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**Section 1 General Information**

Unit Conversion Website Link http://www.digitaldutch.com/atmoscalc/.

**1.1 Unit Conversions**

Prefix Multipliers Angles Angular Acceleration Angular Velocity Area Density Electrical Quantities Energy / Work Force Illumination Inertia Length Linear Acceleration Mass Power Pressure Temperature Time Torque Velocity Viscosity Volume

1.2 Greek Alphabet

1.3 Greek Symbols used for Aircraft

1.4 Common Subscripts

1.5 Common Abbreviations

1.6 Sign Conventions

1.7 Thermodynamic Relations

1.8 Mechanics Relations

Page 01 - 1

*SFTE Reference Handbook Third Edition 2013*

**1.1 Unit Conversions** (references 1.1, 1.2)

**Prefix Multipliers**

1018 exa E 1015 peta P 1012 tera T 109 giga G 106 mega M 103 kilo k 102 hecto h 10 deka da 10-1 deci d 10-2 centi c 10-3 milli m 10-6 micro μ 10-9 nano n 10-12 pico p 10-15 femto f 10-18 atto a

*Multiply by To Obtain*

**(Common FTE conversions in boldface) Angles** circles 1 circumferences

circles 12 signs circles 21,600 minutes circles 2π radians circles 360 degrees degrees .01111 quadrants degrees 3600 seconds degrees 60 minutes mils (Army) .05625 degrees mils (Navy) .05729 degrees quadrants 90 degrees radians 57.2958 degrees revolutions 360 degrees sphere 4π steradians #

#solid angle measurement

**Angular** rev/min2 0.001745 rad/sec2 **Acceleration**

**Angular cycles/sec 6.2814 rads/sec Velocity rads/sec 0.1592 rev/sec (cycles/sec)** rads/sec 9.549 rpm **rad/sec 57.296 deg/sec** rpm 0.01667 rev/sec

Page 01- 2

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*Multiply by To Obtain*

**Area** acres 43,560 ft2 ares 100 m2 barn 10-28 m2 centares 1 m2 circular mils 7.854 x 10-7 in2 cm2 100 mm2 **ft2 144 in2 ft2 0.09290304 m2** in2 6.452 cm2 in2 106 mils2 m2 10.76 ft2 section 2,589,988.1 m2 st. mile2 27,780,000 ft2 st. mile2 2.590 km2 township 93,239,572 m2 yd2 9 ft2 yd2 0.8361 m2

**Density** \* grams/cm3 0.03613 pounds/in3 grams/cm3 62.43 pounds/ft3 kg/m3 16.018463 pounds/ft3 **slugs/ft3 515.4 kg/m3 pounds/in3 \* 1728 pounds/ft3** slugs/ft3 1.94 grams/cm3 \* Converting between force and mass (e.g. kg force to kg mass

or pound force to pound mass) uses g = 32.174 ft/sec^2

**Electrical** amperes 0.1 abamperes **Quantities** amperes 1.0365x10-5 faradays/sec amperes 2.998x109 statamperes amperes.cicmil 1.973x105 amperes/cm2 ampere-hours 3,600 coulombs ampere-hours 1.079x1013 statcoulombs ampere turn/cm 1.257 gilberts/cm ampere turn/cm 1.257 oersteds coulombs 0.1 abcoulombs coulombs 6.243x1018 electronic charges coulombs 1.037x10-5 faradays coulombs 2.998x109 statcoulombs faradays 26.8 apmere-hours farads 10-9 abfarads farads 106 microfarads farads 8.986x1011 statfarads gausses 1 maxwells/cm2

Page 01 - 3

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*Multiply by To Obtain*

**Electrical** gausses 6.452 lines/in2 **Quantities** gilberts 0.7958 ampere turns **Cont.** henries 109 abhenries

henries 1.113x10-12 stathenries maxwells 1 lines oersteds 2.998x1010 statoersteds ohms 109 abohms ohms 1.113x1012 statohms ohm-cm 6.015x106 circ mil-ohms/ft volts 108 abvolts volts 0.003336 statvolts

**Energy** / Btu 1.055x1010 ergs **Work** Btu 1055.1 Joules (N-m)

Btu 2.9302x10-4 kilowatt-hours Btu 251.99 calories (gram) Btu 778.03 foot-pounds calories 4.1868 watt-seconds calories 3.088 foot-pounds electron volt 1.519x10-22 Btu ergs 1 dyne-centimeters ergs 7.376x108 foot-pounds **foot-pounds 1.3558 Joules (N-m)** foot-pounds 3.766x10-7 kilowatt-hours foot-pounds 5.051x10-7 horsepower-hours hp-hours 0.7457 kilowatt-hours hp-hours 2546.1 Btu Joules 0.23889 calories Joules 1 Newton-meters Joules 1 watt-seconds Joules 107 ergs **kilowatt-hours 3.6x106 Joules** thermies 4.1868x106 Joules watt-second 0.73756 foot-pounds

**Force** dynes 3.597x10-5 ounces

**kilogram force 9.80665 Newtons** kilopond force 9.80665 Newtons kip 4,448.221 Newtons **Newtons 0.224808931 pounds** Newtons 100,000 dynes

Page 01- 4

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*Multiply by To Obtain*

**Forc e**ounce 20 pennyweights **Cont.** ounces (troy) 480 grains pennyweights 24 grains pound 12 ounces pounds 32.174 poundals **pounds 4.4482216 Newtons** pounds 5760 grains quintals (long) 112 pounds quintals (met.) 100 kilograms stones 14 pounds tons (long) 2,240 pounds tons (metric)\* 1.102 tons (short) tons (short) 2000 pounds

**Fuel gal 5.8 lbs (U.S. AV gas)**

**gal 7.5 lbs ( U.S. oil) Liter (jet A) 0.812 kilograms Liter (jet A) 1.794 pounds**

**Note: Fuel densities are temperature dependent**

**Illumination** candles 1 lumens/steradian

candles/cm2 π lamberts candlepower 12.566 lumens foot-candles 1 lumens/ft2 foot-candles 10.764 lux foot-lamberts 1 lumen/ft2 lamberts 295.72 candles/ft2 lamberts 929.03 lumens/ft2 lumens 0.001496 watts lumens/in2 1 fots lumens/m2 1 lux lux 1 meter-candles lux 0.0001 fots meter-candles 1 lumens/m2 millilamberts 0.2957 candles/ft2 millilamberts 0.929 foot-lamberts milliphots 0.929 foot-candles milliphots 0.929 lumens/ft2 milliphots 10 meter-candles

Page 01 - 5

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*Multiply by To Obtain*

**Length** angstroms 10-10 meters astronmcl units 1.496x1011 meters cable lengths 120 fathoms caliber 0.01 inches cubit 0.4572 meters fermi 10-15 meters fathoms 6 feet feet 12 inches furlongs 40 rods hands 4 inches **inches 2.54 cm kilometers 3281 feet kilometers 0.53996 nautical miles** leagues (U.S.) 3 nautical miles light years 5.88x1012 statute miles links (engnr’s) 12 inches links (srvyr’s) 7.92 inches **meters 3.28084 feet meters 39.370079 inches** microns 0.16 meters mils 0.001 inches **nautical miles 1.15078 statute miles nautical miles 1,852 meters nautical miles 6,076.115486 feet** paces 0.762 meters parsec 1.9163x1013 statute miles perch 5.0292 meters pica (printers) 0.0042175176 meters point (printers) 0.0003514598 meters pole (=rod) 5.0292 meters skein 109.728 meters **statute miles 5,280 feet statute miles 1.609344 kilometers** statute miles 8 furlongs yards 3 feet

