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IMPLEMENTATION OF A NOISE PREDICTION SOFTWARE FOR CIVIL AIRCRAFT APPLICATIONS

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ABSTRACT

This paper introduces the activities performed at University of Naples Federico II within the ADORNO research project. ADORNO project, "Aircraft Design and NOISE Rating for regional aircraft" is a research project financed by European Commission under the Horizon 2020 Program Clean Sky 2, focused on the development of aircraft models for a regional aircraft engine platform. The main objective is to evaluate the benefits of Clean Sky 2 developed technologies at aircraft system level, with respect to gaseous and noise emissions. One of the enablers is the development of an efficient noise prediction tool and its integration into an existent aircraft design and analysis chain. The developed tool can model the "near field" noise sources and with a propagation model estimate noise level in the space.

The paper presents an application of noise estimation (Effective Perceived Noise Level) on the certification points (flyover, sideline and approach) of a regional turbofan aircraft. The aircraft is designed and analyzed with the aircraft design chain (JPAD) and needed input data passed to noise prediction tool to compute noise level.

Results, in EPNL scale, are compared to EASA certified data, showing an overestimation of noise level lower than 1 dB in the three certifications points.

Keywords: noise prediction, noise certification, aircraft design.

1 INTRODUCTION

Aircraft noise pollution is now considered a serious problem and it is a significant political issue. It is the most significant cause of adverse community reaction related to the operation and expansion of airports. According to standards defined by the ICAO for the commercial aircraft category, the noise certification relies on three main measurements made at different points during the take-off and the landing procedures. The level of noise is recorded continuously at these points during take-off and landing and the time integral value define the noise level known as Effective Perceived Noise Levels (EPNL). This must not exceed a set limits, based on the maximum take-off weight of the airplane and the number of engines. Being able to simulate the trajectories is the starting point for every noise estimation process. Almost every calculation tool currently available relies on flight simulations to derive these trajectories. However, according to the ADORNO consortium experience, it is not sufficient to make proper evaluation for the certification required monitoring point vs certification levels, but since the early stages of the aircraft design it is strongly required to give specific attention to Local Noise Requirements prescribed by local Authorities. Stringent noise restrictions are set at specific monitoring points that therefore need to be addressed during the aircraft preliminary design and making use of specific software subroutines to extrapolate noise contour in the areas of interest along the preferred/suggested departure and arrival track. This has been done by combining the aimed ADORNO noise prediction software tool, ATTILA (AicrafT noise predicTion IncLuding performAnce) with existing Commercial Off-The-Shelf (COTS) software like Integrated Noise Model (INM) and Aviation Environmental Design Tool (AEDT). The objective of ADORNO research activities is focused on the development of aircraft models for a regional aircraft engine platform. An aircraft noise method has been developed and integrated in an aircraft design chain. The state-of-the-art approaches consider numerical prediction tools, separated into two groups, referred to as restricted and parametric prediction methodologies. The first group works with fully empirical approximation derived from measurements and does not require direct simulation of aircraft noise or knowledge of noise generation and propagation. The second one relies on a physics-based approach which expects to analyze all the aircraft noise sources for then estimating the global noise as a sum of all these contributions and their related interferences. ATTILA program considers two main approaches that are used to analyze aircraft noise phenomena. The first one is based on one-third octave band spectra noise analysis of any type of aircraft in any mode of flight. It provides an estimation of aircraft noise by means of set of noise spectra varied during the noise event or for any kind of noise exposure. The second approach is based on the concept of “noise radius” and provides calculations of aircraft noise exposure units around the airports or at any noise monitoring point. Section 2 presents the framework for the ADORNO project. Section 3 presents methodology of ATTILA tool. In section 4 the functioning of the ATTILA tool, through a test simulation performed on the Airbus A220-300, is presented. Finally, the last section presents the conclusions.

2 AIRCRAFT DESIGN AND NOISE RATING FOR REGIONAL AIRCRAFT

The framework for the ADORNO project can be divided into two main modules. The first one deals with the preliminary design and analysis of the aircraft model under examination, while the second one gathers all the standalone analysis tools in charge of the noise, pollutants and cost estimations.

