the index are close to the unit, both in terms of SEL and LASmax, and therefore it is possible to state that among the trends of the NPDs compared there is a so-called "strong direct correlation" (that is, with Pearson's index greater than 0.7). This type of correlation is a necessary condition for the construction of a single set of NPD curves, composed of both series analyzed, since it makes the interpolation processes of the INM software coherent.
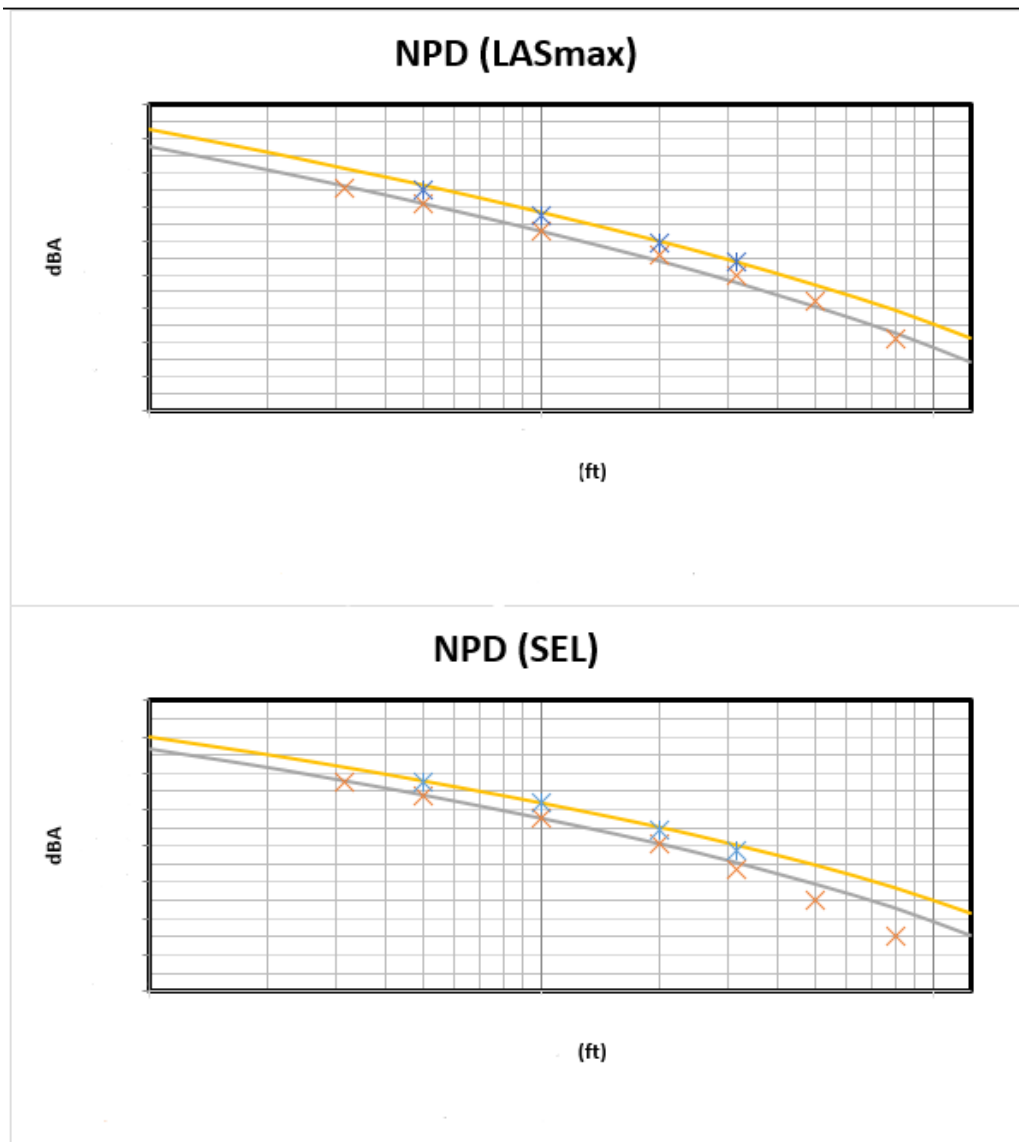
NPD (LASmax)

NPD (SEL)

Figure 7: CIRA-AMI and USAF NPD comparison

4. MODEL VALIDATION AND ENVIRONMENTAL MONITORING

In order to validate the F-35A acoustical model, implemented in INM, a comparative analysis has been conducted, based on the data provided by the forecasting model, itself, and the experimental measures, obtained from the monitoring activity.

In fact, the INM model implements a standardized modeling of the emissive sources, with some corrective factors taking into account the actual characteristics of the operating aircraft and the atmospheric conditions, as, for instance, flight paths, temperature, direction and wind speed, and atmospheric pressure. These corrective terms requires a verification of the deviation of the data provided by the model with respect to field measures. This deviation may increase with the distance of the emitting source from the observation point.

In general, it has been observed that measured SEL and LAmax levels bear a considerable dispersion with respect to the INM simulations for the same type of aircraft, in the same flight conditions and for the same type of trajectory. As the number of flights increases, it can be observed how the average level of SEL obtained with INM can be compared

with the experimental data, while the same quantity computed for a single data is generally differs of about 3 dB from its measured counterpart. This can be understood with the ansatz that, within a statistics, numerical errors of noise evaluation over a single event tends to a null average.

For this reason, and in order to obtain a statistically significant datum, all the F-35A take-off and landing noise measured in the monitoring week, has been condensed in a single index were consolidated, namely LVAm, defined as follows:

$$LVAm = 10 * \log\left[\frac{1}{61200}\sum_{j=1}^{Nd}\left(10^{0.1*SELj}\right)\right] dBA$$

Using the index defined above, it has been verified that the differences between the experimental data and the numerical model were in the order of 0.1dB, clearly stating that:

LVAm(Model) = LVAm(Experimental)

4. CONCLUSIONS

The acoustical characterization and the noise impact forecasting procedure, for assessing the acoustical effects of the new F-35A aircraft, have been described in this document. As mentioned above, eleven phonometric stations have been located along the airport runway in order to ensure the reliability of the acoustical data acquired, fully characterize the acoustical features of the new aircraft and build an integrated acoustical model for evaluating and reducing noise impacts in the airport surrounding area.

The future development of this work will include, first, an extension to other airports and other version of the aircraft, namely the F-35B. Moreover, the activities could be enlarged to include a new experimental set-up, which CIRA and, eventually, AMI will use for including other flight conditions into the characterization and impact forecast evaluation. For instance, an extension for including the study of the Sonic Boom and a forecast of its mitigation due to the Mach cut-off can be foreseen,

5. ACKNOWLEDGEMENTS

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