```
**********************************************************************************
"Test of Vallado's Example 3-15. Performing IAU-76/FK5 Reduction."
  (See p. 235, Vallado, "Fundamentals of Astrodynamics and Applications", 3rd Ed., 2007.)


Given:
        r_itrf = -1033.4793830 Ihat + u.y =  7901.2952754 Jhat + 6380.3565958 Khat
Find:
        r_gcrf  on April 6, 2004, 07:51:28.386009UTC


**********************************************************************************


   Setting Date and Time.
   ------------------------
   Date: 20040406
    UTC:  7.857885002500   (  07ʰ 51ᵐ 28ˢ.386 )


   Setting Earth Orientation Parameters.
   --------------------------------------
   DUT1:  -0.439961900000    ( -00ʰ 00ᵐ 00ˢ.440 )
     xp:  -0.000039078333    ( -00° 00′ 00″.141 )
     yp:   0.000092585833    (  00° 00′ 00″.333 )
  ddPsi:  -0.000014498611    ( -00° 00′ 00″.052 )
  ddEps:  -0.000001076389    ( -00° 00′ 00″.004 )


   Computing Coordinate Transformations.
   --------------------------------------
Time Quantitites:
    fYear          = 2004.265922
    Date           = 20040406
    UTC            = 7.857885 (  07ʰ 51ᵐ 28ˢ.386 )
    UT1            = 7.857763 (  07ʰ 51ᵐ 27ˢ.946 )
    TAI            = 7.866774 (  07ʰ 52ᵐ 00ˢ.386 )
    TT = TAI+32.184s = 7.875714 (  07ʰ 52ᵐ 32ˢ.570 )
    DUT1 = UT1-UTC  = -0.4399619 seconds
    DAT  = TAI-UTC  = 32.0000000 seconds
    JD_UTC         = 2453101.827411875 days
    JD_UT1         = 2453101.827406783 days
    JD_TT          = 2453101.828154746 days
    T_UT1          =    0.0426236114 Julian Centuries
    T_TT           =    0.0426236319 Julian Centuries
    year           = 2004
    month          = 4
    day            = 6
    doy            = 97
    dow            = 2
    dowstr         = Tue
    gmst (hours)   = 20.8539930 (  20ʰ 51ᵐ 14ˢ.375 )
    gmst (degrees) = 312.8098943 (  312° 48′ 35″.619 )
    gast (hours)   = 20.8537835 (  20ʰ 51ᵐ 13ˢ.620 )
    gast (degrees) = 312.8067521 (  312° 48′ 24″.307 )

Eccentricity and Obliquity:
    eccentricity                  = 0.01670732
```

```
    epsilon mean (obliq. of ecliptic) = 23.43873683 (  23° 26' 19".453 )
    epsilon true (obliq. of ecliptic) = 23.44076738 (  23° 26' 26".763 )


Precession Quantities:
    Zeta              = 0.0273055 (  00° 01' 38".300 )
    Zee               = 0.0273059 (  00° 01' 38".301 )
    Theta             = 0.0237306 (  00° 01' 25".430 )


Nutation Quantities:
    dPsi (w.o. corrections)           = -0.00341084 ( -00° 00' 12".279 )
    dEps (w.o. corrections)           = 0.00203163 (  00° 00' 07".314 )
    ddPsi (EOP correction)            = -0.00001450 ( -00° 00' 00".052 )
    ddEps (EOP correction)            = -0.00000108 ( -00° 00' 00".004 )
    dPsi (w. corrections)             = -0.00342534 ( -00° 00' 12".331 )
    dEps (w. corrections)             = 0.00203056 (  00° 00' 07".310 )
    epsilon true (obliq. of ecliptic) = 23.44076738 (  23° 26' 26".763 )
    Equation of the Equinox           = -0.00314219 ( -00° 00' 11".312 )


Low Accuracy Position of Sun:
    lambda_sun       =        16.860732 (  16° 51' 38".635 )
    earth_sun_dist   =    23476.333349 Re
    beta_sun         =              0  (  00° 00' 00".000 )
    RA_sun           =        15.539485 (  01ʰ 02ᵐ 09ˢ.476 )
    DEC_sun          =         6.625038 (  06° 37' 30".138 )


High Accuracy Position of Sun:
    lambda_sun_ha    =        16.856520 (  16° 51' 23".473 )
    r_sun_ha         =    23474.069058 Re
    beta_sun_ha      =      2.08851e-05  (  00° 00' 00".075 )
    RA_sun   (MOD)   =       15.535560  (  01ʰ 02ᵐ 08ˢ.535 )
    DEC_sun  (MOD)   =        6.623444  (  06° 37' 24".397 )