2.1 Preliminary design module

In this first module the parametric model of the aircraft together with the engine deck are passed to the preliminary design tool. This oversees carrying out all the analyses required to make a complete performance assessment. The tool used for this task is JPAD, a Java library developed at the University of Naples Federico II by the Design of Aircraft and Flight technologies (DAF) research group[1] to perform multi-disciplinary analyses and optimizations of civil transport aircraft [1][2][3].
The idea of JPAD derived from the experience gained by the DAF research group in the design of general aviation and turboprop aircraft [4][5][6].
Gathering the best practices coming from the current aircraft design software scenario, JPAD offers the following features: It is modular and easily extendible; is based on advanced features of Java (Java 8+ and JavaFX[2]) and is designed using object-oriented and functional criteria; it is portable; the inputs and the outputs are fully configurable with a flexible XML-

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[1] www.daf.unina.it
[2] https://docs.oracle.com/javase/8/javafx/get-started-tutorial/jfx-overview.htm#JFXST784

based set of files; it can automatically generate CAD outputs via the OpenCASCADE[3] modelling library; its analysis sub-models are based both on semi-empirical formulations combined with more refined simulation-based methods, offering a multi-fidelity analysis approach; it is designed to allow interface with any other external calculation tool. These features make the JPAD framework a modern tool in "continuous" development, according to professional software maintenance criteria [7].

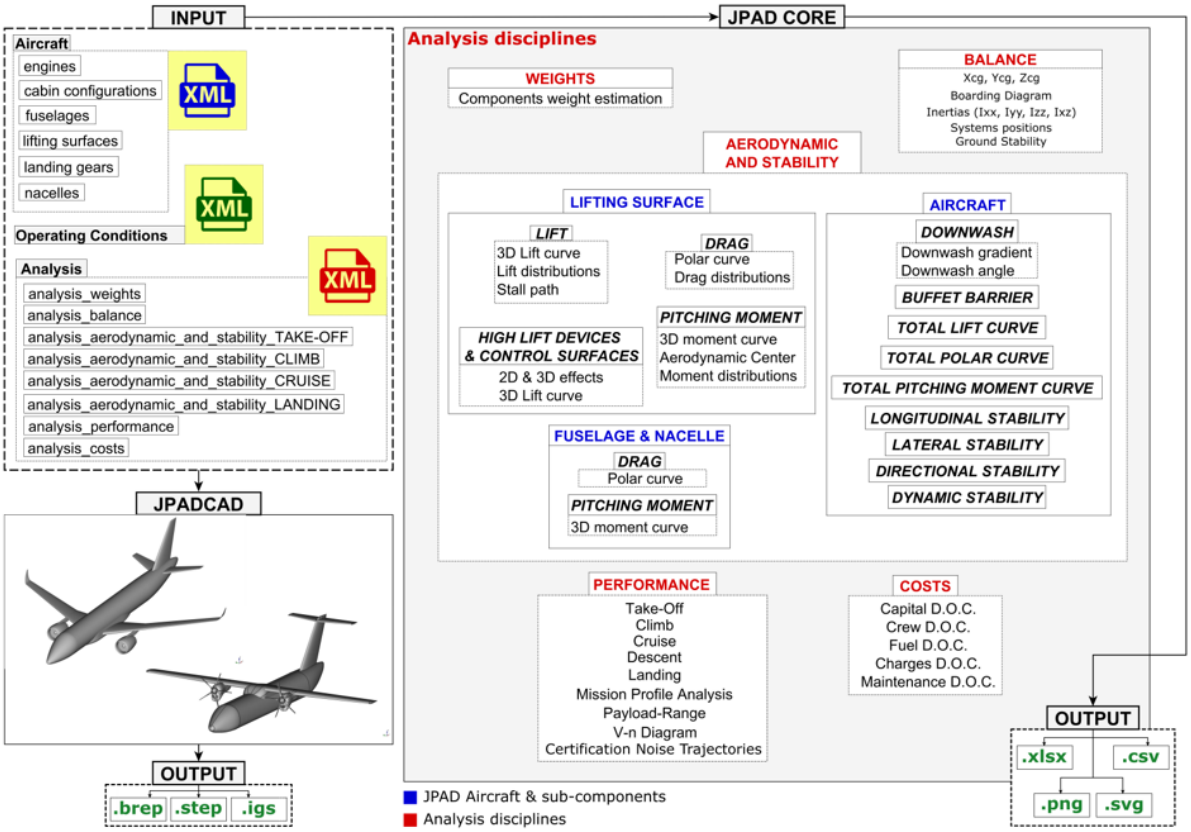

Fig. 1 – The Core of the JPAD library.

