Systems Engineering Framework To Assess the Impacts of Very Large Capacity Aircraft in Airport Operations and Planning

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A methodology is presented to investigate the effect of Very Large Capacity Aircraft (VLCA) operations at existing and future airports. The procedure that is described investigates airport and airline impacts of VLCA operations using a systems engineering approach to understand the trade-offs between economic and technological operational factors. Specific topics discussed in this analysis are (a) the effect of VLCA on airport capacity, (b) development of new geometric design guidelines, (c) landside impacts and gate compatibility issues, (d) airside capacity impacts, and (e) possible noise and pavement design impacts. These aspects are modeled using the Systems Dynamics methodology, which permits a blend of technological and socioeconomic variables into the same model. Realistic parametric templates of feasible aircraft designs are defined using computer methods, and the impacts of proposed designs in airport operations, capacity, and economics are explored. The analysis focuses on the airside and landside capacity, geometric design constraints, and pavement and acoustic impacts of VLCA operations. A systems engineering perspective is used when aircraft design inputs have quantifiable outcomes on airport capacity, on infrastructure changes, and ultimately, on the cost of operations. Cost-effective ways to facilitate the operations of VLCA at existing and future airports are identified, including new design guidelines.

Various studies have suggested that very large capacity aircraft (VLCA) could be operating in the next decade (1–4). There are obvious concerns and limitations for such aircraft to operate on a daily basis at existing airports. Among some of the airport compatibility problems facing VLCA operations are reduced runway acceptance rates, increased passenger flows at the terminal, possible geometric design standard conflicts, and pavement design and noise constraints.

The future success of VLCA depends on adequate preparation by airports to deal with the ancillary problems created by the operation of VLCA. This study attempts to look at the issue as a complex engineering problem involving variables of technological and economic order. The study also addresses a clear trade-off in VLCA operations in which airlines might be forced to operate a nonoptimal aircraft design that complies with current geometric design standards or in which airports face the challenging task of adjusting their infrastructure to allow VLCA operations routinely.

METHODOLOGY

Systems Dynamics (SD) was developed at MIT by Professor Jay Forrester as a methodology to enhance decision-making capabilities in models involving variables of technological and economic nature. Figure 1 illustrates the use of SD for the study of VLCA operations in which various fields of interest (e.g., pavement design, airside capacity, landside capacity) are combined under the umbrella of a single model. Figure 1 shows that various aspects of VLCA operations are addressed using specific models and then combined into a single macromodel that contains pertinent results that can be modeled at a higher decision level (i.e., only results of specific simulations are included in the decision-making VLCA systems engineering model).

Aircraft Preliminary Design Module

Several aircraft manufacturers have undertaken studies to identify markets in which a VLCA could operate efficiently and economically (1–4). The same studies have produced sketchy aircraft configurations ranging in size from 4100 to 5500 kN. An integrated systems engineering analysis of VLCA operations requires a preliminary design module to ascertain the impact of mission profile requirements to airport operations and cost economics. Preliminary design procedures start with the assumption that a mission profile, payload, takeoff and landing requirements are known, along with a few details of the geometric configuration of the vehicle (decision design variables).

Following standard design procedures, the program estimates the required fuel fraction (i.e., fraction of the maximum takeoff weight needed in fuel) to complete the given mission profile. Because the initial aircraft weight is not known, an initial takeoff weight (TOW) is guessed and iterated until it satisfies the mission constraints. For long-range transport aircraft, range and cruise speed are two of the most important design variables used in sizing the vehicle. Once an equilibrium weight configuration is known, aerodynamic characteristics of the vehicle are estimated using standard drag bookkeeping procedures (5–7).

Cruise, landing, and takeoff analyses are carried out to estimate thrust requirements to satisfy high-speed cruise conditions, takeoff, climb, and landing roll constraints. Engine scaling laws are then used to select a power plant to satisfy the most demanding thrust condition criteria. This information is fed back to the aircraft sizing procedure until a suitable convergence is achieved between two successive aircraft configurations. Figure 2 illustrates this iterative procedure.