    RA_sun   (TOD)   =       15.532148  (  01ʰ 02ᵐ 07ˢ.716 )
    DEC_sun  (TOD)   =        6.622675  (  06° 37' 21".629 )


Sun vector and Ecliptic Pole in GEI2000:
    Sun              = (0.957013, 0.266113, 0.115371)
    EcPole           = (0.000000, -0.397768, 0.917486)


Geo-dipole tilt angle:
    psi              = -0.616385  ( -00° 36' 58".986 )
    sin_psi          = -0.010758
    cos_psi          = 0.999942
    tan_psi          = -0.010758


Position of Moon:
    RA_moon                 = 206.871584  (  13ʰ 47ᵐ 29ˢ.180 )
    DEC_moon                = -9.751673  ( -09° 45' 06".024 )
    EarthMoonDistance       = 57.990581
    MoonPhase               = 0.989924


IGRF-derived quantities:
    M_cd             = 30048.883892
    M_cd_McIllwain   = 31165.300000
    CD_gcolat        = 10.285656 (deg.) (  10° 17' 08".363 )
    CD_glon          = -71.751916 (deg.) ( -71° 45' 06".897 )
    ED_x0            = 0.032572  Re  (207.748374 km)
    ED_y0            = -0.062921  Re  (-401.318256 km)
    ED_z0            = 0.049404  Re  (315.107727 km)


Transformation Matrices:
```

```
                        [      0.95701259        0.26611345        0.11537124  ]
    Amod_to_gse     = [     -0.29004636        0.87804557        0.38066925  ]
                        [      0.00000000       -0.39776828        0.91748591  ]


                        [      0.95701259        0.26611345        0.11537124  ]
    Amod_to_gsm     = [     -0.27988060        0.95165720        0.12655210  ]
                        [     -0.07611666       -0.15340212        0.98522791  ]


                        [      0.67886841       -0.73425991       -0.00023984  ]
    Agei_to_wgs84   = [      0.73425985        0.67886845       -0.00031223  ]
                        [      0.00039208        0.00003586        0.99999992  ]


                        [      0.95701259       -0.29004636        0.00000000  ]
    Agse_to_mod     = [      0.26611345        0.87804557       -0.39776828  ]
                        [      0.11537124        0.38066925        0.91748591  ]


                        [      1.00000000        0.00000000       -0.00000000  ]
    Agse_to_gsm     = [     -0.00000000        0.96495123       -0.26242928  ]
                        [      0.00000000        0.26242928        0.96495123  ]


                        [      0.67886841        0.73425985        0.00039208  ]
    Awgs84_to_gei   = [     -0.73425991        0.67886845        0.00003586  ]
                        [     -0.00023984       -0.00031223        0.99999992  ]


                        [      0.95701259       -0.27988060       -0.07611666  ]
    Agsm_to_mod     = [      0.26611345        0.95165720       -0.15340212  ]
                        [      0.11537124        0.12655210        0.98522791  ]


                        [      0.99994213        0.00000000        0.01075774  ]
    Agsm_to_sm      = [      0.00000000        1.00000000        0.00000000  ]
                        [     -0.01075774        0.00000000        0.99994213  ]


                        [      1.00000000       -0.00000000        0.00000000  ]
    Agsm_to_gse     = [      0.00000000        0.96495123        0.26242928  ]
                        [     -0.00000000       -0.26242928        0.96495123  ]


                        [      0.99994213        0.00000000       -0.01075774  ]
    Asm_to_gsm      = [      0.00000000        1.00000000        0.00000000  ]
                        [      0.01075774        0.00000000        0.99994213  ]


                        [      0.99999946       -0.00095315       -0.00041418  ]
    Agei_to_mod     = [      0.00095315        0.99999955       -0.00000020  ]