Page 01- 6

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*Multiply by To Obtain*

**Linear** feet/sec2 1.09728 kilometers/hr/sec **Acceleration** feet/sec2 0.3048 meters/sec2

feet/sec2 0.6818 mph/sec **g 32.174049 feet/sec2 g 9.80665 meters/sec2** gals (Galileo) 0.01 meters/sec2 knots/sec 1.6878 feet/sec2 meters/sec2 3.6 kilometers/hr/sec mph/sec 0.447 meters/sec2 mph/sec 1.609 kilometers/hr/sec

**Mass\*** carats *200* milligrams

grams 0.035274 ounces grains 6.479891x10-5 kilograms hndrdwght long 50.80 234544 kilograms hndrdwght shrt 45.359237 kilograms **kilograms 0.06852 slugs** kilograms 6.024x1026 atomic mass units **kilograms 2.2046 pounds** ounces (avd)\* 28.349523125 grams ounces (troy)\* 31.1034768 grams pounds (mass) 1 pounds (force) **pounds (mass) 0.45359237 kilograms pounds (mass) 0.031081 slugs** scuples (apoth) 0.0012959782 kilograms **slugs 32.174 pounds slugs 14.594 kilograms** tons (long) 1016.047 kilograms tons (assay) 0.02916 kilograms tons (metric) 1000 kilograms tons (short) 907.1847 kilograms \* Converting between force and mass (e.g. kg force to kg mass

or pound force to pound mass) uses g = 32.174 ft/sec^2

Page 01 - 7

*SFTE Reference Handbook Third Edition 2013*

*Multiply by To Obtain*

**Moments** gram-cm2 0.737x10-7 slug-ft2 **of** pound-ft2\* 0.031081 slug-ft2 **Inertia**\* slug-in2 0.0069444 slug-ft2

**slug-ft2 1.3546 kg-m2 slug-ft2 32.174 pound-ft2** slug-ft2 12.00 pound-inch-sec2 slug-ft2 192.00 ounce-inch-sec2 \* Converting between force and mass (e.g. kg force to kg mass

or pound force to pound mass) uses g = 32.174 ft/sec^2

**Power** btu/min 0.01758 kilowatts

calories(kg)/min 3087.46 foot-pounds/min ergs/sec 7.376x10-8 foot-pounds/sec ft(lbs)/min 2.260x10-5 kilowatts ft(lbs)/sec 0.07712 btu/min ft(lbs)/sec 1.356 watts **hp 550 ft(lb)/sec hp 33,000 ft(lbs)/min** hp 10.69 calories (kg)/min **hp 745.7 watts [J/sec] hp (metric) 735.5 watts hp 1.1014 horsepower (metric) kilowatts 1.341 horsepower** watts 107 ergs/sec watts 1 Joules/sec

**Pressure atmospheres 14.696 pounds/in2**

**atmospheres 29.92 inches of Hg** atmospheres 76 cm of Hg bars 1,000,000 dynes/cm2 **bars 29.52 inches of Hg barye 0.1 Newtons/m2** dynes/cm2 10 Newtons/m2 **inches of H2O 5.20237 pound/ft2 inches of Hg 70.72619 pounds/ft2** inches of Hg 0.491154 pounds/in2 inches of Hg 13.595 inches of H2O **kiloPascals 100 bars hectoPascals 1 millibars millibars 0.02953 inches of Hg** mm of Hg 0.019337 pounds/in2

Page 01- 8

*SFTE Reference Handbook Third Edition 2013*

*Multiply by To Obtain*

**Pressure** mm of Hg 133.32 Newtons/m2 **Cont. Pascals 1 Newton/m2** pieze 1000 Newtons/m2 **pounds/ft2 0.01414 inches of Hg pounds/ft2 47.88 Newtons/m2 pounds/in2 2.036 inches of Hg** pounds/in2 27.681 inches of H2O **pounds/in2 6894.75728 Pascal** torrs 133.32 Newtons/m2

**Temperature Kelvin = o*C*+273.15o**

**Rankin = o*F* + 459.67o oCentigrade = [o*F*** − **32o] 5/9** oFahrenheit = (9/5)o*C* + 32

**Time** days (solar) 24 hours days (sidereal) 23.934 hours days (solar) 1.0027 days (sidereal) hours 60 minutes minutes 60 seconds months (sdrl) 27d + 7hr +43min +11.47sec months (lunar) 29d +12hr +44min + 2.78sec year 365.24219879 days

**Torque** \* **foot-pounds 1.3558 Newton-meters** foot-pounds 0.1383 kilogram-meters ounce-inches 72.008 gram-centimeters pound-inches 1129800 dyne-centimeters \* Converting between force and mass (e.g. kg force to kg mass

or pound force to pound mass) uses g = 32.174 ft/sec^2

**Velocity** inches/sec 0.0254 meters/sec

**knots 1.68781 feet/sec km/hr 0.621371 mph km/hr 0.9113 feet/sec Knots (kts) 1.15078 mph Knots (kts) 1.852 km/hr** Knots (kts) 0.51444 meters/sec meters/sec 3.281 ft/sec meters/sec 3.6 km/hr **meters/sec 196,85 feet/min** mph 1.466667 feet/sec

Page 01 - 9

*SFTE Reference Handbook Third Edition 2013*

*Multiply by To Obtain*

**Viscosity** centistokes 10-6 m2/sec ft2/sec 0.0929 m2/sec pound sec/ ft2 47.880258 Newton secs/ m2 poise 0.1 Newton secs/ m2 rhe 10 m2/Newton second

**Volume** acre-feet 43,560 ft3 acre-feet 1,233 m3 acre-feet 3.259x105 gals (U.S.) barrels 31.5 gals (U.S.) board-feet 144 in3 bushels 1.244 ft3 bushels 32 quarts (dry) bushels 4 pecks cm3 0.001 liters cm3 0.03381 fluid ounces cm3 0.06102 in3 cord-feet 4x4x1 ft3 cords 128 ft3 cups 0.5 pints (liquid) dram (fluid) 3.69669x10-6 m3 **ft3 0.0283167 m3** ft3 1728 in3 ft3 28.32 liters **ft3 7.481 gals (U.S.) gals (Imperial) 1.2009 gals (U.S.)** gals (Imperial) 277.42 in3 gals (U.K.) 4546.1 cm3 **gals (U.S.) 231 in3 gals (U.S.) 0.003785 m3 gals (U.S.) 3.785 liters** gals (U.S.) 4 quarts (liquid) gals (U.S.) 0.0238095 barrels (U.S.) gils 7.219 in3 hogshead 2 barrels in3 16.39 cm3 liters 0.02838 bushels liters 0.9081 quarts (dry) liters 1.057 quarts (liquid) liters 1000 cm3 liters 61.03 in3 m3 1.308 yd3

