AIRCRAFT PARAMETER AND PROCEDURE DRIVEN SIMULATION OF AIRPORT AIRSIDE OPERATIONS

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Abstract

The objective of this paper is a method of simulating airport airside operations at an aircraft parameter and procedure level, which has been implemented into a software tool. It enables the user to evaluate new aircraft technologies according to their effects on various aspects such as capacity, noise and emissions, focusing on a high variability of both, aircraft parameters and operational procedures.

1 General Introduction

Today air traffic is steadily growing at an average rate of approximately 5% per year. Simultaneously the potential for infrastructural expansion to accommodate the future growth is limited. As a consequence, operational procedures and aircraft technologies are increasingly being examined. Thus, with growing numbers of flights operated at an airport, even small improvements per aircraft movement are gaining more and more weight. New technologies for aircraft or complete new aircraft concepts should be evaluated in respect of their effect on aspects like capacity or emissions. Therefore a methodology is needed that allows breaking down the air traffic at airports to a level where aircraft parameter changes and new procedures can be studied.

Existing commercial software tools for the simulation of airport airside operations are mainly based on current regulations and operational conditions [1]. In comparison, this project features a new approach, designed especially focused on a high variability of aircraft parameters and procedures.

2 Motivation and Objectives

The requirements for the new simulation concept were derived from results of a research covering existing simulation tools [5].

2.1 Status Quo

Whereas in the past airport airside traffic simulation mainly focused on infrastructure, nowadays new methods to evaluate aircraft based technologies in combination with new procedures are required.

Research on existing simulation tools [2][3][4] covering the respective flight segments has shown that most of them target the optimization of aspects such as approach patterns, departure routes, runway exits and taxiways through the optimization of airport infrastructure design. Therefore the representation of aircraft as “moving points” was sufficient [5]. The aircraft’s motion characteristics were mostly derived from empirically collected data. As a result, aircraft parameters were not needed for the purpose of the simulation and possibilities to evaluate aircraft based technologies through parameter variations very restricted.

The identified high specialization of the studied tools is the reason for most of them only allowing the evaluation of single aspects of a given problem. Additionally a SWOT-analysis of ten well-established tools revealed the lacking of suitable interfaces as another problem [5]. Therefore the combination of multiple evaluation results (such as capacity, delay, emissions and noise) on the same simulation basis is virtually impossible.

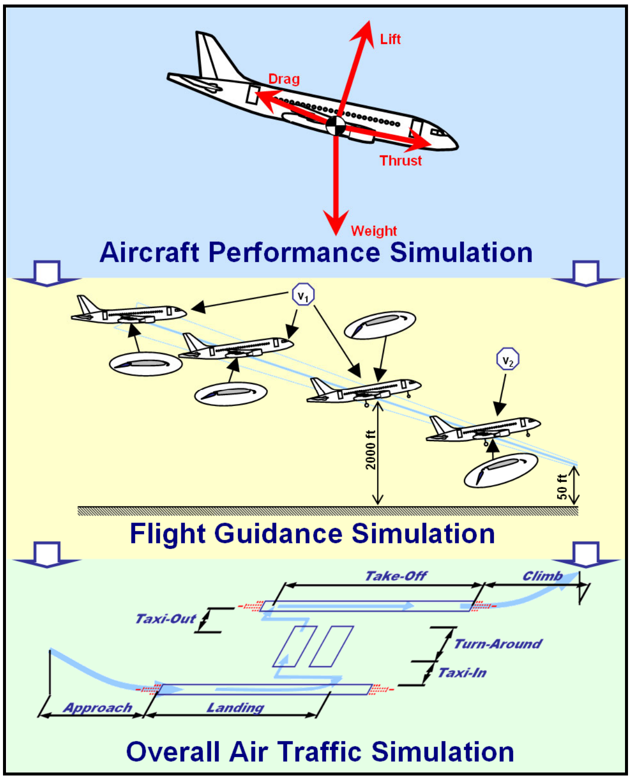

Fig. 1. Simulation phases within the tool concept.

