INTEGRATED OPTIMIZATION OF AIR TRANSPORTATION SYSTEMS (AIRCRAFT AND NETWORK)

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ITA

*À minha amada família*

*Luciana, Anna Carolina e Enzo*

Acknowledgments

Esta parte é dedicada aos agradecimentos aos professores, funcionários, colegas e familiares que ajudaram no seu trabalho.

Caso o aluno tenha sido bolsista, é importante agradecer à agência de fomento responsável pelo suporte financeiro (CAPES, FAPESP, CNPq, etc).

*"Esta página é opcional. Pode conter uma epígrafe,*

*ou seja, a citação de um pensamento, de uma frase ou de um provérbio”.*

(Nome do Autor da Citação)

Abstract

Assim como a pesquisa científica segue normas, regras e procedimentos definidos para gerar novos conhecimentos, os resultados obtidos também devem ser padronizados conforme as diretrizes nacionais e internacionais de normalização para serem disseminados entre os pesquisadores, facilitando a leitura e compreensão da comunidade acadêmica e científica. Aplicar corretamente as normas no planejamento e apresentação de projetos e trabalhos científicos requer algumas exigências na elaboração dos elementos pré-textuais, textuais e pós-textuais dos documentos de forma a valorizar os resultados da pesquisa realizada. O presente manual se propõe a apresentar o formato que dissertações e teses desenvolvidas no ITA devem seguir, atento às peculiaridades do Instituto e às regras de padronização da Associação Brasileira de Normas Técnicas (ABNT), adotando a estrutura desde o modelo da folha de rosto até o último elemento pós-textual, exemplificando e ampliando suas aplicações de modo mais didático para obtenção da qualidade na sua editoração.