                        [      0.00041418       -0.00000020        0.99999991  ]


                        [      0.99999946        0.00095315        0.00041418  ]
    Amod_to_gei     = [     -0.00095315        0.99999955       -0.00000020  ]
                        [     -0.00041418       -0.00000020        0.99999991  ]


                        [      1.00000000        0.00005485        0.00002378  ]
    Amod_to_tod     = [     -0.00005485        1.00000000       -0.00003544  ]
                        [     -0.00002378       -0.00000020        1.00000000  ]


                        [      1.00000000       -0.00005485       -0.00002378  ]
    Atod_to_mod     = [      0.00005485        1.00000000        0.00003544  ]
                        [      0.00002378       -0.00003544        1.00000000  ]


                        [      0.67952777       -0.73364979        0.00000000  ]
    Atod_to_pef     = [      0.73364979        0.67952777        0.00000000  ]
                        [      0.00000000        0.00000000        1.00000000  ]
```

```
                        [      0.67952777        0.73364979        0.00000000 ]
    Apef_to_tod     = [     -0.73364979        0.67952777        0.00000000 ]
                        [      0.00000000        0.00000000        1.00000000 ]


                        [   6.79568000e-01   -7.33612523e-01    0.00000000e+00 ]
    Ateme_to_pef    = [   7.33612523e-01    6.79568000e-01    0.00000000e+00 ]
                        [   0.00000000e+00    0.00000000e+00    1.00000000e+00 ]


                        [   6.79568000e-01    7.33612523e-01    0.00000000e+00 ]
    Apef_to_teme    = [  -7.33612523e-01    6.79568000e-01    0.00000000e+00 ]
                        [   0.00000000e+00    0.00000000e+00    1.00000000e+00 ]


                        [   1.00000000e+00    0.00000000e+00    6.82045583e-07 ]
    Awgs84_to_pef   = [  -1.10213630e-12    1.00000000e+00    1.61592763e-06 ]
                        [  -6.82045583e-07   -1.61592763e-06    1.00000000e+00 ]


                        [   1.00000000e+00   -1.10213630e-12   -6.82045583e-07 ]
    Apef_to_wgs84   = [   0.00000000e+00    1.00000000e+00   -1.61592763e-06 ]
                        [   6.82045583e-07    1.61592763e-06    1.00000000e+00 ]
```

```
  Setting ITRF Coordinates (km).
  -------------------------------
  u_itrf: -1033.479383000   7901.295275400   6380.356595800


  Transforming to PEF Coordinates (km).
  ---------------------------------------
   u_pef: -1033.475031306   7901.305585585   6380.344532749
   u_pef: -1033.475031300   7901.305585600   6380.344532800   (Vallado's result)
    DIFF:    -0.000000006      -0.000000015      -0.000000051   (LGM - Vallado's result)


  Transforming to TOD Coordinates (km).
  ---------------------------------------
   u_tod:  5094.516203638   6127.365277834   6380.344532749
   u_tod:  5094.514780400   6127.366461200   6380.344532800   (Vallado's result)
    DIFF:     0.001423238      -0.001183366      -0.000000051   (LGM - Vallado's result)


  Transforming to MOD Coordinates (km).
  ---------------------------------------
   u_mod: 5094.02837421   6127.87081613   6380.24851689
   u_mod: 5094.028374500   6127.870816400   6380.248516400   (Vallado's result)
    DIFF:    -0.000000286      -0.000000269       0.000000486   (LGM - Vallado's result)


  Transforming to GCRF Coordinates (km).
  ---------------------------------------
   u_gcrf:  5102.508957169   6123.011400718   6378.136928791
   u_gcrf:  5102.508953000   6123.011396000   6378.136937000   (Vallado's result)
    DIFF:     0.000004169       0.000004718      -0.000008209   (LGM - Vallado's result)
```