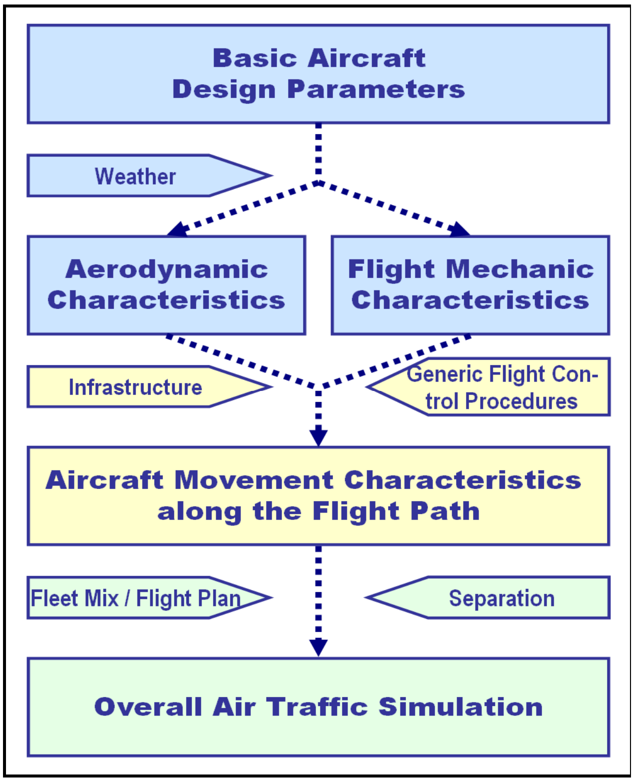

Fig. 2. Consecutive parameter transformation.

2.2 Objectives

Based on these results [5], the requirements for the new simulation concept for airport airside operations were defined.

Firstly, it should provide a large number of aircraft related process variables, opening up a wide range of different simulation modes. Therefore all aircraft movements shall be simulated based on aircraft flight physics which can be achieved employing an aircraft parameter and procedure driven modeling approach.

Secondly, the simulation tool shall provide a platform enabling to use its results for a variety of different evaluations including but not restricted to airport capacity, noise and emissions issues.

3 Tool Concept

The implemented simulation process is subdivided into three phases (see. fig. 1.).

In the **aircraft performance simulation**, the first phase, the aircraft's flight characteristics are calculated based on basic design parameters.

Using theses results as input, the **flight guidance simulation** generates the actual flight data along a predefined flight path. The aircraft control is modeled through the definition of generic procedures for each flight segment.

Finally, the **overall air traffic simulation** merges the previous phases' results, incorporating air traffic management parameters and procedures such as fleet mix, flight plan and separation.

The successive parameter transformation starting from basic aircraft design parameters until the overall air traffic simulation is visualized in fig. 2.

3.1 Aircraft Performance Simulation

In the first step of the performance simulation, aircraft preliminary design equations for aerodynamics [6][7][8][9] and flight mechanics [10] are employed to transform basic aircraft parameters (e.g. geometry data, design weights, engine data, aircraft technology) into flight mechanic and aerodynamic variables such as design speeds and lift and drag coefficients (see fig. 3.).