In Fig. 1 the entire structure of the software is schematized. It is possible to clearly note that there are two main blocks: input and core. The input block is defined by two main parts: aircraft and analyses definitions. The first one defines a parametric aircraft model using a main file (Aircraft.xml) which collects all the components positions and the related xml file name (i.e. fuselage.xml, vtail.xml, and so on) which contains all geometrical data. This structure allows to generate different aircraft, or different configurations of the same model, by simply combining different components allowing to easily perform comparisons between these latter. The second one defines all necessary data for each analysis present inside the Core module [3].
The Core block collects all analysis managers related to the five disciplines considered at the moment of writing: Weights, Balance, Aerodynamic and Stability, Performance and Costs. As illustrated in Fig. 1, each of those can be further divided in several sub-modules related to a specific discipline calculation. A more detailed explanation of each analysis module can be found in [3].
To enhance the framework flexibility, the framework has been conceived to allow both a complete analysis loop involving all disciplines, both standalone analyses using one or more

[3] https://www.opencascade.com/

calculation modules. As explained in [3], in case the user wants to carry out a complete analysis cycle, JPAD uses a combination of its analysis modules.
Concerning the complete analysis loop, the starting point is the estimation of the amount of fuel needed for the specified mission. A balance analysis is carried out to determine the center of gravity excursion which is used by the aerodynamic and stability module to estimate the trimmed drag polar curves needed by the performance module to make a detailed simulation of the design mission profile estimating the new amount of fuel for that mission. An iterative process is carried out until the first estimated fuel mass is equal to the one calculated by the mission profile analysis [3].
A key feature related to the topic of this paper is the capability of JPAD to perform take-off and noise trajectories simulations and the capability to simulate general waypoint-based flight trajectories according to a non-linear performance model. The simulation is carried out according to FAR-36 regulations [16] by solving a dedicated set of Ordinary Differential Equations (ODE) representing the equation of motion of the aircraft during those phases. An example of how this approach has been used for the take-off simulation is provided in [7]. Some examples of simulation outputs are shown from Fig. 4 to Fig. 5 concerning the Airbus A220-300, showing take-off trajectories (Fig. 4 with and without cut-off) and thrust settings (Fig. 5).

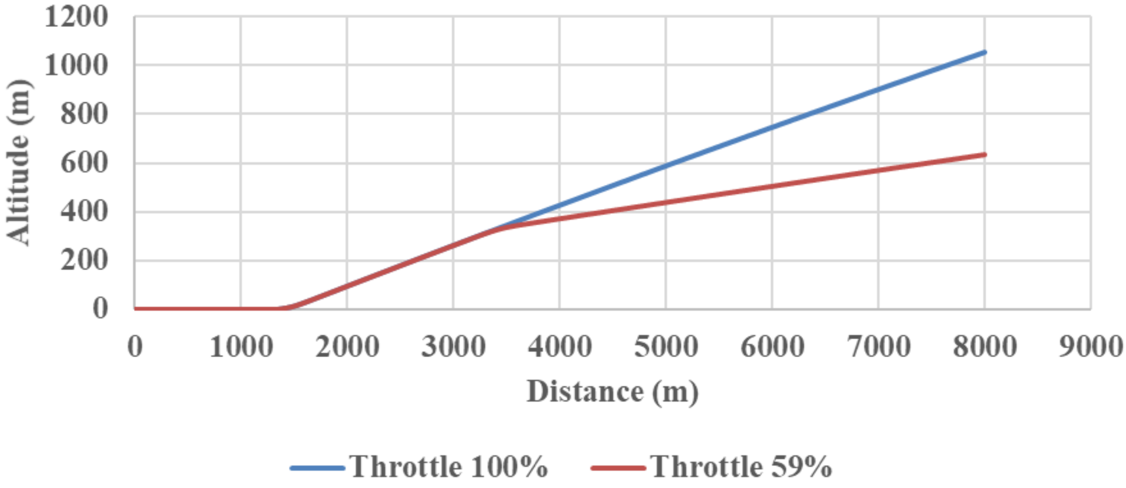

Fig. 2 – Example of take-off noise trajectories simulation result: trajectories.