Page 01- 10

*SFTE Reference Handbook Third Edition 2013*

*Multiply by To Obtain*

**Volume** m3 1000 liters **Cont.** m3 264.2 gals (U.S.)

**m3 35.314667 ft3** mil-feet (circ.) 0.0001545 cm3 ounces (U.K.) 28.413 cm3 ounces (U.S.) 29.574 cm3 pecks 8 quarts (dry) pecks 8.81 liters perches 0.7008 m3 perches 24.75 ft3 pints (dry) 33.60 in3 pints (liquid) 28.88 in3 pints (liquid) 4 gals quarts (dry) 1.164 quarts (liquid) quarts 2 pints register tons 100 ft3 shipping ton (U.S.) 40 ft3 shipping ton (Br.) 42 ft3 steres 1000 liters tablespoons 0.0625 cups teaspoons 0.3333 tablespoons

Page 01 - 11

*SFTE Reference Handbook Third Edition 2013*

**1.2 Greek Alphabet**

Α α Alpha Β β Beta Γ γ Gamma Δ δ Delta Ε ε Epsilon Ζ ζ Zeta Η η Eta Θ θ Theta Ι ι Iota Κ κ Kappa Λ λ Lambda Μ μ Mu Ν ν Nu Ξ ξ Xi Ο ο Omicron Π π Pi p ρ Rho Σ σ Sigma Τ τ Tau Υ υ Upsilon Φ φ Phi Χ χ Chi Ψ ψ Psi Ω ω Omega

Page 01- 12

*SFTE Reference Handbook Third Edition 2013*

**1.3 Greek Symbols Used for Aircraft**

α angle of attack (degrees or radians) ατ tail angle of attack β angle of sideslip (degrees) γ flight path angle relative to horizontal γ specific heat ratio (1.4 for air) δ relative pressure ratio (*Pa*/*Po*) δa aileron deflection angle δr rudder deflection angle δe elevator deflection angle ε downwash angle at tail (degrees) ζ damping ratio η efficiency θ body axis/pitch angle θ relative temperature ratio, *Ta*/*To* ι angle of incidence ι*F* thrust angle of incidence ι*T* horizontal tail angle of incidence λ pressure lag constant Λ wing sweep angle μ coefficient of absolute viscosity = ρν μ Mach cone angle ν kinematic viscosity = μ/*g* π nondimensional parameter ρ density ρ*a* ambient air density ρ*o* standard atmospheric density (slugs/ft3 ) σ air density ratio (ρα /ρο) σcr critical density τ shear stress (pounds per square inch) psi τR Roll Mode Time Constant (sec) φ bank angle (degrees) ψ aircraft heading (degrees) ω frequency ω rotational velocity (radians per second) ω*d* damped natural frequency ω*n* natural undamped frequency

Page 01 - 13

*SFTE Reference Handbook Third Edition 2013*

**1.4 Common Subscripts**

*a* aileron *a* ambient alt at test altitude avg average *c* calibrated *e* elevator *e* equivalent *E* endurance leg of mission *F* final *I* initial *i* inbound leg of mission *i* indicated *ic* instrument corrected *l* subscript for coefficient of rolling moment *m* mission conditions *m* pitching moment *n* yawing moment *O* outbound leg of mission *o* sea-level standard day *o* sea level *r* reserve leg of mission *r* rudder *S* standard day *s* standard day at altitude *SL* sea level *T* True *t* test day

Page 01- 14

*SFTE Reference Handbook Third Edition 2013*

**1.5 Common Abbreviations**

a lift curve slope a linear acceleration (ft/sec2 or m/sec2) a speed of sound A/A air-to-air a/c aircraft AAA anti aircraft artillery AC aerodynamic center ac alternating current ACM air combat maneuvering A/D analog to digital ADC air data computer ADC analog-to-digital converter ADF automatic direction finder ADI attitude direction indicator AFMC Air Force Materiel Command AFOTEC Air Force Operational Test and Evaluation Center A/G air-to-ground AGL above ground level AHRS attitude heading reference system AM amplitude modulation AOA angle of attack AOED age of ephemeris data APU auxiliary power unit AR air refuel (mode of flight) *AR* aspect ratio = b2 / S ARDP advanced radar data processor ARSP advanced radar signal processor ASPJ airborne self protection jammer ATC air traffic control avg average ax longitudinal acceleration ay lateral acceleration AZ azimuth b span of wing (feet) B/N bombadier/navigator bbl barrel *BHP* brake horsepower BICOMS bistatic coherent measurement system BID bus interface device BIT built-in test *BSFC* brake specific fuel consumption Btu British thermal unit BW bandwidth o*C* degrees centigrade...see *T* c brake specific fuel consumption (BSFC)

Page 01 - 15

*SFTE Reference Handbook Third Edition 2013*

c speed of light in a vacuum

(186,282 miles/sec = 299,792,500 [m/s]) c mean aerodynamic chord (MAC) of a wing C/A coarse acquisition C/No carrier to noise ratio CADC central air data computer CARD cost analysis requirement document *CD* coefficient of drag *CD* i induced drag coefficient *CD* o zero lift drag coefficient

(also parasitic drag coefficient for symmetric wing) CDI course deviation indicator CDMA code division multiplex access CDR critical design review CDRL contracts data requirement list CDU control display unit CEA circular error average CEP circular error probable *Cf* coefficient of friction CFE contractor furnished equipment CFT conformal fuel tank *cg* center of gravity (normally in % MAC) CH hinge moment coefficient cine cinetheodolite *Cl* rolling moment coefficient, airfoil section lift co

efficient *CL* lift coefficient CLHQ closed loop handling qualities *Clp* roll damping coefficient *Clr* roll moment due to yaw rate coefficient *Cm* pitching moment coefficient *CM* moment coefficient cm centimeters cos cosine cot cotangent *Cl*β (dihedral) rolling moment due to sideslip *Cl*δa aileron power coefficient *Cmq* pitch damping coefficient *Cm*α longitudinal static stability coefficient *Cm*δ*e* elevator power coefficient *Cn* yawing moment coefficient *Cnr* yaw damping coefficient cnst constant *Cn*β directional stability coefficient *Cn*δ*a* adverse yaw coefficient *Cn*δ*r* rudder power coefficient COTS commercial, off–the-shelf

Page 01- 16

*SFTE Reference Handbook Third Edition 2013*

CP center of pressure *CP* propeller power coefficient CPU central processing unit cr wing root chord CRM crew resource management ct wing tip chord CTF combined test force CY calendar year *CY* side force coefficient *CY*β side force due to sideslip coefficient *CY*δ*r* side force due to rudder coefficient D diameter D drag D/A digital/analog DAC digital to analog converter DAPS data acquisition and processing system DARPA Defense Advanced Research Projects Agency db decibel DC direct current deg degrees DG directional gyro DGPS differential GPS DMA Defense Mapping Agency DME distance measuring equipment DoD Department of Defense DOP dilution of precision DSN defense switched network DT development test DTC data transfer cartridge DTIC Defense Technical Information Center *e* Oswald efficiency factor e natural mathematical constant = 2.718281828459 E energy E lift-to-drag ratio (CL/CD, L/D) EAS equivalent airspeed EC electronic combat ECCM electronic counter countermeasures ECM electronic countermeasures ECP engineering change proposal ECS environmental control system EGT exhaust gas temperature EL elevation ELINT electronic intelligence ELV expendable launch vehicle EM electromagnetic *E*max maximum lift-to-drag ratio EMC electromagnetic compatibility EMI electromagnetic interference EMP electromagnetic pulse