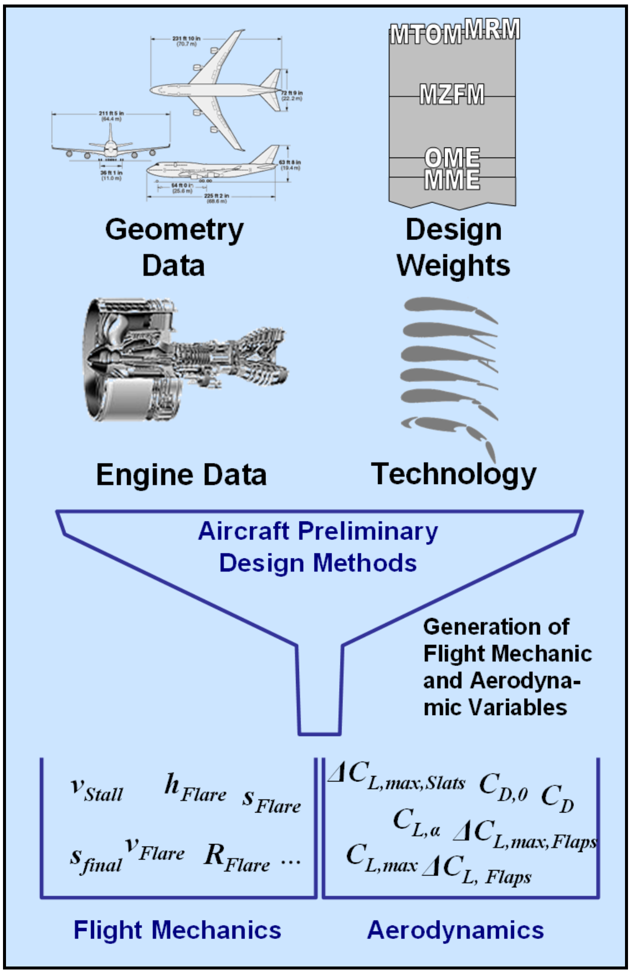

Fig. 3. Transformation of basic aircraft design parameters into flight mechanic and aerodynamic variables.

In a second step this information is combined with dynamic "flight path variables" such as angle of attack, current mass and altitude, to set up the balance of forces. Vertically, the balance of forces is regulated by adequately adjusting the aircrafts' angle of attack. Differences in the horizontal balance of forces result in positive or negative accelerations of the airplane and thus influence the aircraft's motion characteristics.

This phase of the simulation provides for the targeted high variability of basic aircraft design and performance variables.

Assumptions and Schematic Description of the Movement Characteristics Calculation Process

The calculations are performed for each simulation interval i which is defined by the selected

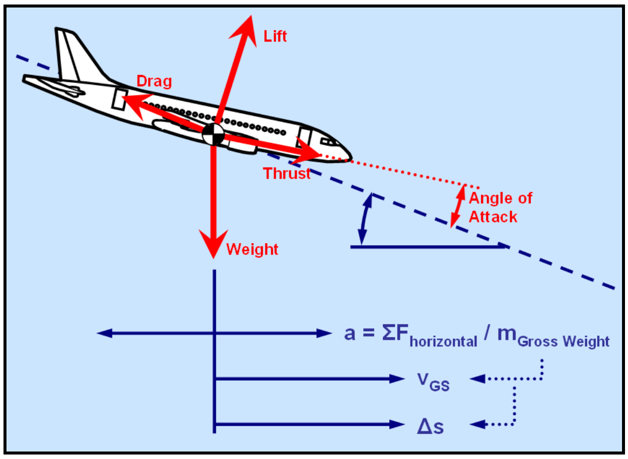

Fig. 4. Simplified visualization of the flight mechanical model employed.

resolution (e.g. 1 second) based on the flight path variables' state at the preceding step (i-1).

In order to reduce the simulation model to its essential mechanisms the following assumptions are regarded as acceptable (see also fig. 4.):

- Mass point representation of aircraft and
- the angle of attack and thrust (to some extent) serve as free variables to tune in the balance of forces.

Based on these assumptions the calculation of the aircraft movements during approach might look like the schematic description given in the following example. The aircraft movement of the state i+1 is calculated based on the state i:

Lift Coefficient $C_{L,i}$ = f(aerodynamic configuration)

↓ ↓

Thrust F_i, Angle of Attack α_i = f(Lift Coefficient $C_{L,i}$, Glide Angle γ_i, Aircraft Mass m_i)

↓ ↓

Drag Coefficient $C_{D,i}$ = f(Lift Coefficient $C_{L,i}$, Parasite Drag Coefficient $C_{D0,i}$)

↓ ↓

Sum of Horizontal Forces $\Sigma F_{x,i}$ = f(Thrust F_i, Drag D_i)

↓ ↓

Acceleration a_i = f(Sum of Horizontal Forces $\Sigma F_{x,i}$, Aircraft Mass m_i)

↓ ↓

Ground Speed v_{i+1} = f(Ground Speed v_i, Acceleration a_i)