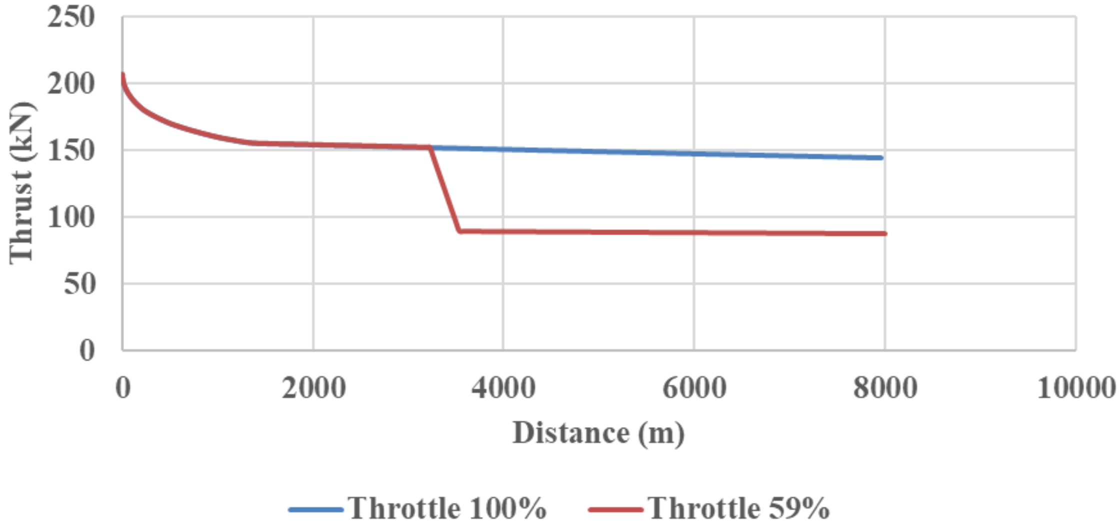

Fig. 3 – Example of take-off noise trajectories simulation result: thrust evolution.

2.2 Analysis module

The second module is designed as a collection of different tools each of which dedicated to a different analysis.
The first one, ATTILA, is related to environmental noise estimation and will be described in the following section. The main goal is to carry out a rapid assessment of the perceived level of noise at the three certification points shown in Fig. 7, approach, sideline and flyover.
The second one deals with the evaluation of the pollutant emissions using the related engine deck data combined with the mission profile analysis carried out by the preliminary analysis tool. Knowing the thrust required in each mission phase and the related amount of fuel burnt, the tool can estimate the breakdown of the pollutant emissions in terms of NOx, HC, CO and CO2 comparing them with a given set of maximum allowed values.
The third one is in charge of performing an economic assessment calculating the direct operating costs of the aircraft.

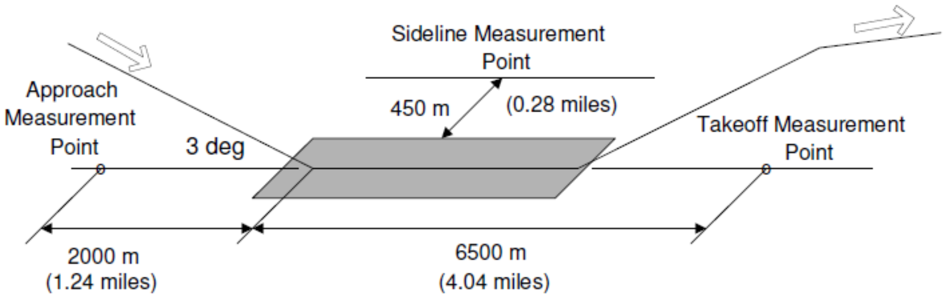

Fig. 4 - ICAO/Annex 16/Chapter 3 measuring locations Flow chart of Attila

3 METHODOLOGY OF THE ATTILA TOOL

The overall aircraft noise is the result of the interaction of several contributions related mainly to engines and airframe. A comprehensive overview of the methodologies used by the ATTILA tool to estimate these contributions and their related validations can be found in [8]. However, several semi-empirical approaches are still used in the preliminary design phase like the ones proposed in [9][10][11][12][13][14][15][16]. A brief description of each of these contributions, as well as some relevant calculation methodologies, will be presented below.