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List of Abbreviations

|  |  |
| --- | --- |
| *a0* | Speed of sound at sea level on standard atmosphere [m/s] |
| *ACO* | Ant colony optimization algorithm |
| *ADj* | Arrival delay at airport j [min] |
| *AED* | Airport and econometrics database |
| *AFA* | Approach and landing fuel allowance [kg] |
| *AFP* | Aircraft fixed parameters |
| *ailpos* | Aileron position on wing semi-span [%] |
| *AisleW* | Aisle width |
| *AIP* | Aeronautical Information Publication |
| *ALD* | Average landing delay [min] |
| *ANN* | Artificial neural network |
| *ANOPP* | Airplane Noise Operations Prediction Program |
| *AOCFP* | Aircraft operational/certification fixed parameters |
| *APTID* | ICAO’s four-letter code airport designator |
| *ATA* | Approach and landing time allowance [kg] |
| *ATAG* | Air Transport Action Group |
| *ATD* | Average takeoff delay [min] |
| *ATM* | Air Traffic Management |
| *AVL* | Aerodynamics Vortex Lattice |
| *B* | City pair combined buying power index |
| *Bi* | Buying power index related to the city of the i-th airport |
| *BPR* | Engine by-pass ratio |
| *b* | Passenger capacity |
| *bflap* | Flap length on semi-span [%] |
| *bk* | Passenger capacity of k-th aircraft |
| *BuffMGN* | Buffet margin (g) |
| *CARGO* | Total cargo loaded onboard [kg] |
| *C* | City pair airport catchment area product |
| *Ci* | City pair airport catchment related to the i-th airport [km2] |
| *CabHt* | Passengers cabin internal height [m] |
| *CAS* | Calibrated airspeed [kt] |
| *CAPEX* | Capital expenditure [US$] |
| *CAPSAL* | Captain´s hourly salary [US$/h] |
| *CD* | Total aircraft drag coefficient |
| *CD0* | Zero lift drag coefficient |
| *CD0 ubridge* | Zero lift drag increase due to wing-fuselage interference |
| *CDflap* | Drag increase due to takeoff flap extended |
| *CD ind* | Induced drag coefficient |
| *CDgear* | Drag increase due to landing gear extended |
| *CDMMO* | Drag coefficient evaluated at maximum operating Mach number |
| *CD wave* | Wave drag coefficient |
| *CD wing* | Total wing drag coefficient |
| *CDwindmill* | Drag increase due to wind milling of a failed engine |
| *CDrudder* | Drag increase due to ruder deflection |
| *CD0.70* | Drag coefficient evaluated at 0.7 Mach number |
| *Ceiling* | Maximum aircraft certified altitude [ft] |
| *Cflt* | Flight component of direct operational cost (crew, oil, fuel and insurance) [US$/nm] |
| *Cmaint* | Maintenance (labor and material) component of the direct operational cost [US$] |
| *Cdepr* | Depreciation (airframe, engines and avionics) component of the direct operational  cost [US$] |
| *Cfee* | Fees (Navigation, Airport and Register) component of the direct operational cost [US$] |
| *Cfin* | Financial (airframe and engine leasing) component of the direct operational cost [US$] |
| *CFD* | Computer fluid dynamics |
| *CG* | Aircraft’s center of gravity |
| *chordc* | Airfoil chord length at central fuselage [m] |
| *chordk* | Airfoil chord length at wing kink [m] |
| *chordr* | Airfoil chord length at wing root [m] |
| *chordt* | Airfoil chord length at wing tip [m] |
| *City* | City name |
| *CL* | Lift coefficient |
| *CLMAX* | Maximum lift coefficient at undeflected flap/gear up configuration |
| *CLMAX APP* | Maximum lift coefficient at approach flaps/gear up configuration |
| *CLMAX LD* | Maximum lift coefficient at landing flaps/gear down configuration |
| *CLMAX TO* | Maximum lift coefficient at takeoff flaps/gear down configuration |
| *CL 2nd seg* | Lift coefficient evaluated at the 2nd segment takeoff flight path |
| *CMA* | Wing mean aerodynamic chord length [m] |
| *CNS* | Communication, Navigation and Surveillance Technologies |
| *Cmα* | Pitch moment coefficient |
| *Cnβ* | Yawing moment coefficient |
| *CO* | Collaborative optimization framework |
| *CO2* | Carbon dioxide |
| *CORSIA* | Carbon Offsetting and Reduction for International Aviation |
| *CRAD* | Catchment area radius [km] |
| *Crew* | Number of crew members (flight attendants + pilots) |
| *ck* | Average direct operational cost [$/nm] of k-th aircraft at design range |
| *D* | Total aircraft drag [N] |
| *DATCOM* | United States Air Force Stability and Control Data Compendium |
| *DDi* | Departure delay at i-th airport [min] |
| *DESC* | Sales price discount rate |
| *dij* | Distance from i-th to j-th airport [nm] |
| *DOC* | Direct operational cost [US$/nm] |
| *DOCijk* | Direct operational cost from i-th to j-th airport [US$/nm] |
| *DOE* | Design of experiments |
| *DMG* | Airport magnetic declination [o] |
| *DU* | Average daily aircraft utilization [h] |
| *eCLR* | Engine minimum clearance to ground [m] |
| *ELEV* | Airport’s reference point elevation [ft] |
| *EPNdB* | Effective perceived noise in decibels |
| *le* | Engine length [m] |
| *eDiam* | Engine fan diameter [m] |
| *eM* | Engine Design Point Mach Number |
| *ePOS* | Engine position flag |