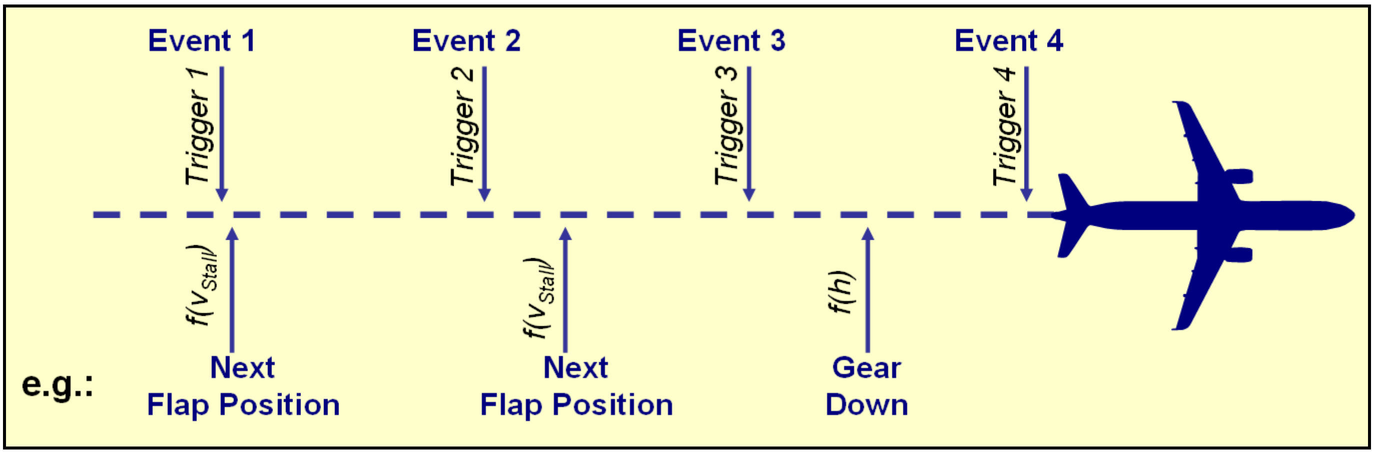

Fig. 5. Generic flight control procedures in the flight guidance simulation.

In the subsequent calculation interval, the thus calculated aircraft speed v_{i+1} and other flight path variables are the basis for the calculation of the state i+2.

3.2 Flight Guidance Simulation

The flight guidance simulation represents the function of a pilot, following generic aircraft control procedures [11][12] which are defined in a way that makes them applicable to any aircraft, independent of its type or model.

Concretely it controls changes of the aircraft's speed, glide path, flight direction, aerodynamic configuration, etc. according to triggers defined in the generic flight control procedures (see fig. 5.). Any available flight path variable can be used as trigger (e.g. aircraft position, speed, environmental conditions, time difference, and altitude).

Additionally the flight guidance simulation incorporates infrastructural [13] aspects regarding the circumstances at the study airport. It is parameterized incorporating all relevant information such as glide path, runway heading and altitude, position of runway exits and taxi procedures to the apron (currently only single runways can be studied).

3.3 Overall Air Traffic Simulation

The overall air traffic simulation incorporates air traffic management aspects and consolidates the results of the preceding simulation phases, providing the final simulation data-sets ready for further processing and analysis.

Implementation of Separation Regulations for the Final Approach

Once an aircraft has entered the final approach segment the aircraft's speed can be assumed as not being influenced by air traffic control inputs and only determined according to its specific flight characteristics.

Currently a distance based separation is implemented into the simulation according to existing ICAO regulations. To calculate the minimum allowed separation time, the flights of a pair of consecutive airplanes are simulated for the final approach segment. Due to compression effects and differences in the aircrafts specific motion characteristics a minimum separation distance can be measured at some point within final approach. The required separation time is then determined such that the minimum permitted separation distance during final approach is reached but never violated. Thus it is possible to calculate a densest sequence of approaching airplanes without violating any regulations. By incorporating an "ATC efficiency factor" (η_{ATC}) it is possible to adjust the theoretical densest sequence to throughput rates that are practically achievable at real operations.