3.1 **Airframe Noise**, Ref. [10]

In the last decades the aircraft engine noise has come down to a level comparable to that of noise originating from turbulent flow around the airframe, for approach and landing conditions, that is, with deployed landing gears and high-lift devices.
Efforts in aircraft noise reduction, therefore, must focus on the airframe as relevant noise contributor. From its definition, it does not include powerplant noise and therefore sets a lower limit below which reductions in engine noise emission have no significant effect on the total noise level from the aircraft.
The level of airframe noise is dependent upon the aircraft configuration. In basic terms, an aerodynamically 'clean' aircraft produces less noise in the airflow than a 'dirty' one. The landing configuration with slats extended, flaps down and undercarriage lowered is therefore considerably noisier than the clean configuration.
The prediction method, which is a semi-empirical one, has been developed from that proposed by Fink, [9], with changes to directivity and spectral functions based on more recent available data, and allows the estimation of the OASPL and of one-third octave band sound pressure levels within a frequency range and over polar and azimuthal angular ranges set by the user.

The prediction method works by modelling individual components of the airframe as elementary sources or source distributions. The spectral and directivity characteristics of these sources have been derived analytically or empirically or have been assumed to be similar to sources of known characteristics. The individual components of the airframe that are considered here are the wing, flaps, slats, tail and landing gear; no interaction between components is assumed.

3.2 **Propeller Noise**, Ref. [11]

This module permits the prediction of near-field and far-field harmonic noise from propellers, with subsonic relative Mach numbers at the blade tip. The airflow into the propeller need not to be parallel to the propeller axis. The near-field is considered to extend approximately as far as one propeller diameter from the propeller tip. For the application of the ATTILA tool, the near field component may be neglected. A detailed description of the propeller blade geometry is required. Aerodynamically induced propeller noise may be separated in two components: broadband and discrete frequency. The broadband component arises from turbulent flow and is only likely to assume significance at high angles of attack of propeller blades. This component is neglected in ATTILA. The discrete component is produced as a result of the rotational motion of the propeller blades. The main sources of noise that generate the discrete component are:

- Air volume displacement effects as each blade passes through the air, referred to as thickness noise;
- Loading noise generated by the steady aerodynamic loading which, because of blade rotation, has a phase velocity relative to the observer and a periodic unsteady loading when the propeller axis is at an angle of incidence to the airflow.

3.3 **Engine Noise**

This module has a preliminary global computation of the engine noise which is a very important parameter in predicting the acoustical emission of an airplane. ATTILA has the capability to accept external input generated by the user, or to compute using heuristic approximations, the noise coming from the engine. In case of external input, the Sound Pressure Level should be inputted as decibels versus frequency in one-third octave bands. The program computes the Doppler shift and the propagation from the source to the receiver. Linear interpolation, or extrapolation, is employed for missed data required during the computation. As for the other sources, the resulting values are properly added for the total noise calculation.

3.4 **Ground Reflection**, Ref. [12]

This module provides a means of estimating the effect on noise measurements, made at a position above the ground, due to the reflection of the sound wave by the ground. The ground reflection correction is estimated in the form of a difference spectrum, which may be subtracted from a measured spectrum to give a free-field spectrum or added to a free-field spectrum to give a measured spectrum.

3.5 **Atmospheric attenuation**, Ref. [13][14]

A sound wave propagating through the atmosphere loses acoustic energy by several processes. The most significant of these are the spherical spreading of the wave and gaseous absorption. In the acoustic far field, the loss of energy due to spherical spreading of the wave

is inversely proportional to the square of the distance of propagation. This loss is independent of atmospheric conditions.
This module provides a means of estimating the loss in sound energy due to gaseous absorption as the sound wave propagates through the atmosphere. The absorption processes are those due to molecular translation, molecular rotation, and the internal vibrational relaxation of oxygen and nitrogen molecules.

3.6 **Effective Perceived Noise Level**, Ref. [15][16]

The calculation of EPNL has been accomplished according to the indicated references, which provide a test case used for the verification of the correct programming.