| *epydz* | Engine pylon height [m] |
| *eSwet* | Engine wet area [m2] |
| *eTIT* | Engine turbine inlet temperature [K] |
| *F* | Frequency of sound source [Hz] |
| *FASAL* | Flight Attendant´s hourly salary [US$/h] |
| *FAR25* | Part 25 of the United States Code of Federal Regulations Title 14 (Airworthiness Standards: Transport Category Airplanes) |
| *FCt* | Cashflow at period t |
| *fij* | Daily demand from airport i-th to j-th airport |
| *fp* | Vector of fixed parameters |
| *FF* | Engines total fuel flow [kg/s] |
| *FOB* | Total fuel on board [kg] |
| *FOSAL* | First Officer´s hourly salary [US$/h] |
| *FPR* | Engine fan pressure ratio |
| *flapLD* | Landing flap deflection [o] |
| *flapTO* | Takeoff flap deflection [o] |
| *fusd* | Fuselage diameter [m] |
| *fusdz* | Fuselage external height [m] |
| *fush* | Fuselage height [m] |
| *fush2w* | Fuselage height-to-width ratio |
| *fusw* | Fuselage width [m] |
| *fuswetS* | Fuselage wet area [m2] |
| *g* | Gravity acceleration [m/s2] |
| *g(x,fp)* | Inequality constraint function |
| *G* | Combined city pair Gross Domestic Product [US$] |
| *GA* | Genetic algorithm |
| *GAFA* | Go-around fuel allowance [kg] |
| *GATA* | Go-around time allowance [min] |
| *GDP* | Gross Domestic Product [US$] |
| *GDPi* | Gross Domestic Product related to the city of the i-th airport [US$] |
| *GSP* | Gas Turbine Simulation Program |
| *h(x,fp)* | Equality constraint function |
| *Hmaxbuffet* | Maximum pressure altitude limited by buffet margin [ft] |
| *hAR* | Horizontal tail aspect ratio |
| *hS* | Horizontal tail area [m2] |
| *hSweep* | Horizontal tail sweep angle |
| *hTR* | Horizontal tail aspect ratio |
| *HOLDT* | Regulatory holding time (min) |
| *Hp* | Pressure altitude [ft] |
| *hpos* | Horizontal tail position flag |
| *HT* | Horizontal tail |
| *hTR* | Horizontal stabilizer tapper ratio |
| *ID* | Average inflight delay cost [US$/min] |
| *IDF* | Individual Discipline Feasible framework |
| *IATA* | International Air Transport Association |
| *ICAO* | International Civil Aviation Organization |
| *inc kink* | Airfoil incidence at wing kink [o] |
| *inc root* | Airfoil incidence at wing root [o] |
| *inc tip* | Airfoil incidence at wing tip [o] |
| *J(x,fp)* | Objective function |
| *k1* | Total operational costs to direct operational costs ratio |
| *k2* | Total revenue to ticket revenue ratio |
| *KinkPos* | Wing kink semispan position [%] |
| *lco* | Forward fuselage length [m] |
| *lf* | Fuselage length [m] |
| *ltail* | Tailcone length [m] |
| *L* | Airplane lift force [N] |
| *LAT* | Airport’s reference point latitude [o] |
| *LATi* | Latitude of the origin airport [o] |
| *LAtj* | Latitude of the destination airport [o] |
| *LDA* | Landing distance available [m] |
| *lf* | Fuselage length [m] |
| *LFL* | Design Landing Field Length, @ sea level, ISA conditions [m] |
| *LFref* | Reference Load Factor |
| *LON* | Airport’s reference point longitude [o] |
| *LONi* | Longitude of the origin airport [o] |
| *LONj* | Longitude of the destination airport[o] |
| *LPM* | Linear Programming Model |
| *LRWY* | Most used landing runway |
| *LW* | Landing weight [kg] |
| *L/Dbest ROC* | Best rate of climb lift over drag ratio |
| *M* | Mach Number |
| *MaxAlt* | Maximum Certified Cruise Altitude Ceiling [ft] |
| *MAXFUEL* | Maximum Fuel Capacity @ 0.81kg/l fuel density [kg] |
| *MaxPax* | Maximum Cabin Passengers Capacity |
| *MAXRATE* | Maximum Takeoff Thrust @ sea level / ISA conditions [lbf] |
|  | Engine turbofan compressor actual mass flow [kg/s] |
| *MDA* | Multidisciplinary design analysis |
| *MDF* | Multidisciplinary Feasible |
| *MDO* | Multidisciplinary design and optimization |
| *Nc* | Turbofan engine compressor corrected rotor speed [%] |
| *MAR* | Minimum acceptable rate of return of investment [%] |
| *MILP* | Mixed Integer Linear Programing |
| *MINCRZT* | Minimum cruise time [min] |
| *MIT* | Massachusetts Institute of Technology |
| *MLW* | Maximum landing weight [kg] |
| *MMO* | Maximum certified speed (Mach number) |
| *MOGA* | Multi-objective genetic algorithm |
| *MTOW* | Maximum takeoff weight [kg] |
| *MZFW* | Maximum zero fuel weight [kg] |
| *Nacftk* | Total number of k-th aircraft |
| *Naisles* | Number of aisles in the cabin |
| *NAND* | Nested Analysis Design |
| *NASA* | United States National Aeronautics and Space Administration |
| *NDOC* | Average air transport network’s direct operational cost [US$/ nm] |
| *NFP* | Network fixed parameters |
| *NLR* | National Aerospace Laboratory of Netherlands |
| *NPV* | Net present value [US$] |
| *ne* | Number of engines installed in the aircraft |
| *Ngalleys* | Number of galley stations in the aircraft |
| *NP* | Total network profit [US$/(PAX.nm)] |
| *Npax* | Number of Passengers (single class, pitch 32”) |
| *Nseat* | Number of Seat Abreast |
| *NPV* | Total sum of manufacturer´s net present value cashflow during the aircraft development and production period |