This example shows how the final approach segment currently is modeled within the simulation. But the simulation concept is not restricted to existing aircraft sequencing rules but offers the opportunity to incorporate different separation types in an analogue manner. Also new separation rules can be integrated, which could for example be based on time or actual vortex intensity by implementing new vortex calculation models. These could then make use of the availability of the variety of different flight path variables.

3.4 Output Data-Sets

At the end of every simulation two different data sets are available for further processing and analysis.

For every aircraft within the fleet mix a specific set of flight parameters is generated in a predefined resolution (e.g. 1 second intervals). Examples for the data contained are airspeed, acceleration, altitude, angle of attack, thrust setting, fuel burn and actual gross weight.

Secondly, information regarding the landing sequence and further separation data are provided separately.

4 Validation

The software tool was validated using recorded in-flight data of different aircraft types.

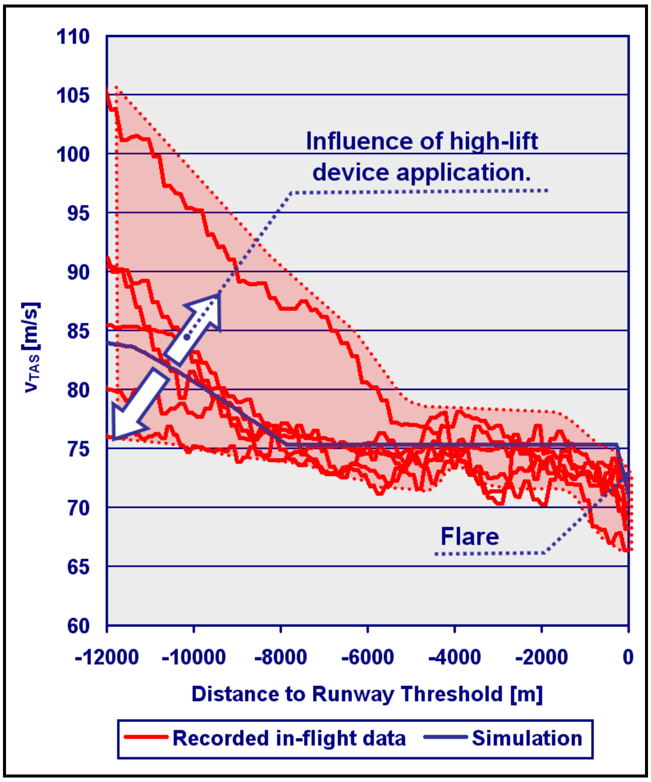

Fig. 6. True Air Speed validation example (Airbus A320, Airport: LSZH).

Example: True Air Speed

The example shown in fig. 6. compares simulated and real data of the final approach of an Airbus A320 at Zurich airport. It has to be noted, that due to missing environmental information at the time of recording of the real data, weather influence can not be estimated in this example. The mean value of different flights, however, can be regarded as a sufficiently realistic basis for comparison.

The diagram shows airspeed in relation to the aircraft's distance to the runway threshold prior to touch-down. The red lines represent the real recorded data whereas the blue line shows the simulation result.

In the left part of the analyzed flight sector, the variable application of high lift devices accounts for most of the spreading of the speed characteristics. Here the simulation results achieve realistic values, roughly representing the average speed of the measured data. In the right part of the diagram an issue becomes apparent which will have to be targeted at a following fine-tuning of the software tool: Deficiencies in the flare modeling. But when taking into account that this inaccuracy affects only a very short flight segment and that the touch-down-speed is correct, the currently rough modeling of this phase can be regarded as acceptable without major distortion of the final simulation results.

Further Validation Results

A variety of different flight parameters generated by the simulation tool were compared to real data for validation in the same way as shown in the preceding example.

As it was the case at validating the true air speed characteristics, a comparison of values for the lift coefficient (C_A) also revealed a coarse modeling of the flare, which is in need of further improvement.

Whereas it was possible to qualitatively validate the simulated characteristics of the angle of attack and the drag coefficient, their quantitative values consistently deviate form the real data. This is another area where further fine-tuning of the calculation model is still in progress.