Page 01 - 17

*SFTE Reference Handbook Third Edition 2013*

EO electro optical EOM equations of motion EPR engine pressure ratio EPROM electrically programmable read only memory *Es* specific energy ESA European Space Agency ESD Electronic Systems Division *ESHP* equivalent shaft horsepower ETA estimate time of arrival ETE estimate time en-route EW early warning EW electronic warfare o*F* degrees Fahrenheit *f* frequency...hertz (originally cycles per second) F.S. fuselage station *Fa* aileron force FAA Federal Aviation Administration FAR Federal Aviation Regulation FCF functional check flight FDC flight data computer *Fe* elevator force *Fex* excess thrust *Fg* gross thrust FL flight level Flip flight information publication FLIR forward-looking infra red FM frequency modulation FMC fully mission capable FMS flight management system FMS foreign military sales *Fn* net thrust *Fn*/δ corrected thrust parameter FOM figure of merit FOT&E follow-on test & evaluation FOUO for official use only FOV field of view fpm feet per minute fps feet per second FQT formal qualification test *Fr* rudder force FRD functional requirements document FRL fuselage reference line FRL force, rudder, left FRR force, rudder, right FRR flight readiness review FSD full scale development FSI full scale integration ft feet ft-lb English unit of work...foot-pound...

Page 01- 18

*SFTE Reference Handbook Third Edition 2013*

fwd forward FY fiscal year *g* acceleration due to gravity at altitude *G* gravitational constant = 6.6732x10-11 [N m2/kg2] GAO Government Accounting Office GCA ground control approach GCI ground controlled intercept GDOP geometric dilution of precision GMT Greenwich mean time *go* standard acceleration due to gravity

(sea level, 46 deg latitude) GPS global positioning system GS ground speed GSI glide slope indicator *h* % MAC *H* altitude HARM high-speed anti-radiation missile *Hc* calibrated altitude

(assumed to be pressure altitude in flight test) *HD* density altitude HDDR high density digital recorder HDOP horizontal dilution of precision HF high frequency *Hg* mercury *Hi* indicated altitude *hm* stick-fixed maneuver point (%MAC) *h'm* stick-free maneuver point (%MAC) *hn* stick-fixed neutral point (%MAC) *h'n* stick-free neutral point (%MAC) hp horsepower hr hour hrs hours HSI horizontal situation indicator HUD head-up display HV host vehicle *Hz* hertz I/O input/output IAS indicated airspeed IAW in accordance with ICAO International Civilian Aviation Organization ICU interface computer unit ICBM intercontinental ballistic missile IFF identification friend or foe IFR instrument flight rules ILS instrument landing system IMC instrument meteorological conditions IMN indicated Mach number IMU inertial measuring unit in inch

Page 01 - 19

*SFTE Reference Handbook Third Edition 2013*

INS inertial navigation system INU inertial navigation unit IOC initial operational capability IOT&E initial operational test & evaluation IUGG International Union of Geodesy and Geographics *Ix, Ix, Iz* moments of inertia *Ixy, Ixz, Iyz* products of inertia *J* joules energy, (Newton-Meter) *J* propeller advance ratio J&S jamming and spoofing JCS Joint Chiefs of Staff *K* Kelvin (absolute temperature) K temperature probe recovery factor *K, k*1 constants KCAS knots calibrated airspeed KEAS knots equivalent airspeed kg kilogram, metric unit of mass KIAS knots indicated airspeed KISS keep it simple, stupid km kilometer KTAS knots true airspeed kt knots *L* Lift (lbs) *l* length *L* rolling moment L/D Lift-to-drag ratio LANTIRN low altitude navigation and targeting IR for night lat lateral lb pound lbf English unit of force, often just lb (pound) lbm English unit of mass, often just lb (slug) LCC life cycle cost LCD liquid crystal display LED light emitting diode LLH latitude, longitude, height ln natural log, log to the base e LO low observables Log common log, to the base 10 LOS line of sight *l*t distance from *cg* to tail's aerodynamic cent Lδa rolling moment due to aileron deflection *M* moment (ft-lbs) *M* Mach number m mass m meter (length) *M* pitching moment MAG magnetic MAP manifold pressure

Page 01- 20

*SFTE Reference Handbook Third Edition 2013*

mb millibar MCA minimum crossing altitude *Mcr* critical Mach number *Md* drag divergence Mach number Mac mean aerodynamic cord MGC mean geometric chord MHz megahertz mHZ millihertz *Mic* instrument-corrected Mach number MilSpec military specification MIL-STD military standard (publication) min minute (time) Mm millimeters MOA memorandum of agreement MOE measure of effectiveness MOP measures of performance MOU memorandum of understanding MP manifold pressure MSL mean sea level MTBF mean time between failures MTTR mean time to repair MX maintenance N newton (force) N rotational speed (RPM) *n* load factor (g's) N yawing moment *N*1 low pressure compressor speed *N*2 high pressure compressor speed NACA National Advisory Committee for Aeronautics NADC Naval Air Development Center NASA National Aeronautics and Space Administration NAV navigation NED North, East, Down NM, nm nautical mile (6080 feet) NOE nap-of-the-earth NOFORN not releasable to foreign nationals NOTAM notice to airmen NRC National Research Council (Canada) NWC Naval Weapons Center *Nx* longitudinal load factor (g's) Ny lateral load factor (g's) *Nz* normal load factor (g's) OAT outside air temperature OAT on aircraft test OEI One engine inoperative OPR Office of Primary Responsibility OSD Office of the Secretary of Defense OT&E operational test & evaluation p aircraft roll rate (degrees/sec)

Page 01 - 21

*SFTE Reference Handbook Third Edition 2013*

P pressure (N/m2 ,pounds per square inch) Pa ambient pressure PCM pulse code modulation P-code precision code PD pulse Doppler PDM pulse duration modulation PGM precision guided munitions PIO pilot induced oscillations Piw total thrust horsepower required Pk probability of kill PLF power for level flight Po standard atmospheric pressure (2116.22 lb/ft2 ) POC point of contact Pp pitot pressure ppm parts per million Prop propeller Ps static pressure PS pulse search psf pounds per square foot psi pounds per square inch PT total pressure PW pulse width *Q* or *q* dynamic pressure = 0.5ρ*V* 2 q aircraft pitch rate Q engine torque qo*R* c impact pressure (*Pt* degrees Rankine = − o*F P*+ *a*)

459.67 R perfect gas constant = 8314.34 [J/kmol K] r aircraft yaw rate (degrees/sec) R earth radius R range R&D research and development R&M reliability and maintainability R/C rate of climb rad radians Radar radio detection and ranging RAF resultant aerodynamic force RAM radar absorbing material RAT ram air turbine RCS radar cross section Re Reynolds number (dimensionless) REP range error probable RF range factor RLG ring laser gyro rms root mean square RNG range ROC rate of climb ROC required obstacle clearance RPM revolutions per minute (a.k.a. N)