| *NSGA* | Non-Dominated Sorting Genetic Algorithm |
| *NSGA-II* | Fast Non-Dominating Sorting Genetic Algorithm |
| *OEW* | Operational empty weight [kg] |
| *OPR* | Engine overall pressure ratio |
| *p* | Average ticket price [US$] |
| *p0* | Static air pressure at sea level on International Standard Atmosphere (102325Pa) |
| *ptin* | Engine turbofan compressor inlet total pressure [Pa] |
| *Ptout* | Engine turbofan compressor outlet total pressure [Pa] |
| *P* | City pair population product |
| *Pi* | City pair population related to the city of the i-th airport |
| *PAX* | Passenger or Passengers |
| *PAXWT* | Total passenger’s weight including baggage [kg] |
| *PAYLOAD* | Total payload carried by the aircraft [kg] |
| *POP* | City population |
| *PR* | Turbofan engine compressor pressure ratio |
| *PSO* | Particle swarm optimization algorithm |
| *qHTeff* | Dynamic pressure efficiency on horizontal tail [%] |
| *r* | Distance from the sound source to the receiver [m] |
| *R* | Earth’s average radius [km] |
| *r0* | Airfoil leading edge radius |
| *RANGE* | Design Range, Full passengers @ 100kg, ISA conditions [nm] |
| *RROC* | Residual rate of climb [ft/min] |
| *rsparps* | Rear spar position on mean aerodynamic chord [%] |
| *S* | Accumulated enroute distance [m] |
| *SA* | Simulated annealing optimization algorithm |
| *SAND* | Simultaneous analysis and design |
| *SeatW* | Passenger´s seat width |
| *sflap* | Flap area [m2] |
| *SlatPres* | Slat presence flag |
| *SFC* | Engine specific fuel consumption [kg/s/N] |
| *SPDLIM* | Speed Limit below 10000ft pressure altitude in terms of indicated airspeed [kt] |
| *SP* | Aircraft sales price [Millions of US$] |
| *SPL* | Sound Pressure Level [dB] |
| *T* | Engine net thrust [N] |
| *T0* | Static air temperature at sea level on International Standard Atmosphere (288,15K) |
| *TAT* | Turnaround time [min] |
| *tc* | Airfoil thickness ratio |
| *tcmax* | Airfoil maximum thickness chord-wise position |
| *tckink* | Airfoil thickness ratio at wing kink |
| *tcroot* | Airfoil thickness ratio at wing root |
| *tctip* | Airfoil thickness ratio at wing tip |
| *Tctcmax* | Camber at maximum thickness chord-wise position |
| *t* | Time measure [s, min, h, years or months] |
| *Tij* | Trip time spent between i-th and j-th airports [min] |
| *TBij* | Block time spent between i-th and j-th airports [min] |
| *TIT* | Taxi-in time [min] |
| *TODA* | Takeoff Distance Available [m] |
| *TOFL* | Design Takeoff Field Length @ sea level, ISA conditions [m] |
| *TOT* | Taxi-out time [min] |
| *totSwet* | Total aircraft wet area [m2] |
| *ToWreq* | Required thrust-over-weight ratio |
| *Tref* | Airport reference temperature |
| *TOF* | Takeoff fuel (fuel on board at beginning of takeoff run) [kg] |
| *TOFA* | Takeoff and climb-out fuel allowance [kg] |
| *TOTA* | Takeoff and climb-out time allowance [min] |
| *TOW* | Takeoff weight [kg] |
| *TRWY* | Most used takeoff runway |
| *T/W* | Thrust-to-weight ratio |
| *ULH* | Uniform Latin Hippercube |
| *V* | True airspeed [m/s] |
| *vAR* | Vertical stabilizer aspect ratio |
| *VMO* | Maximum certified speed (indicated airspeed, kt) |
| *VT* | Vertical tail |
| *vAR* | Vertical Tail aspect ratio |
| *Vbest ROC* | Best rate of climb speed [m/s] |
| *vS* | Vertical tail area [m2] |
| *vSweep* | Vertical tail sweep angle |
| *vTR* | Vertical stabilizer aspect ratio |
| *W* | Airplane weight [kg] |
| *Wc* | Turbofan engine compressor corrected mass flow [kg/s] |
| *Wf* | Total fuel burned from origin to destination airport [kg] |
| *Wfapp* | Total fuel burned on approach phase [kg] |
| *Wfalternate* | Total fuel burned from destination to alternate airport [kg] |
| *Wfcontingency* | Contingency fuel [kg] |
| *Wfholding* | Fuel for the holding flight phase [kg] |
| *Wftaxi* | Taxi fuel [kg] |
| *wAR* | Wing aspect ratio |
| *wDih* | Wing Dihedral [o] |
| *WingletPres* | Winglet presence flag |
| *wb* | Wing semi-span [m] |
| *WoSreq* | Required wing load [N/m2] |
| *wS* | Wing reference area [m2] |
| *wSweep1/4* | Wing quarter-chord sweepback angle [o] |
| *wSweepLE* | Wing leading edge sweepback angle [o] |
| *wTR* | Wing tapper ratio |
| *wTwist* | Wing Twist Angle [o] |
| *WL\_AR* | Winglet Aspect ratio [m2] |
| *WL\_TR* | Winglet tapper ratio |
| *WL\_sweep* | Winglet sweep angle |
| *WL\_cantl* | Winglet cantlever angle [deg] |
| *WL\_twist* | Winglet twist angle [deg] |
| *W/S* | Wing loading [N/m2] |
| *x* | Vector of design parameters |
| *xle* | Wing leading edge position |
| *xLB* | Design variable lower band limit |
| *xUB* | Design variable upper band limit |
| *XDSM* | Extended Design Structure Matrix |
| *Ycmax* | Airfoil maximum camber |
| *Xiltj* | Fraction of the passenger’s demand flow fij from origin i to destination j |
| *Yijk* | Number of type-k airplane linking i-th to j-th city (route frequency) |
| *XYcmax* | Camber at maximum thickness chord-wise position |
|  |  |