The thrust characteristics which are crucial for emission evaluations could be verified to be sufficiently accurate.

5 Applications of the Simulation Tool

The first step of every simulation is the modeling of technologies and procedures which are to be studied. In a second step a scenario is defined. Following on the scenario definition the simulation can be started and the output data sets will be generated. These are then to be analyzed using postprocessors enabling to study a variety of different aspects such as airport capacity, emissions and noise.

Modeling of Technologies and Procedures

Through an adequate modeling of aircraft technologies and operational procedures complex problems can be prepared for the study. They are transferred into abstract aircraft, airport and procedural parameters. Technologies are analyzed according to their concrete parameter effects which enter the simulation either as percentage change or fixed difference values.

The thus compiled technology vector is entered into the simulation model. Thereby attention must be paid that the parameter changes are inherently consistent and ranging within realistic limits.

It depends on the intended study weather exact or qualitative changes are employed to represent a technology's or procedure's influence. Accordingly the simulation results have to be interpreted either quantitatively or qualitatively.

Scenario Definition

The compilation of the study variables and their variations, the infrastructural parameters and the weather conditions are among the main aspects when setting up a scenario. Depending on the simulation objectives a fleet mix or flight plan might also be included.

5.1 Capacity Studies

Delays are a direct indicator for the increasing congestion at airports, showing that capacity limits are reached. Since in most cases constructional extension of airport facilities is limited, other possibilities of capacity enhancement have to be found. Therefore areas such as flight procedures or aircraft technologies are increasingly being studied as possible solutions to the problem. Here the aircraft parameter and procedure driven simulation shows its strengths offering completely new simulation opportunities to determine technology and procedure impacts on the "Maximum Throughput Capacity" as defined at [14].

Preferred Application Area

Looking at the different phases of aircraft movements in the airport terminal area, it becomes apparent that many segments are only indirectly influenced by aircraft performance parameters. Thus the main focus for the parameter and procedure driven simulation is on approach, landing, take-off and climb, leaving out taxi and turn-around phases [15].

Parameter Studies in the Approach Segment

The variation of single aircraft design parameters allows studying their influence on the aircraft throughput in the approach segment and helps to understand how aircraft design aspects influence airport capacity. For this kind of study discrete parameters are varied for the sensitivity analysis, whereas interdependent variables are intentionally disregarded.

In a parameter study where different variables were altered and their effect on aircraft throughput was measured, aircraft mass, wing surface area and wing sweep could be identified as having major impact on throughput rates. This behavior can either directly or indirectly be traced back to the parameters' influence on the approach speed, which in turn depends on the stall-speed.

This exemplary study showed that most parameters only have minor influence on the aircraft throughput in the approach segment. But for some parameters clear trends became visible which could also be verified for different scenarios comprising different airport infrastructures [15].

Direct and Indirect Correlations' Impact on Aircraft Throughput Rates

Fig. 7. shows a flowchart of how configuration change procedures impact aircraft throughput rates during approach. This example visualizes the many direct and indirect correlations that cannot be discussed theoretically but require a simulative approach. Two major influence channels can be seen in fig. 7. Whereas the influence of approach speed is trivial and has a straight proportional impact, the influence share caused by differences of motion characteristics between aircraft cannot be predicted without simulation.

This kind of flow chart visualization provides a valuable tool when discussing simulation results and helps to understand the underlying principles.

5.2 Further Applications

A second field where the simulation tool is currently applied, is the analysis and evaluation of aircraft technologies regarding their impact on emissions within the airport vicinity. Thus the tool can contribute to develop new technologies and procedures helping to reduce pollution and to improve air quality around airports.

The testing of the simulation platform as input for noise studies is planned.

6 Further Development of the Tool

So far the tool concept covers the inbound segments of airport airside operations.

Next development steps will comprise a further refinement of the modeling and the inclusion of outbound operations (development currently in progress). In a next stage it is targeted to increase the complexity of the systems to allow simultaneous and interdependent simulation of inbound and outbound traffic and also the simulation of multiple runway systems shall be possible in the future.