To illustrate the design module, a parametric study of an aircraft capable of carrying up to 650 passengers in a three-class configuration over various design ranges is shown in Figure 3. Note that gross
takeoff weight grows rapidly with increments in desired range due to the added fuel fraction needed to accomplish the mission. Table 1 contains the expected design requirements of a conceptual VLCA. Figure 3 illustrates the results of a parametric sizing process for VLCA for various aspect ratios and range configurations. Figure 3a demonstrates that there is a clear nonlinear relationship between the size of the aircraft and the desired range for constant-cruise Mach number and payload conditions. The same figure shows that higher-aspect ratio wings are more efficient in cruise and thus result in lighter aircraft for a given mission profile. Figure 3b uses the same analysis and shows small increments in aircraft wingspan for the same mission range.

This illustrates the trend in current technology aircraft toward higher-aspect ratio wings (AR > 8.5). Historically, few aircraft have been restricted by airport infrastructure constraints. The Boeing 777 constitutes an example of good airport compatibility planning with an optional folding wing mechanism. However, no airline has yet ordered this aircraft with this option (8), which reflects airline concerns about the operational economics rather than gate compatibility issues. New generation transport aircraft have wing aspect ratios (i.e., a measure of the wing planform that dictates aerodynamic efficiency) approaching 10 to minimize induced drag in cruise conditions. It is reasonable to expect that VLCA will have aspect ratios between 9 and 10, thus complicating the airport gate and taxiway compatibility issue.

Current FAA design standards contain provisions for large aircraft with wingspans up to 79.5 m (9,10). It is clear, however, that very few airports could actually accommodate such a vehicle if one is to be launched within the next 3 years unless some improvements to landside and airside facilities are implemented. According to the preliminary parametric study of Figure 3, the current aircraft wingspan limits contained in the FAA Design Group VI could actually be surpassed by designs capable of nonstop trips of up to 13 000 km with a full complement of passengers. Figure 4 shows a schematic VLCA...
design to satisfy the design requirements of Table 1. The obvious trade-off is that, if a designer is willing to limit the design to current airport design standards (i.e., FAA Design Group VI), the airlines could end up paying a large penalty in operational performance in the long term.

**Airside Capacity Considerations**

Airside capacity is generally dictated by large in-trail longitudinal separations that are required between successive aircraft arrivals and departures. The vortex wake generated by large and heavy transport aircraft is considerable and thus needs to be accounted in the overall capacity of the facility. A simple procedure to establish aircraft in-trail separations has been the roll control ratio criteria (referred to as “criteria” hereafter) proposed by Andrews and Robinson (11). The procedure estimates the ratio of the roll acceleration produced by a leading aircraft vortex shed on a trailing aircraft and the roll acceleration of the trailing aircraft at maximum aileron deflection. Using the nomenclature proposed by Rossow and Tinling (12), this parameter is defined mathematically as

\[ \dot{P} = \frac{\dot{P}_v}{\dot{P}_{\text{max}}} \]  

where

\[ \dot{P}_v = \text{the induced roll acceleration on a trailing aircraft due to the wake vortex of a leading aircraft,} \]
\[ \dot{P}_{\text{max}} = \text{the maximum roll acceleration possible with full deflection of the lateral control aerodynamic surfaces, and} \]
\[ \dot{P} = \text{the roll acceleration quotient.} \]

Flight evaluations conducted by NASA and the FAA in the seventies suggested separation minima between successive aircraft arrivals according to the rolling acceleration quotient principle (11,13,14). Several studies have suggested that values of 0.5 to 1.0
are acceptable for most Instrument Meteorological Conditions approach conditions (12), but even such guidelines imply a wide range of separation minima between aircraft.

