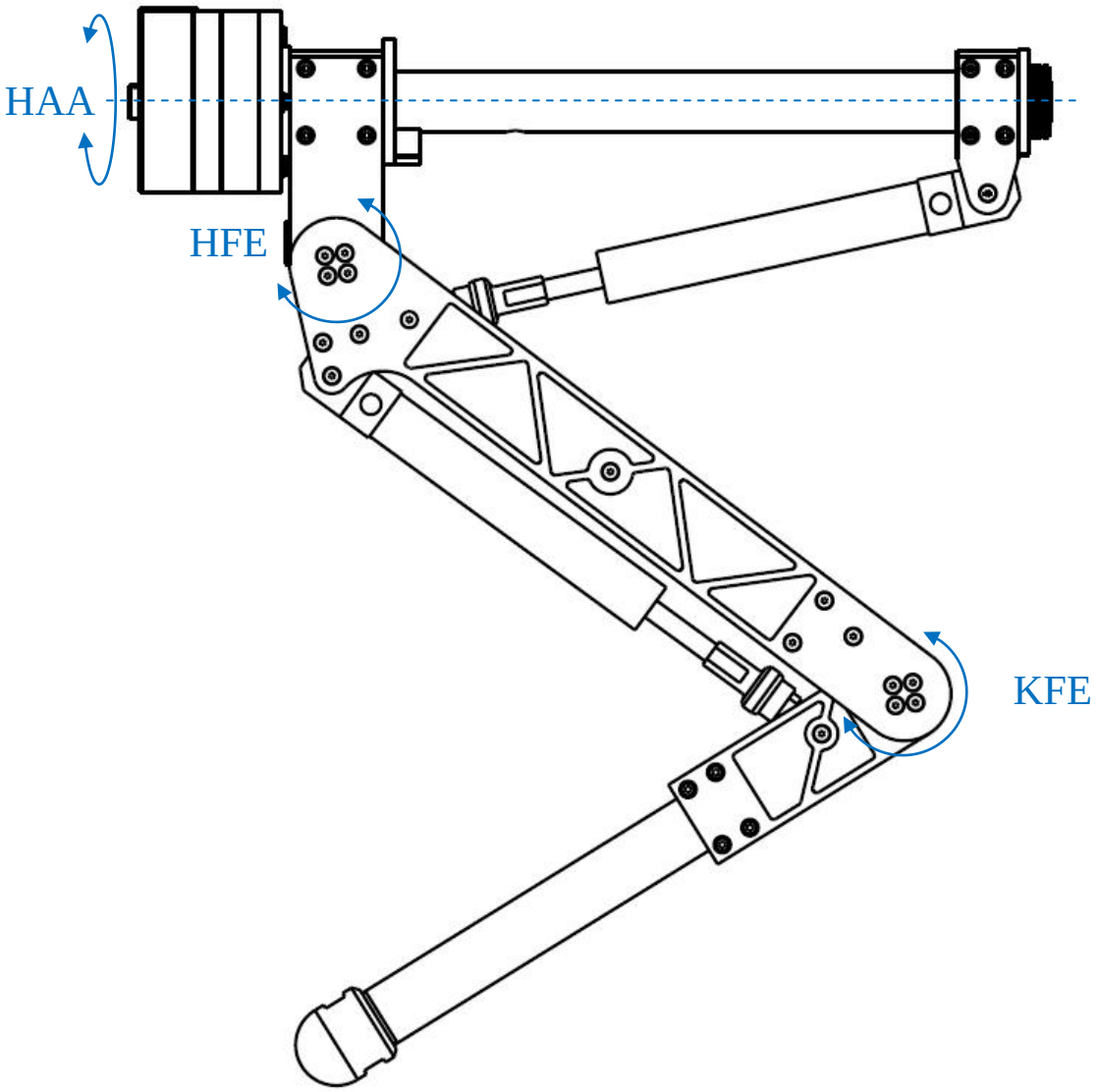
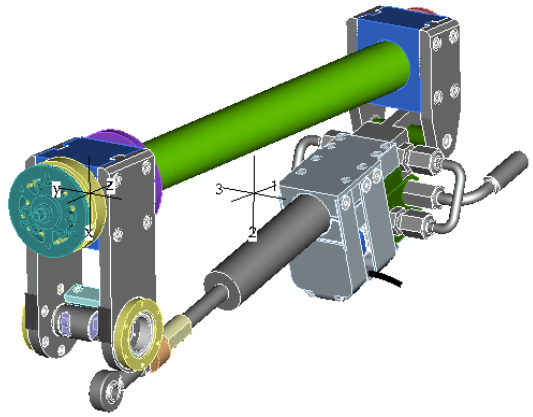
Inertia Parameters of the links of the HyQ Leg V2.5