4 CASE ANALYSIS

The aim of this section is to show the functioning of the ATTILA tool, through a test simulation, performed on the Airbus A220-300.
Firstly, it has been defined the geometric data of the reference aircraft, according to [17], see Fig. 8.
The configurations and trajectories of the aircraft in the landing and take-off conditions are obtained with *Preliminary design module* (described in section 2.1).
Following, the trajectories are provided to the ATTILA tool, to calculate the noise and to evaluate the EPNL at the certification points. Below are the results for the three certification points: Approach, Flyover and Lateral, see Fig. 9.
In order to demonstrate the validity of the results, a comparison with the EPNL calculated using ATTILA tool and medium EPNL of Airbus A220 family from EASA database [18]. The results are shown in the following Tab. 1.

MAIN GEOMETRIC DATA AND INTERIOR ARRANGEMENTS	
Cockpit crew	2 pilots
Cabin crew	3 (minimum)
Passengers	130 (2-class) - 160 (1-class)
Seats configuration	Two-by-three (economy)
Seat pitch	81.3 cm (economy, 135 pax)
Seat width	47 - 48 cm (economy)
Cargo volume	31.6 m^3
Overall lenght	38.71 m
Wing span	35.1 m
Wing area	112.3 m^2
Overall height	11.5 m
Fuselage diameter	3.7 m
Cabin width	3.28 m
Cabin height	2.13 m
Engines	2x Geared Turbofan, $T_0 \simeq$ 24,000 lbf

Fig. 8 - Reference regional turbofan aircraft

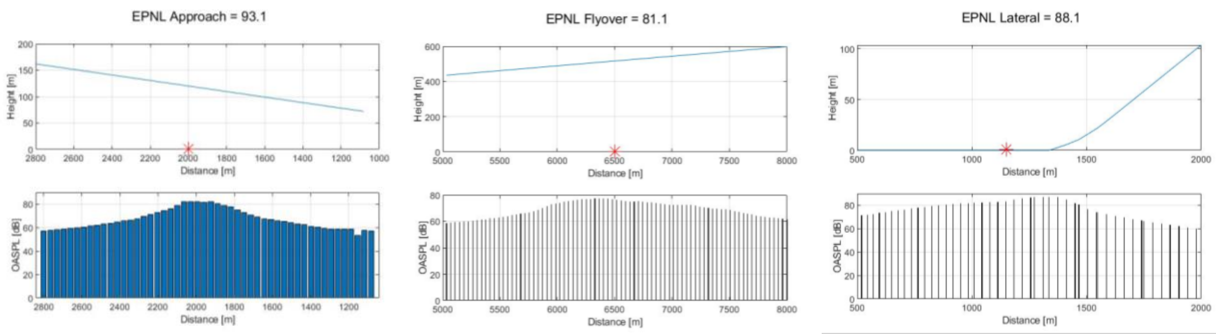

Fig. 9 – Results of ATTILA tool

	Numerical Data	Certification Data
Approach	93.1	92.4
Flyover	81.1	80.5
Lateral	88.1	87.3

Tab. 1 - EPNL evaluated at the certification points

5 CONCLUSIONS

This paper has presented the initial activities which have been agreed in a research project on the simulation of the design of commercial airplanes including noise emission. Usually the noise figures have been considered always a retrofit problem to be solved once the prototype of a new airplane is ready. In this project such problem is arising the dignity of a design problem from the very beginning of the design phase of new airplanes. Several studies can be found in the open literature which propose solutions like blended wings with over-mounted engines. In this case the driving idea was to start from existing airplanes in order to have the possibility to tune the software on known (or almost known) values, including options for potentially sensitive parameters, and moving from such architectures to evaluate feasibilities, mainly from the noise aspects, but without relaxing too much other parameters, of different (or slightly different) configurations. From the actual results and typical configurations, the noise module is able to predict the importance of the acoustic sources and can be tuned around the noise certification points. The first results indicate the strong importance of the engine noise and the capability to reproduce certification flight paths which have the same trend of the real measurements. The development of the project is expected to return confidence and potential benefits of other parameters, but always maintaining the focus on their mutual interaction which is the basis of a multidisciplinary design tool.

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