Page 01- 22

*SFTE Reference Handbook Third Edition 2013*

R/T receiver/transmitter RTO Rejected/refused takeoff RTO responsible test organization S wing area (ft2 or m2) Sa horizontal distance between liftoff and specified

height or between specified height and touch down. SA selective availability SA situational awareness SE specific endurance sec seconds (time or angle) SFC specific fuel consumption Sg ground roll distance SHP shaft horsepower SI international system of units SIGINT signal intelligence sin sine SL sea level SLAM standoff land attack missile SLR side-looking radar S/N serial number S/N signal -to-noise ratio SOF special operations forces SOW stand-off weapon SR specific range SRB safety review board ST tail area std standard ST total takeoff or landing distance (Sa + Sg) STOL short takeoff and landing STOVL short takeoff and vertical landing T period of oscillation T temperature t thickness T, t time (sec) t/c thickness-to-chord ratio Ta ambient temperature TACAN tactical air navigation tan tangent Tas standard temperature at altitude TAS true airspeed TBD to be determined TD touchdown TED trailing edge down TEL trailing edge left TEMP test and evaluation master plan TER trailing edge right TEU trailing edge up

Page 01 - 23

*SFTE Reference Handbook Third Edition 2013*

TF terrain following THP Thrust Horsepower THPalt horsepower available at altitude THPmax maximum horsepower available THPmin minimum horsepower required THPSL horsepower required at sea level TIT turbine inlet temperature TM telemetry TMN true Mach number T/O takeoff To standard sea level temperature (59.0 oF, 15 oC) TO technical order TRB technical review board TRD technical requirements document TRP technical resources plan TSFC thrust specific fuel consumption TSPI time, space, position information Tt total temperature TV television T/W thrust to weight ratio TWT track while scan TWT traveling wave tube u velocity along aircraft's x-axis UAV uninhabited aerial vehicle UHF ultra high frequency UPT undergraduate pilot training USA US Army USAF US Air Force USCG US Coast Guard USMC US Marine Corps USN US Navy UT universal time UV ultraviolet v velocity along aircraft's lateral axis VH horizontal tail volume coefficient VV vertical tail volume coefficient V1 takeoff decision speed V2 takeoff safety speed VA design maneuvering speed VAC volts AC Vb buffet airspeed VB design speed for max gust intensity Vbr velocity for best range Vc calibrated airspeed VD design diving speed VDC volts DC VDOP vertical dilution of precision Ve equivalent velocity VFE maximum flap extended speed

Page 01- 24

*SFTE Reference Handbook Third Edition 2013*

VFR visual flight rules Vg ground speed VHF very high frequency Vi indicated airspeed Vic indicated airspeed corrected for instrument error Viw velocity at sea level std day and std weight VLE max speed with landing gear extended VLO max speed while operating landing gear VLOF lift off speed VLSIC very large scale integrated circuit Vmc minimum directional control speed VMC visual meteorological conditions Vmca minimum directional control speed in the air Vmcg minimum directional control speed on the

ground Vmo/Mmo maximum operating limit speed Vmu minimum unstick speed VNE never exceed velocity Vno max structural cruising speed Vopt optimum velocity for endurance flight VOR VHF omni-directional range VORTAC VHF omni-directional range Tactical Air Navi

gation VPmin velocity for minimum power VPmin,SL velocity for minimum power at sea level VR rotation speed VS stall speed VS0 stall speed in landing configuration VS1 stall speed in some defined configuration VSTOL vertical/short takeoff and landing VT true airspeed VTOL vertical takeoff & landing VVI vertical velocity indicator VW wind velocity VX speed for best angle of climb VY speed for best rate of climb W weight w component of velocity along aircraft's Z-axis WDL weapon data link W/δ weight-to-pressure ratio Wf fuel weight WGS-84 World Geodetic System, 1984 WI watch item WOD word of day WOW weight on wheels WPT waypoint wrt with respect to

Page 01 - 25

*SFTE Reference Handbook Third Edition 2013*

*W*x

*f* , corrected fuel flow parameter δ

θ W/S wing loading Wf fuel flow (lb/hr) x aircraft longitudinal axis,

a line running through the nose & tail Xac distance from leading edge to aerodynamic cen

ter Xlink cross link y aircraft lateral axis, a line running the wingtips Y force along y-axis Y-code encrypted P-code z aircraft vertical or yaw axis,

a line perpendicular to the longitudinal and lat eral axes Δ*Hic* altimeter instrument correction Δ*Hpc* altimeter position error correction ΔPp pitot pressure error ΔPs static pressure error ΔVc scale attitude correction to airspeed ΔVic instrument correction to airspeed indicator ΔVpc correction for airspeed position error ∞ infinity, or freestream conditions

Page 01- 26

*SFTE Reference Handbook Third Edition 2013*

**1.6 Sign Conventions** (reference 1.8)

***Editor’s note*** *There is near unanimous agreement on most sign conventions except for pilot inputs and control surface deflections. Although individual organizations generally are consistent in-house, confusion often arises when trying to mathematically translate inputs & deflections from one organization to another. This section documents the generally accepted “body axes” sign conventions then discusses the rationale for several view- points addressing the “inputs & deflections” debate. Below is the SFTE sign convention.*

**Wind Axes Sign Convention** Winds are listed according to the direction they are coming from. Airports refer winds to magnetic North while winds at altitude are typically referred to true North. Headwind is true airspeed minus ground speed. (*Vw=VT- Vg*).

**Body Axes Sign Convention** The generally accepted body axes sign convention is based on the establishment of a three-dimensional axis sys- tem with the following properties: 1. It is right-handed orthogonal 2. Its origin is at the vehicle's reference center of gravity (defined by builder). 3. The axis system moves with the airframe.

*y*

*x*

Typical

+ Aft view, looking forward Fuselage Buttock Reference line = 0 Station

+

Waterline

+ *x*

*y*

*z*

*z* Page 01 - 27

*SFTE Reference Handbook Third Edition 2013*

Translational displacements, rates, accelerations, & forces are positive along the positive body axes di- rections. In spite of the simplicity of this logic, it is important to recognize that lift and normal load factor are positive in the *negative z* direction and the drag is positive in the *negative x* direction. Angular displacements, rates, accelerations & moments, are positive according to the “right hand rule” (a clock- wise rotation while looking in the direction of the positive axis) as shown in the figure.

The body axes, forces & translations along them, and moments & rotations about them are shown with arrows indicating the positive direction. Angular displacements, rates, accelerations & moments, are positive according to the “right hand rule” (a clock- wise rotation while looking in the direction of the positive axis) as shown in the figure.

The body axes, forces & translations along them, and moments & rotations about them are shown with arrows indicating the positive direction.

Page 01- 28

*SFTE Reference Handbook Third Edition 2013*

Angle of attack is positive clockwise from the projection of the velocity vector on the *xz* plane to the reference *x* body axis. The angle of sideslip is positive clockwise from the *xz* plane to the velocity vector (wind in the pilot’s right ear).

Aircraft *true* heading is the angle between *true* North and the projection of the x-body axis onto the hori- zontal plane. Mag. heading refers to mag North

The velocity vector is measured relative to the air mass while the flightpath is measured relative to the ground. They are equivalent only when winds are zero. Flightpath heading angle (ground track heading) σ*g*, is the horizontal angle between true North and the projec- tion of the flightpath on the horizontal plane. Positive rotation is from north to east.

Flightpath elevation angle; γ, is the vertical angle between the flightpath and the horizontal plane. Posi- tive rotation is up. During a descent, this parameter is commonly known as glide path angle. Flightpath bank angle; μ, is the angle between the plane formed by the velocity vector and the lift vector and the vertical plane containing the velocity vector. Positive rotation is clockwise about the velocity vector, looking forward. Fuselage reference station (FRS), Water line (WL), and Buttock line (BL) are reference coordinates es- tablished by the design group.