Using a roll acceleration quotient of unity, Andrews and Robinson (9) estimated the separation between three types (sizes) of aircraft: small, medium, and large transports as they follow large and heavy jet transports. Using linear interpolation and the predicted landing weights of VLCA transports, a simple general relationship can be found to estimate aircraft separation criteria. Let $W_i$ and $W_j$ be the approach landing weights (in kN) of a leading and a trailing aircraft, respectively. Define a general in-trail separation expression as

$$\delta_{ij} = \max\left(L_1 + L_2 W_i, K_1 + K_2 W_i + K_3 \left(W_j\right)^{K_4}\right)$$

where $\delta_{ij}$ is the recommended separation distance between aircraft $i$ and $j$ in km, and $K_1, K_2, K_3,$ and $K_4$ are regression constants found to be 6.1000, 0.00378, -0.24593, and 0.44145, respectively. Constants $L_1$ and $L_2$ are 4.7000 and 0.00172 and have been derived using empirical roll control flight simulation data (14) with modifications by the authors to reflect possible application to VLCA. This equation is plotted in Figure 5a. Extrapolating these results for a hypothetical VLCA weighing 4100 kN in the landing configuration, one

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>Passenger Capacity</td>
<td>650 passengers in a three-class layout plus crew</td>
</tr>
<tr>
<td>Desired Range</td>
<td>13,000 Kilometers with 1.50 hour reserve</td>
</tr>
<tr>
<td>Speed</td>
<td>Mach 0.85 at 11.0 Km</td>
</tr>
<tr>
<td>Runway Length</td>
<td>Use of conventional runways (i.e., 3,300 m at MTOW and Sea Level ISA conditions)</td>
</tr>
</tbody>
</table>
FIGURE 4 Conceptual VLCA transport developed by the aircraft design module.

FIGURE 5 Recommended in-trail separation criteria for approaching aircraft using (a) the $P$ criteria and (b) tangential velocity matching criteria.
can see that aircraft separations of up to 18 km (9.7 nautical mi) might be needed to dissipate the harmful effects of the wake vortex generated against general aviation and small business jet aircraft. Under current IFR rules, most airports in the United States would use separations of 11.1 to 14.8 km (6 to 8 nautical mi) when heavy aircraft are followed by small ones. This practical separation standard is closely represented in Figure 5 if the landing mass of a Boeing 747-400 (2795 kN maximum) is used as the lead aircraft data point. The same analysis seems to be consistent with simple vortex decay models reported in the literature (12,15).

Another clue to estimate just how strong the wake vortex effects from a VLCA transport can be obtained from basic aerodynamic theory. The circulation around an aircraft wing with elliptical spanwise lift distribution is

$$\Gamma = \frac{4mg}{\pi \rho \bar{V} b}$$

where

- $\Gamma = \text{the vortex circulation (in m}^2/\text{s)}$,
- $mg = \text{the gross weight of the wake-generating aircraft (N)}$,
- $\rho = \text{the air density (kg/m}^3)$,
- $\bar{V} = \text{the true airspeed (m/s)}$, and
- $b = \text{the aircraft wingspan (m)}$.

The location of the vortex core for this elliptical lift distribution occurs at a distance $\pi b/8$ from the aircraft plane of symmetry, and the vortex tangential speed distribution is given by

$$V_t = \frac{\Gamma}{2 \pi \gamma} \left[1 - e^{-\frac{\gamma^2}{2e^2}}\right]$$

where

- $V_t = \text{the tangential velocity right or left from vortex core (m/s)}$,
- $\gamma = \text{the spanwise coordinate measured from the vortex core location}$,
- $e = \text{the vortex decay value that has been found to be dependent on the strength of the circulation}$, and
- $t = \text{the time behind the wake-generating aircraft (in s)}$.