The inertia parameters are based on the ProE (CAD) model where all parts are assigned with material properties (density etc.). Inertia matrices are calculated with respect to their axis of rotation (the one closer to the robot torso, marked with a red coordinate system). The coordinate systems of the links are defined according to the HyQ standard definition. The CAD model does not include the electronic boards (hub board and load cell amplifier board), electric wiring, rubber layer on end-stops and hydraulic hosing/connectors.
The screen shots are saved in high-resolution, so zoom in to read the numbers. Note that the units are expressed in [mm] and not [m].

HAA (hip abduction/adduction)
for Leg LF and RH



VOLUME = 7.3068034e+05 MM^3
SURFACE AREA = 3.3912166e+05 MM^2
AVERAGE DENSITY = 4.0502175e-06 KILOGRAM / MM^3
MASS = 2.9594143e+00 KILOGRAM

CENTER OF GRAVITY with respect to ACS1 coordinate frame:
X Y Z 4.1878827e+01 2.8130506e-01 1.6725579e+02 MM

INERTIA with respect to ACS1 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 1.3485663e+05 -3.6171448e+01 -2.2688097e+04
Iyx Iyy Iyz -3.6171448e+01 1.4416796e+05 -5.1274914e+01
Izx Izy Izz -2.2688097e+04 -5.1274914e+01 1.0889957e+04

INERTIA at CENTER OF GRAVITY with respect to ACS1 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 5.2068267e+04 -1.3073993e+00 -1.9589507e+03
Iyx Iyy Iyz -1.3073993e+00 5.6189503e+04 8.7965228e+01
Izx Izy Izz -1.9589507e+03 8.7965228e+01 5.6993949e+03

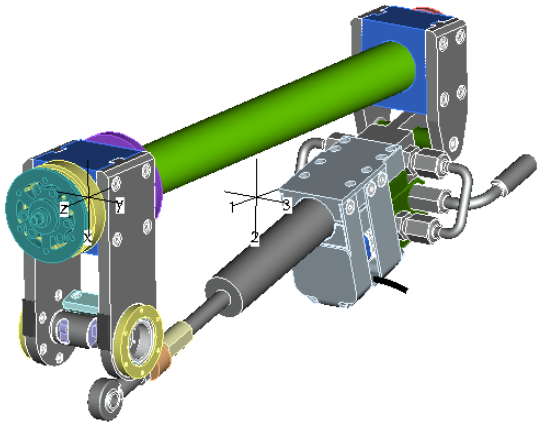
PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 5.6166296e+03 5.2150874e+04 5.6189662e+04

ROTATION MATRIX from ACS1 orientation to PRINCIPAL AXES:
0.04213 0.99911 -0.00117
-0.00174 0.00124 1.00000
0.99911 -0.04213 0.00179

ROTATION ANGLES from ACS1 orientation to PRINCIPAL AXES (degrees):
angles about x y z -89.898 -0.067 -87.585

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 4.3564728e+01 1.3274798e+02 1.3779242e+02 MM

for Leg LH and RF



VOLUME = 7.3068034e+05 MM^3
SURFACE AREA = 3.3912166e+05 MM^2
AVERAGE DENSITY = 4.0502175e-06 KILOGRAM / MM^3
MASS = 2.9594143e+00 KILOGRAM

CENTER OF GRAVITY with respect to ACS1 coordinate frame:
X Y Z -4.1878827e+01 -2.8130506e-01 1.6725579e+02 MM