7 Conclusion

A versatile tool concept could be realized which currently enables the simulation of inbound traf-

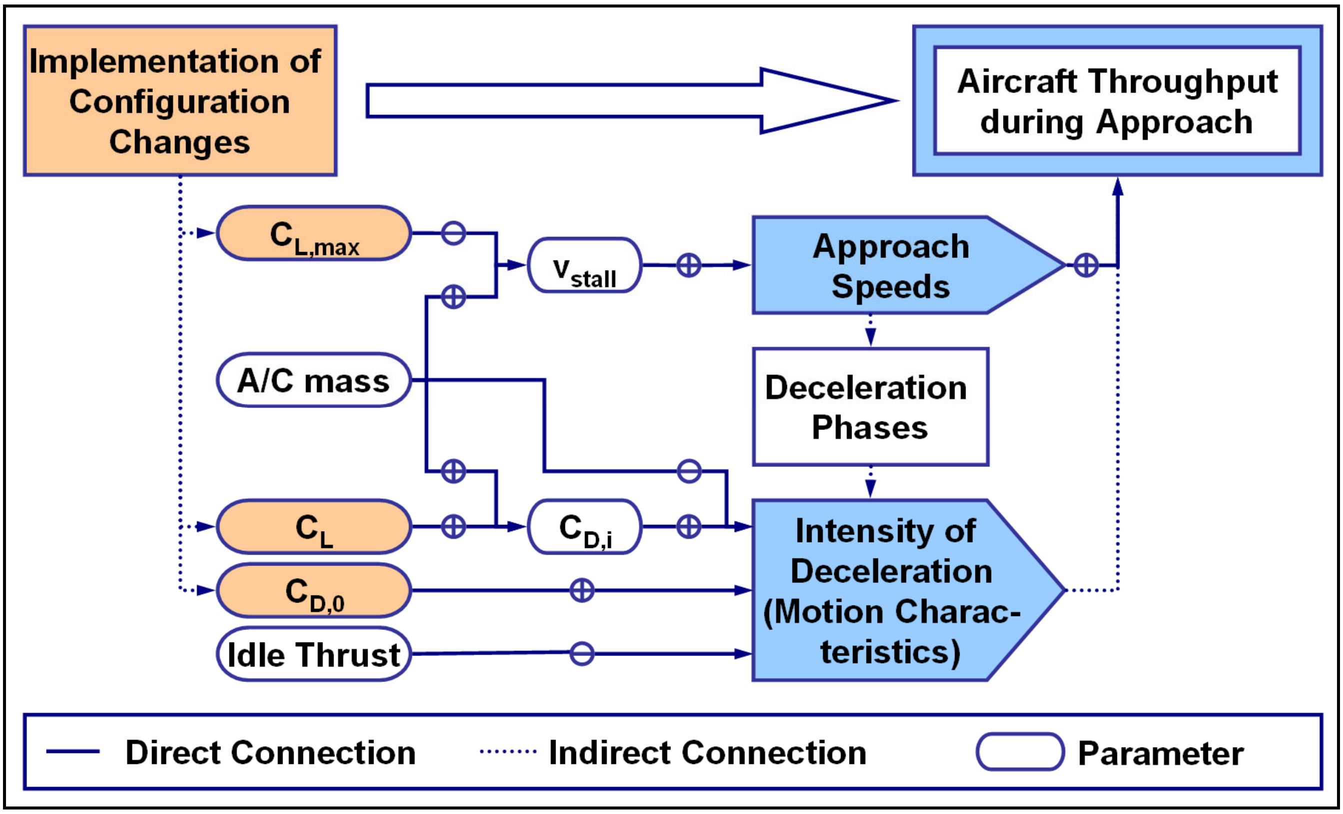

Fig. 7. Direct and indirect correlations between technology or procedure variations and aircraft throughput rates in the approach segment.

fic at single runway systems for nearly any scenario. The simulation results were validated using real flight data. Currently it is used for airport capacity and emission studies with plans for testing further applications in areas such as noise evaluations. The concept contains the potential for the inclusion of all phases of aircraft operation at airports. The output data of the simulation tool is universally utilizable and contains aircraft movement information as well as relevant aircraft parameters with variable resolution.

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