Using these basic aerodynamic principles, the wake vortex intensity of a VLCA transport (i.e., 81.5 m in wingspan), measured by the peak tangential speed of the vortex, is expected to be around 33 percent higher than that of a Lockheed C5A military transport aircraft approaching at 82.3 m/s (160 kns) at sea level. If it is assumed that existing separation standards are safe for four aircraft groups (i.e., general aviation, small, large, and heavy), then a second in-trail separation criterion can be derived by equating the peak vortex tangential speeds of existing heavy aircraft with those of a future VLCA as they lead smaller aircraft. Using this guiding principle, in-trail separation results are shown in Figure 5 for various VLCA designs described in this paper. Note that, while these in-trail separation distances are somewhat smaller than those derived using the $P$ criteria, they are still higher than those used today.

The results shown in Figure 5 clearly illustrate the need for detailed analysis of wake vortex interactions of future transports. The results shown in Figure 6 demonstrate the impact of VLCA in airport capacity. For example, mixing VLCA with commuters/business jets and even small transport aircraft (i.e., approach Class C) offers significant penalties to the runway capacity, as illustrated in Figure 6. Using a generic airport scenario with two parallel runways (i.e., > 1310 m separation and standard radar scan rate of 4 s) with mixed traffic on both runways, a reduction of 18 percent in the arrival saturation capacity is found when 20 percent of the aircraft mix is of the VLCA type. These results have been obtained using the saturation capacity formulation of Harris (16). The same figure shows that, under high VLCA operations (i.e., 20 percent of the total airport mix), there is a reduction of up to 10 percent in the departure saturation capacity due to larger departure-departure separations, as well. The ultimate effect on capacity is dependent on the fleet composition operating at the airport.

### Landside Capacity Considerations

The most prominent effect of VLCA operations at large airports is the possible growth in passenger flows inside terminals, the gate compatibility problems associated with large wingspans, and the terminal compatibility with double-deck designs. Analysis of VLCA/airport terminal compatibility can be executed with the use of computer simulation models such as ALSIM and ALPS (17). This involves the modeling of terminals to determine Terminal Levels of Service (TLOS) given new passenger demand flows. To illustrate the usefulness of the simulation models, passenger flows through a large international concourse are simulated using ALPS—a computer simulation model developed at the Transportation Sys-

![FIGURE 6 Runway saturation capacity for various aircraft mixes (parallel runway configuration with mixed traffic on both runways).](image-url)
tems Laboratory at Virginia Tech. The results presented in Figure 7 suggest possible reductions in TLOS at this terminal if no enhancements are made to accommodate VLCA operations. Figure 7a shows the physical representation of the international terminal with five gates for the VLCA scenario and seven gates for current heavy-transport technology. The VLCA deplaning model is shown in Figure 7b. In both scenarios in Figure 7a, the terminal frontage requirements are equivalent (thus assuming complete replacement of current wide-body technology with new VLCA to study the effect of VLCA without folding wings), and the corresponding transient queueing parameters at the immigration section of this terminal are illustrated in Figure 7c. The simulation results shown assume 30 immigration servers with normally distributed service times ($\mu = 1.0$ and $\sigma = 0.25$, min) and with aircraft arrivals evenly spaced within a 90-min period.

Note that, in the worst-case scenario (i.e., assuming VLCA at 85 percent load factor), the maximum queue lengths expected are 14.3 and 9.5 passengers per station for the VLCA and baseline (i.e., current wide-body technology aircraft) scenarios, respectively. Expected delays per passenger vary from 14.5 to 8.7 min for the VLCA and baseline scenarios, respectively. The simulations carried out here assume normally distributed deplaning rates of 16 and 25 passengers per minute for wide-body and VLCA, respectively. This considers a second-level processing facility for VLCA to expedite turnaround times. The results presented here would be more dramatic if the effect of VLCA operations using folding wings is

![Figure 7](image)

**FIGURE 7** VLCA airport terminal operations using an airport terminal planning model.
studied, with an equal number of VLCA and current wide-body aircraft being serviced.