Page 01 - 29

*SFTE Reference Handbook Third Edition 2013*

**Summary of Generally Accepted Body Axes Sign Convention**

**Parameter Name Symbol Positive Direction**

Translational Measurements

Longitudinal axis x from ref *cg* towards nose

Lateral axis y from reference *cg* towards right wing tip

Vertical axis z from reference *cg* towards vehicle bottom

(body axis)

Longitudinal velocity u along +x axis

Lateral velocity v along +y axis

Vertical velocity w along +z axis

Long. acceleration ax along + x axis

Lateral acceleration ay along +y axis

Vertical acceleration az along +z axis

Longitudinal load factor Nx along +x axis

Lateral load factor Ny along +y-axis

Normal load factor Nz along –z axis

Longitudinal force Fx along the +x axis

Lateral force Fy along the +y axis

Normal force Fz along the + z axis

Drag force D along the –x axis

Side force Y along the + y axis

Lift Force L along the –z axis

Page 01- 30

*SFTE Reference Handbook Third Edition 2013*

**Summary of Generally Accepted Body Axes Sign Convention**

**Parameter Name Symbol Positive Direction**

Angular Measurements

Bank angle φ right wing down

Pitch angle θ nose-up

Heading ψ 0 North, +Eastward

Angle of attack α normal flight attitude

Angle of sideslip β “wind in the right ear”

Roll rate p right wing down

Pitch rate q nose up

Yaw rate r nose right

Roll moment *L* right wing down

Pitch moment *M* nose up

Yaw moment *N* nose right

Flightpath bank angle μ right wing down

Flightpath elevation γ climb

Flightpath heading σ*g* 0 true North, + East-

ward

**Discussion of “Input & Deflection“ Conventions**

The debate regarding proper inputs and deflections stems from the user’s viewpoint. From the body axis convention above, flight testers recognize that a climbing right turn generates positive angular measurements. Logically then, pull, right roll and right yaw pilot inputs and subsequent surface deflections should also be posi- tive. The traditional flight tester’s convention follows as “All input forces & displacements, surface deflections, and motions that cause a climbing right turn are positive.”

Due to differential nature of aileron deflections, they require more discussion. The flight tester’s logic implies (but does not dictate) positive deflections are right aileron up and left aileron down. It is, however, equally acceptable to assign downward (or upward) deflection as positive for both ailerons and calculate the dif- ference between the two as a measure of rolling moment.

Page 01 - 31

*SFTE Reference Handbook Third Edition 2013*

The rationale within the wind tunnel community is also logical: any control surface deflection that in- creases lift is positive. From this, positive deflections are trailing edge down (TED) for each: trailing edge flap, stabilizer, elevator, stabilator, rollervator, ruddervator, canard, aileron, flaperon, and all their tabs. Leading edge flap down is also positive. Similarly, since side force is positive to the right, then positive rudder and rudder tab deflections are trailing left (TEL). The only exception to this straightforward logic is for spoilers and speed brakes that extend only in one direction: this deflection is positive even though it might decrease the lift.

Since the above rationale defines downward deflection as positive for both ailerons, a measurement of rolling moments requires calculation of the differential aileron deflection. This rationale does not, however, spe- cifically dictate whether a “positive” differential deflection should generate right wing down (RWD) or left wing down (LWD) moments. Differential aileron can be calculated as either.

δ *a* = δ *aR* − δ *aL* or

δ *a* = δ *aL* − 2

Selection of the RWD convention is obvious from the flight tester’s viewpoint since deflections that generate right rolls are positive. An alternative interpretation is that a positive differential aileron deflection is one that lifts the positive (right) wing lifts more than the left (LWD).

Another common convention for ailerons is one that gives the same sign to both ailerons for any input. The “right hand screw” convention is opposite to the flight tester’s convention, but may be more common:

δ*aR* = +TED, δ*aL* = +TEU.

The above wind tunnel rationale dictates only the polarity for individual control surface deflections, and leaves open the sign convention debate about controller (inceptor) input forces & displacements. One approach is that positive inputs should generate positive *motions* while an alternate approach is that positive inputs gener- ate positive *surface deflections*. Only the flight tester’s convention states that positive inputs yield positive mo- tions *and* deflections. All approaches are mathematically connected to the hinge moment sign convention dis- cussed below.

The simplest control surface hinge moment convention is that *all* positive hinge moments (generated by the pilot and the aerodynamics) move the surface in a positive direction, i.e., positive input forces yield positive deflections. This has different implications for the different sign conventions:

• According to the above flight tester’s sign convention, a positive pull force is required to generate a positive (TEU) elevator deflection (positive stick force generates a climb).

• According to wind tunnel sign convention, a positive *push* force is required to generate a positive (*TED*) ele- vator deflection (positive stick force generates a *dive*).

The alternate viewpoint defines a positive inceptor hinge moment as one that *opposes* the aerodynamic mo- ments. In other words, a positive inceptor hinge moment moves the surface to a position which generates posi- tive aerodynamic hinge moments or “positive input forces & displacements generate negative surface deflec- tions.”

Page 01- 32 δ *aR* 2

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Based on the above background, the SFTE technical council proposes the following standard convention for in- ceptor & surface forces & deflections:

• Due to its widespread use and its simple & robust nature, use the wind tunnel convention for control surface deflections.

• Due to widespread test pilot & FTE familiarity and logical nature, use the flight tester’s convention that pos- itive inceptor forces & displacements generate a climbing right turn.

• A fallout from these conventions is that positive inceptor hinge moments generate positive aerodynamic hinge moments (negative surface deflections).

• Consistent use of the above logic requires that the calculated value for aileron deflection be negative for right wing down moments. Similarly, differential ruddervator deflections generating nose right yawing mo- ments should have negative values.

**Conventions for Positive Control Surface Deflections**

**Parameter Symbol Flight Test SFTE/**

**Wind Tunnel**

Horizontal Stabilizer δ*i* TEU TED

Elevator δ*e* TEU TED

Elev. Tab δ*et* TED

Stabilators or Rollerva- tors, average: differential:

Page 01 - 33 δ*eL ,* δ*eR* TEU TED

δ*e* = (δ*eR* + δ*eL* )/2

Δδ*e* = (δ*eR* - δ*eL*)/2

Elevons average: differential

δ*vL ,* δ*vR* TEU TED

δ*v* = (δ*vR* + δ*vL*)/2

Δδ*v* = (δ*vR* - δ*vL*)/2

Flaperons or trailing edge flap average: differential:

δ*fR* , δ*fL* TED

δ*f* = (δ*fR* + δ*fL*)/2

Δδ*f* = - (δ*fR* - δ*fL*)/2 = (δ*fR* - δ*fL*)/2

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**Conventions for Positive Control Surface Deflections (Cont’d)**

**Parameter Symbol Flight Test SFTE/**

**Wind Tunnel**

Canards average: differential

Page 01- 34 δ*cL ,* δ*cR* TED

δ*c* = (δ*cR* + δ*cL*)/2

Δδ*c* = - (δ*cR* - δ*cL*)/2 = (δ*cR* - δ*cL*)/2

Leading edge flap Average: Differential:

δ*lefL ,* δ*lefR* TED

δ*lef* = (δ*cR* + δ*cL*)/2

Δδ*lef* = - (δ*cR* - δ*cL*)/2 = - (δ*cR* - δ*cL*)/2

Ruddervators Average: Differential:

δ*rvL ,* δ*rvR* TEU TED

δ *rv* = (δ*rvR* + δ*rvL*)/2 Δδ *rv* = - (δ*rvR* - δ*rvL*)/2

Ailerons Aileron Tab Average:

δ*aL ,* δ*aR* δ*aR*TEU, δ*aL* TEDor {δ

*aR*, δ*aL*TED} δ*aR,* δ*aL TED*

δ*at* = (δ*aR* +δ*aL*)/2 δ*at* TED

δ*a* = - (δ*aR* -δ*aL*)/2} = (δ*aR* -δ*aL*)/2 \*

Spoilers average: Differential:

δ*sL* , δ *sR* Extended

δ*s* = (δ*sR* +δ*sL*)/2

Δ*ds* = (δ*sR* -δ*sL*)/2 = - (δ*sR* -δ*sL*)/2

Rudders Average:

δ*rR ,* δ*rL* TER TEL

δ*r* = (δ*rR* +δ *r L*)/2

Rudder tab δ*rt* TEL

Speed brake δ*sb* Extended

**Conventions for Positive Inputs and Hinge Moments**

**Parameter Symbol Flight Test SFTE/**

**Wind Tunnel**

Stick/Wheel Long Force Fe Pull

Stick/Wheel Lateral Force Fa Right

Pedal Force Fr Right pedal push

Stick/Wheel Long. deflectn δse Aft

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**Conventions for Positive Inputs and Hinge Moments (Cont’d)**

**Parameter Symbol Flight Test SFTE#**

Stick/wheel Lat. deflection \*The wind tunnel rationale does not inherently define the polarity for control surface differential deflections.

#The wind tunnel rationale does not specify a convention for positive inputs or hinge moments. Historically, Dutch, U.S. and some British aircraft use a climbing right turn, while it is a diving left turn for Canadian, Aus- tralian, and some British aircraft.

*The SFTE Technical Council recognizes that several combinations of the above possibilities are currently in use around the world, and invites comments, additions, or corrections to the above summary and proposal. Alt- hough SFTE does not expect all organizations to adopt this standard, it still* ***provides a cornerstone for reference purposes***

Page 01 - 35 δsa Right

Pedal deflection δ*pR*, δ*pL* Right pedal push

Aerodynamic Hinge

Moments Chδ Chα Chδο Chδtab

positive moments generate positive deflections

Inceptor Hinge Moments

ChFe ChFa ChFr

+ moments generate + deflections

+ moments generate - deflections

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**1.7 Thermodynamics Relations (references 1.3, 1.4, 1.5, 1.6)**

A **Process** is an event with a redistribution of energy within a system.

A **Reversible** process is one that can be reversed such that the system returns to its original state (form, location & amount).

An **Irreversible** process cannot return to its original state due to heat flow from higher to lower temperatures, fluid turbulence, friction, or inelastic deformation. The change in entropy is non-zero.

An **Isothermal** process is one in which the temperature of the fluid is constant.

An **Adiabatic** process is one in which heat is not transferred to or from the fluid.

**Work** is the energy *transfer* by way of changing mechanical energy.

**Heat** is the energy *transfer* from one body to another by virtue of a temperature difference between them.

An **Isentropic** process has constant entropy.

**Conduction** is the energy transfer from a warmer body by tangible contact (transfer of some internal molecular kinetic energy).

**Convection** is the repositioning the energy of a fluid without state changes or energy transformations (e.g. heat- ed air moving from one room to another room).

**Radiation** is the energy transmission through space.

Page 01- 36

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A = area C = compressibility factor

C = speed of sound

E = u = specific internal energy (e.g. Btu /lb)

H = specific **enthalpy** *≡ E + PV* (e.g. Btu/lb) J = Joule’s equivalent 107 ergs = 778 ft-lb/Btu

Q = energy supplied to a system or region as heat (e.g. Btu/lb)

P = absolute pressure (e.g. lbs/ft2)

V = specific volume (e.g. ft3/lb)

W = work (+ if entering) *V*

= velocity

Δ = change ( final – initial value)

Z = altitude S = specific entropy ≡ ∫ *dE*

+ *TPdV* for a reversible process

R = gas constant for each gas (for air = 287 J/[kg K] = 53.35 ft-lb/lbmR)

*R*

= R[M] = universal gas constant

= 8.314 kJ/[kmol K] = 1545 ft lb/[lbmol R] M = molar mass (for air = 28.97 kg/kmol) N = number of moles ρ = density

The **First Law of Thermodynamics** shows that the net amount of energy added to a system equals the net change in energy within the system (Principle of Conservation of Energy): *W + Q = (E2 - E1)*

The **Second Law of Thermodynamics** states that entropy increases during any irreversible process: S2>S1

**Ideal Gas Equation of State** (a.k.a. Perfect gas law): PV=RT, P = ρRT, PV = mRT, PV = nRT

δ = σθ where δ *Pa*/*Po*, σ = ρ*a*/ρ*o*, θ = *Ta*/*To*

Page 01 - 37

*SFTE Reference Handbook Third Edition 2013*

**Boyle’s Law** states that when the temperature of a given mass of gas is held constant, then the volume and pres- sure vary inversely.

**Charle’s Law** states that when a volume of a given mass is held constant, then the change in pressure of the gas is proportional to the change in temperature.

**Real Gas** Relation: PV = CRT

for reversible processes

*W*

−=

∫ *PdV Q*

= ∫*TdS* for reversible adiabatic process

*P* 1 *P*2=

⎡ ⎢⎣*V V*12

⎤ ⎥⎦γ

*T*

1 *T*2=

⎡ ⎢⎣*V V*12 ⎤ ⎥⎦Steady Flow Energy Equation

Bernoulli Equation:

Page 01- 38 γγρ γρ− −1

1 221 γ1 *T*

1 *T*2=

⎡ ⎢⎣*PP* 1

2*P P*=

⎡ ⎢⎣⎤ ⎥⎦2 ⎤ ⎥⎦*HQ* + 1 + *V* 2 1

*g*2+ *HWZ* 1

= + 2 + *V* 2 2 *g*2+ *Z* Δ *P*ρ *g*+ *VV*

2 22

− *g*21 Δ+ *Z* = 0

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Flow per Unit Area:

*W*

*RA*= γ

*P*

*M T*⎛ ⎜⎝1 +

γ

2 − 1 *M*2

⎞ ⎟⎠)12 γ ( γ+ −1

Velocity of sound in a perfect gas:

*c* = γ *gRT* Development of **Specific Heat Relations**

*c p* ≡

∂ ∂*H TP*

specific heat at constant pressure (for air = 1004.76 J/[kg oK])

*c v* ≡

∂∂ *Tu v*

specific heat at constant volume (for air = 717.986 J/[kg oK])

κ = γ ≡ *c pcv*Enthalpy equation in differential form is: *d*H = *d*u +*d*(PV) Substituting definitions and ideal gas law gives cp *d*T = cv *d*T + R*d*t or cp = cv + R

Rearranging gives and

Development of **Poisson’s Equation**: 1) From the 1st law: W+Q = E2-E1 2) Substitution for each term gives T *d*S – P *d*V = *d*u 3) Divide through by T: *d*S = *d*u/T + P *d*V/T 4) Recall *d*u = cv *d*T and PV = RT 5) Substitution gives *d*S = cv *d*T/T + R *d*V/V 6) Assume constant specific heat and integrate:

Page 01 - 39 = ratio of specific heats

*Rc p* = κ1− κ *cv* = κ1− *R css* 2 −

1 = *v* ln *T T*2 1+ *R* ln *V V*2 1

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7) Assuming a reversible adiabatic process

*cv* ln *T T*12 =− *R* ln *V V*12

8) Substitute *cv*

=κ*R* 1− to get:

*T TV*

κ

*V*9) Differentiate H: *d*H = *d*u + P *d*V + V *d*P 10) Substitution into step #2: T *d*S = *d*H-V *d*P

11) Integrate:

*css* 2 −

1 = *p* ln *T T*2 1+ *R* ln *P P*12

12) Assuming a reversible adiabatic process:

*cp* ln *T T*12 =

− *R* ln *P P*12

13) Substitute *Rc p*

= κκ 1− to get:

14) Combine steps #8, #13 to get: or PVκ = const.