List of Symbols

|  |  |  |
| --- | --- | --- |
| *α* | Angle of attack [o] | |
| *β* | Sideslip angle [o] | |
| *δ* | Atmospheric pressure ratio (s*tatic air pressure/p0*) at a given pressure altitude | |
| *δ1* | Inner wing panel dihedral [o] | |
| *δ2* | Outer wing panel dihedral [o] | |
| *δmax* | Atmospheric pressure ratio at altitude where buffet margin is achieved | |
| *ε* | Airfoil camber line angle at trailing edge [o] | |
| *φ* | Airfoil thickness line angle at trailing edge [o] | |
| *ϕ* | Acceleration factor function | |
| *γ* | Flight path angle [rad] | |
| *П* | Engines throttle position [%] | |
| *η* | Turbofan engine compressor efficiency | |
| *ρ* | Air density at a givel pressure altitude | |
| *ρ0* | Air density at sea level on International Standard Atmosphere (1,225kg/m3) | |
| *Ψij* | Average true heading at the great circle path from origin airport *i* to destination airport *j* | |
| *σ* | Atmospheric density ratio (*air density/ρ0*) at a given pressure altitude | |
| *θ* | Atmospheric temperature ratio (*static air temperature/T0)* at a given pressure altitude | |
| *θc* | Airfoil camber line angle at leading edge [o] | |
| *Θ* | Directivity angle of the sound source [o] | |
| *ΔISA* | Temperature deviation from the temperature predicted by ICAO International Standard Atmosphere at a given pressure altitude (Hp) | |
| *ΔDdiv* | | Airplane total drag percentual increase due to compressibility effects near MMO [%] | |

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