**Geometric Design Considerations**

Simulations of VLCA movements around the airfield are useful in developing new guidelines for runway and taxiway widths, taxiway to taxiway/taxilane separations, obstacle free zone (OFZ) and holding area dimensions, and other geometric design factors (9). Aircraft undercarriage width dimensions of conceptual VLCA studied in this analysis range from 13.0 to 18.0 m (42.6 to 59.0 ft) for various wingspan scenarios, aircraft center of gravity configurations (c.g. values), engine position, and landing gear arrangements. Figure 8a shows feasible aircraft undercarriage width configurations for several aircraft center of gravity configurations (c.g.) and turnover angles. Current commercial transport aircraft designs employ turnover angles ranging from 39 to 46 degrees with wide-body aircraft averaging 42 degrees (18). The turnover angle consideration is necessary to provide a good stability margin during high-speed rollout conditions. Based on the detailed taxiway fillet estimations provided in Figure 8b, it can be concluded that current design standards (i.e., FAA Design Group VI) are marginally acceptable for this type of aircraft. Advanced versions of a VLCA will have marginal turning capability with current fillet design criteria unless a new design standard is developed. The same conclusion has been reported by Boeing for proposed supersonic transport aircraft.

**Pavement Design Considerations**

Pavement design considerations also must be considered in our systems approach study given the large weights expected for VLCA. It is expected that the effects of VLCA on runway, taxiway, and terminal apron pavements can be somewhat alleviated through the use of complex landing gear assemblies with multiple wheels. However, potential weights for VLCA of up to around 500 metric tons (1.2 million lb) would certainly call for a close look at the effects of such loading on existing pavements. Our principal interest lies in the possible assessment of maintenance and infrastructure improvements actions that airport authorities should undertake to allow routine VLCA operations to specific airports.

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**FIGURE 8** Expected VLCA undercarriage dimensions and fillet radius versus turnover angle and aircraft c.g. position.
Recent studies using elastic and inelastic multilayer methodologies suggest that current practices overpredict the thickness of airport flexible pavements for multiwheel aircraft configurations (19,20).

**Noise Considerations**

Acoustical design considerations also should be taken into account in this integrated systems engineering evaluation of VLCA operations. VLCA are likely candidates to use the new generation of high-bypass-ratio engines such as the Rolls Royce Trent 800, Pratt and Whitney PW 4086, and General Electric GE90. Although these engines offer better fuel efficiencies in cruise than previous high-bypass-ratio engines, they develop considerably more thrust, thus potentially generating more noise.

This analysis estimates $L_{DEN}$ noise contours that compare VLCA with existing third-generation, wide-body transport aircraft (i.e., Boeing-Douglas MD-11). Using the FAA Integrated Noise Model—INM 5.1 (21) and the aerodynamic and engine performance derived in the preliminary design module, we estimate the noise signature of the VLCA during takeoff to be 15 to 20 percent higher than that of a Boeing-Douglas MD-11. Several economic methods have been proposed in the literature to assess the impact of aircraft noise (22); they also can be adapted to convert noise measures of merit to nonuser annoyance costs.

**Economic Impacts and Trade-Off Methodology**

The economic decision to operate VLCA will ultimately rely on each airline and its passenger demand base. However, the operational advantages of VLCA in the future would have to be weighted objectively with a methodology that addresses all technical and economic factors simultaneously and not in isolation.

The method of analysis proposed here integrates the expertise and knowledge of various fields in air transportation engineering to determine best strategies and possible new policies to help VLCA become an operational reality and to minimize negative impacts to existing airports. Figure 9 illustrates the integrated Systems Dynamics Model for VLCA operations developed using

![FIGURE 9 Systems Dynamics trade-off model for VLCA analysis.](image)
STELLA II, a Systems Dynamics graphical software developed by High Performance Systems (STELLA is a trademark of High Performance Systems, Inc., New Hampshire). The model takes into account inputs from all of the technical disciplines described before and looks at the impact of VLCA operations in an integrated fashion. The methodology is site-specific in its application because not all cost components are the same for all airports/airlines. Nevertheless, the method establishes a clear trade-off between aircraft design optimization and user and service provider costs. Table 2 shows possible design standards that airport planners could adopt to accommodate VLCA transports.