INERTIA with respect to ACS1 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 1.3485663e+05 -3.6171448e+01 2.2688097e+04
Iyx Iyy Iyz -3.6171448e+01 1.4416796e+05 5.1274914e+01
Izx Izy Izz 2.2688097e+04 5.1274914e+01 1.0889957e+04

INERTIA at CENTER OF GRAVITY with respect to ACS1 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 5.2068267e+04 -1.3073993e+00 1.9589507e+03
Iyx Iyy Iyz -1.3073993e+00 5.6189503e+04 -8.7965228e+01
Izx Izy Izz 1.9589507e+03 -8.7965228e+01 5.6993949e+03

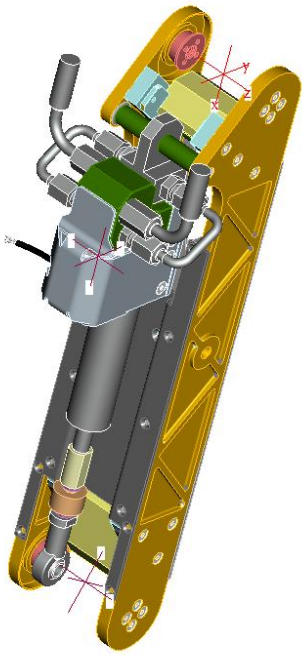
PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 5.6166296e+03 5.2150874e+04 5.6189662e+04

ROTATION MATRIX from ACS1 orientation to PRINCIPAL AXES:
-0.04213 0.99911 -0.00117
0.00174 0.00124 1.00000
0.99911 0.04213 -0.00179

ROTATION ANGLES from ACS1 orientation to PRINCIPAL AXES (degrees):
angles about x y z -90.102 -0.067 -92.415

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 4.3564728e+01 1.3274798e+02 1.3779242e+02 MM

HFE (hip flexion/extension)
for Leg LF and RF



VOLUME = 7.1714332e+05 MM^3
SURFACE AREA = 4.0880446e+05 MM^2
AVERAGE DENSITY = 3.6579865e-06 KILOGRAM / MM^3
MASS = 2.6233006e+00 KILOGRAM

CENTER OF GRAVITY with respect to ACS0 coordinate frame:
X Y Z 1.5090382e+02 -2.7343882e+01 2.6497945e-02 MM

INERTIA with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 5.7024730e+03 7.8883389e+03 -8.1698297e+00
Iyx Iyy Iyz 7.8883389e+03 8.7096628e+04 1.9214046e+01
Izx Izy Izz -8.1698297e+00 1.9214046e+01 9.0075993e+04

INERTIA at CENTER OF GRAVITY with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 3.7410611e+03 -2.9361765e+03 2.3198079e+00
Iyx Iyy Iyz -2.9361765e+03 2.7358923e+04 1.7313316e+01
Izx Izy Izz 2.3198079e+00 1.7313316e+01 2.8376880e+04

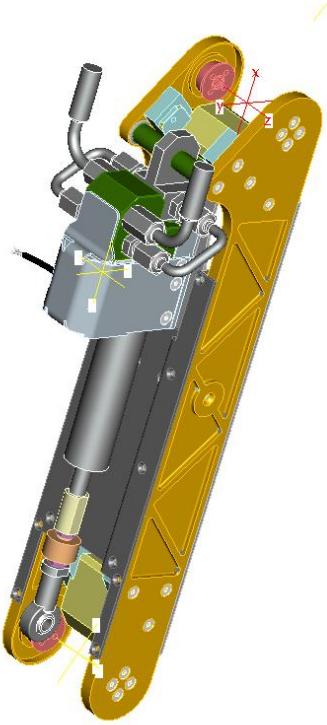
PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 3.3815081e+03 2.7718042e+04 2.8377315e+04

ROTATION MATRIX from ACS0 orientation to PRINCIPAL AXES:
0.99259 -0.12151 -0.00294
0.12155 0.99226 0.02548
-0.00018 -0.02565 0.99967

ROTATION ANGLES from ACS0 orientation to PRINCIPAL AXES (degrees):
angles about x y z -1.460 -0.169 6.979