Page 01- 40 2 1=

⎛ ⎜⎜⎝1

2⎞ ⎟⎟⎠− 1

κ 1

2

2 κ11− *T T*= ⎛ ⎜⎜⎝*P*

*P*⎞ ⎟⎟⎠*P* 2 *P*1=

⎛ ⎜⎜⎝*VV* 1 2⎞ ⎟⎟⎠κ

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**1.8 Mechanics Relations**

**Abbreviations**

a = linear acceleration = *d*V/*d*t ar = centripetal (radial) acceleration aT = tangential acceleration F = force g = acceleration due to gravity (32.174 ft/s2 = 9.80 meters/s2) G = moment H = angular momentum = Iw H = height Hp = horsepower (Hp = 550ft-lbs/sec) I = rotational moment of inertia (see section 10) J = impulse = change in momentum k = radius of gyration m = mass Nr = radial load factor = ar/g P = power = *d*W/*d*t L = linear momentum = mV Q = moment (a.k.a. torque) r = radius S = distance, displacement s = seconds t = time V = true inertial velocity Vo = initial inertial velocity W = work = FS = 1⁄2 m [V2 - Vo2] q = angular displacement *Vol* = volume ω = angular velocity (radians/second) ώ = angular acceleration

Page 01 - 41

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**Newtons Laws 1st law** (law of inertia): “Every body persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it.

**2nd Law**: “ The change in motion is proportional to the motive force impressed and is made in the direction of the straight line in which that force is impressed” (motion defined as velocity *x* quantity of matter or linear momentum, mV). *d*F = *d*mV/*d*t = (*d*m/*d*t) + (*d*V/*d*t) For constant mass in rectilinear motion: F = ma For constant mass distribution in curvilinear motion: G = I

**3rd Law**: “Every action has an equal and opposite reaction; or, the mutual attraction of two bodies upon each other are always equal and directed to contrary parts.[opposite directions]”

**Planar Kinetics, Work, Power and Energy Rectilinear motion Curvilinear motion** displacement S angular displacement θ

velocity V = *d*S/*d*t angular velocity ω = dθ/dt

acceleration a = *d*V/*d*t angular acceleration = d ω /dt

inertia m rotational inertia

momentum L = mV angular momentum H = I ω

force F = ma torque Q = I

work W = work W =

power P = FV power P = Q ω kinetic energy 1⁄2 mV2 kinetic energy 1⁄2 I ω2 potential energy mgH n/a

Page 01- 42

ωx

∫ *FdS*

ωx*dmrI* = ∫ 2ωx

∫ *Qd*

θ

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**Planar Kinematics at Constant Acceleration**

**Rectilinear motion Curvilinear motion** V = Vo + at ω = ωo + t V2 = Vo2 + 2aS ω 2 = ω o2+2 S = Vot + 1⁄2 at2 θ = ω ot + 1⁄2 Page 01 - 43 ωxθ

ωx

t2

S = 1⁄2(V + Vo)t θ = 1⁄2( ω + ω o)t *aVVS*

=

(

2

− 0

22/) θ

= ( ω 2 − ω 0

22/) ω x

*t*

=

− *aSVV* 0

+ 0 2+ 2

*a*

*t* = − ω 0

+ ω 0 2− 2 θω xω

x

*a*

=

(2

*tVS t* − 2

) ω x

= (2 θ *t*

− ω *t* ) **Curvilinear motion with constant acceleration and radius:** r = V2/gNr V = ωr NR = ar/g ω = gNr/V

ω x = *V*x *R* ar = rω2 = V2/r *a r* =ωx *r* **Aircraft in level turn:**

Nzw = load factor normal to flight path *r* = turn radius Ω = turn rate (rad/sec)

( )

( )

1

V= inertial velocity 0

0 2

*r*

=

*V* 2

*Ng zw*ω= ⎛ ⎜⎜⎝2

− 1

=

*Ng*

*Vzw* 1*N*

*zw*

*V g*⎞ ⎟⎟⎠2− ω +

*SFTE Reference Handbook Third Edition 2013*

Page 01- 44

*SFTE Reference Handbook Third Edition 2013*

**Gyroscopic Motion** (reference 1.7) for bodies spinning about an axisymmetric axis

ψxφxθx

Page 01 - 45 **=** spin rate = precession rate = nutation rate

*Iz* = moment of inertia about spin axis *It* = transverse moment of inertia about the spin point

(perpendicular to spin axis) *Icg* = moment of inertia about the *cg* (perpendicular to spin axis) Mx = moment about spin point (acting along plane that defines θ)

**. .** For steady precession (constant θ, φ , ψ )

∑ *Mx* = − *I t* φ x 2 sin θ cos θ + *I z* φ x sin θ ( φ x cos θ + ψ x ) For torque free motion (gravity is only external force)

ψ x

=

*II cg*− *I*

*z z* φ x cos θ note that *Icg>Iz* yields regular precession while *Icg<Iz* yields retrograde precession

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**Section 1.9 International Phonetic Alphabet and Morse Code**

A Alpha • ▬ B Bravo ▬●●● C Charlie ▬ • ▬ • D Delta ▬ • • E Echo ● F Foxtrot • • ▬ • G Golf ▬ ▬ • H Hotel • • • • I India • • J Juliet • ▬ ▬ ▬ K Kilo ▬ • ▬ L Lima • ▬ • • M Mike ▬ ▬ N November ▬ • O Oscar ▬ ▬ ▬ P Papa • ▬ ▬ • Q Quebec ▬ ▬ • ▬ R Romeo • ▬ • S Sierra • • • T Tango ▬ U Uniform • • ▬ V Victor • • • ▬ W Whiskey • ▬ ▬ X X-ray ▬ • • ▬ Y Yankee ▬ • ▬ ▬ Z Zulu ▬ ▬ • •

1 One • ▬ ▬ ▬ 2 Two • • ▬ ▬ ▬ 3 Three • • • ▬ ▬ 4 Four • • • • ▬ 5 Five • • • • • 6 Six ▬ • • • • 7 Seven ▬ ▬ • • • 8 Eight ▬ ▬ ▬ • • 9 Niner ▬ ▬ ▬ ▬ • 0 Zero ▬ ▬ ▬ ▬ ▬

Page 01- 46

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Page 01 - 47

*SFTE Reference Handbook Third Edition 2013*

**NOTES**

Page 01- 48