Table 2 Proposed Airfield Geometric Design Standards for Various VLCA Designs

<table>
<thead>
<tr>
<th>VLCA Aircraft Design Range in Km (m)</th>
<th>FAA Design Group VI</th>
<th>12,038 6,500</th>
<th>12,038 6,500</th>
<th>12,965 7,000</th>
<th>12,965 7,000</th>
<th>13,890 7,500</th>
<th>13,890 7,500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Wing Aspect Ratio</td>
<td>N/A</td>
<td>9.0</td>
<td>10.0</td>
<td>9.0</td>
<td>10.0</td>
<td>9.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Aircraft Weight (KN)</td>
<td>N/A</td>
<td>5,034</td>
<td>4,588</td>
<td>5,702</td>
<td>5,123</td>
<td>6,504</td>
<td>5,791</td>
</tr>
<tr>
<td>Aircraft Wingspan (m)</td>
<td>80 (262)</td>
<td>77 (253)</td>
<td>78 (255)</td>
<td>82 (268)</td>
<td>82 (268)</td>
<td>87 (285)</td>
<td>87 (285)</td>
</tr>
<tr>
<td>RW\textsuperscript{c} C\textsubscript{L} \textsuperscript{b} to TW\textsuperscript{c} C\textsubscript{L}, Spacing (m)</td>
<td>183 (600)</td>
<td>183 (600)</td>
<td>183 (600)</td>
<td>183 (600)</td>
<td>183 (600)</td>
<td>183 (600)</td>
<td>183 (600)</td>
</tr>
<tr>
<td>TW C\textsubscript{L} to TW C\textsubscript{L}, Spacing (m)</td>
<td>99 (324)</td>
<td>95 (313)</td>
<td>96 (316)</td>
<td>101 (331)</td>
<td>101 (331)</td>
<td>107 (352)</td>
<td>107 (351)</td>
</tr>
<tr>
<td>TW C\textsubscript{L} to Object Spacing (m)</td>
<td>59 (193)</td>
<td>57 (187)</td>
<td>57 (188)</td>
<td>60 (197)</td>
<td>60 (197)</td>
<td>64 (209)</td>
<td>64 (209)</td>
</tr>
<tr>
<td>TL\textsuperscript{d} C\textsubscript{L} to Object Spacing (m)</td>
<td>51 (167)</td>
<td>49 (161)</td>
<td>50 (163)</td>
<td>52 (170)</td>
<td>52 (170)</td>
<td>55 (181)</td>
<td>55 (181)</td>
</tr>
</tbody>
</table>

a. Runway, b. Centerline, c. Taxiway, d. Taxilane

CONCLUSIONS

The intent of this paper was to propose an integrated analysis method to measure the effects of VLCA operations. The approach proposed here has been implemented into a computer using Matlab and STELLA II. The proposed approach attempts to tie aircraft design parameters with airport design standards.

From the analysis carried out here, it is believed that operations by VLCA could benefit the airlines and the public by potentially offering lower direct operating costs than existing wide-body aircraft. Depending on the analysis technique used, a reduction of up to 15 percent in Direct Operating Cost could result from a typical VLCA operation. However, certain airport costs incurred before VLCA operations are expected to arise because these aircraft will require changes to airside and landside terminal designs to offer tolerable levels of service and to meet airside safety criteria. Until now, few aircraft have been designed with airport compatibility as a primary constraint in the aircraft optimization design process. This consideration is expected to play a more prominent role in the design of VLCA because many international airports have limited opportunity to expand their airside infrastructure. Over a typical life cycle, aerodynamic cost efficiencies might ultimately dominate the design because both passengers and airlines will benefit from the lower cost economics of VLCA.

There is a clear trade-off in designing aircraft that will comply with existing airport design standards and those designs in which the vehicle is fully optimized for the mission without airport constraints. If a new design is constrained by existing airport design guidelines, a performance penalty will be paid by the airlines and, ultimately, by users because the airlines would have to offset higher operating costs associated with nonoptimal designs for a given route structure.

RECOMMENDATIONS

The results presented in this study demonstrate that, while VLCA are likely to meet some geometric design standards, a few issues such as wingspan, wake vortex, and terminal designs should be studied in an integrated fashion. These issues require a more in-depth examination to weight the real advantages of VLCA. It
is suggested that the FAA revises the existing dimensional standards for Design Group VI to include stretched versions of VLCA. The proposed revised standards should consider vehicles of up to 87 to 90 m in wingspan because these are feasible for stretched VLCA serving long-range international markets of up to 13,860 km (7,500 nautical mi) with 750 passengers in a three-class seating configuration.

Because the methodology presented here is airport-specific and has been applied only to a modern airport designed to meet FAA Design Group V criteria, it is recommended that future investigations consider existing international airports such as JFK International Airport, San Francisco International Airport, and Chicago O’Hare International Airport. These analyses should provide realistic trade-off figures between the size of the aircraft and the costs associated with their operation at real airports.

REFERENCES


| TABLE 3 | Airport Infrastructure Improvement Parametric Study To Support VLCA Operations |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Desired Range in km. | 10,186 (5,500) | 12,965 (7,000) | 13,890 (7,500) |
| and (n.m.) | 9.5 | 9.5 | 9.5 |
| Aspect Ratio | 0.85 | 0.85 | 0.85 |
| Cruise Mach Number | 650 | 650 | 650 |
| VLCA Capacity (pass.) | 3,830 (860,000) | 5,385 (1,210,000) | 6,100 (1,370,000) |
| MTOW RN (lbs) | 70 | 82 | 87 |
| Wingspan (m.) | | | |

Airfield Pavement Section Improvement | 0 | 0 | 0 |

Noise Mitigation | 5,000,000 | 7,872,000 | 10,000,000 |

Runway Improvement | 19,250,000 | 19,250,000 | 24,319,277 |

Taxiway Improvement | 13,663,234 | 13,663,237 | 15,413,237 |

90 Degree Exit Improv. | 276,343 | 384,694 | 386,622 |

Runway Blast Pad Area Improvement | 1,200,000 | 1,200,000 | 1,589,673 |

Terminal Apron Area Improvement | 0 | 77,685 | 113,207 |

Land Acquisition Cost | 63,869 | 229,328 | 297,101 |

Airfield Geometric Infrastructure Improvement Cost | 39,017,641 | 48,299,715 | 59,736,701 |

Terminal Curb Frontage Improvement Cost | 45,900 | 45,900 | 45,900 |

Parking Garage Improvement Cost | 2,653,750 | 2,653,750 | 2,653,750 |

Landside Improvement Cost | 2,699,650 | 2,699,650 | 2,699,650 |

International Terminal Infrastructure Improvement Cost | 77,523,165 | 77,523,165 | 77,523,165 |

Total Airport Infrastructure Improvement Cost | 124,240,456 | 136,394,530 | 149,959,516 |

The basic airport infrastructure used in this hypothetical example consists of two parallel runways spaced 1.45 km away, dual taxiways spaced 87.5 m away and distance between runway and outer taxiway at 183 m. The results are meant to illustrate orders of magnitude expected at medium size airports designed under FAA Design group V criteria. The reader should note that many international airports in the U.S. have been designed under older standards and thus infrastructure costs could be higher than those presented here.

Amounts are in dollars and represent overall economic impact to airport authorities and airlines.

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