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 3.5903037e+01 1.0279151e+02 1.0400677e+02 MM

for Leg LH and RH



VOLUME = 7.1714332e+05 MM^3
SURFACE AREA = 4.0880446e+05 MM^2
AVERAGE DENSITY = 3.6579865e-06 KILOGRAM / MM^3
MASS = 2.6233006e+00 KILOGRAM

CENTER OF GRAVITY with respect to ACS0 coordinate frame:
X Y Z -1.5090382e+02 2.7343882e+01 2.6497945e-02 MM

INERTIA with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 5.7024730e+03 7.8883389e+03 8.1698297e+00
Iyx Iyy Iyz 7.8883389e+03 8.7096628e+04 -1.9214046e+01
Izx Izy Izz 8.1698297e+00 -1.9214046e+01 9.0075993e+04

INERTIA at CENTER OF GRAVITY with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 3.7410611e+03 -2.9361765e+03 -2.3198079e+00
Iyx Iyy Iyz -2.9361765e+03 2.7358923e+04 -1.7313316e+01
Izx Izy Izz -2.3198079e+00 -1.7313316e+01 2.8376880e+04

PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 3.3815081e+03 2.7718042e+04 2.8377315e+04

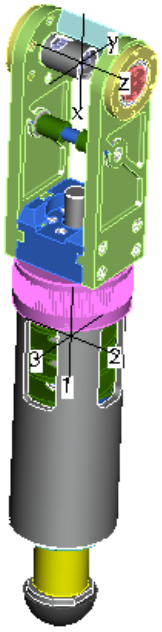
ROTATION MATRIX from ACS0 orientation to PRINCIPAL AXES:
0.99259 -0.12151 0.00294
0.12155 0.99226 -0.02548
0.00018 0.02565 0.99967

ROTATION ANGLES from ACS0 orientation to PRINCIPAL AXES (degrees):
angles about x y z 1.460 0.169 6.979

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 3.5903037e+01 1.0279151e+02 1.0400677e+02 MM

KFE (knee flexion/extension, with compliant foot)

for Leg LF and RF



VOLUME = 5.1727738e+05 MM^3
SURFACE AREA = 2.6108889e+05 MM^2
AVERAGE DENSITY = 3.7552274e-06 KILOGRAM / MM^3
MASS = 1.9424942e+00 KILOGRAM

CENTER OF GRAVITY with respect to ACS0 coordinate frame:
X Y Z 1.7417804e+02 2.4644061e-01 -7.8690992e-02 MM

INERTIA with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 9.6125136e+02 -1.2213873e+01 5.5312142e+00
Iyx Iyy Iyz -1.2213873e+01 7.8473524e+04 -2.0672713e-01
Izx Izy Izz 5.5312142e+00 -2.0672713e-01 7.8246171e+04

INERTIA at CENTER OF GRAVITY with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 9.6112136e+02 7.1166801e+01 -2.1093082e+01
Iyx Iyy Iyz 7.1166801e+01 1.9542145e+04 -2.4439725e-01
Izx Izy Izz -2.1093082e+01 -2.4439725e-01 1.9314686e+04

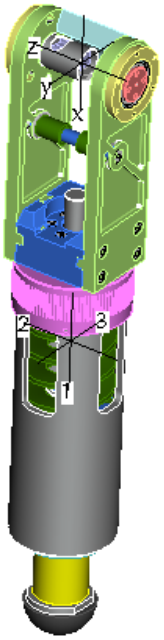
PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 9.6082455e+02 1.9314710e+04 1.9542418e+04

ROTATION MATRIX from ACS0 orientation to PRINCIPAL AXES:
0.99999 -0.00114 -0.00383
-0.00383 0.00143 -0.99999
0.00115 1.00000 0.00143

ROTATION ANGLES from ACS0 orientation to PRINCIPAL AXES (degrees):
angles about x y z 89.918 -0.220 0.066

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 2.2240379e+01 9.9715859e+01 1.0030193e+02 MM

for Leg LH and RH



VOLUME = 5.1727738e+05 MM^3
SURFACE AREA = 2.6108889e+05 MM^2
AVERAGE DENSITY = 3.7552274e-06 KILOGRAM / MM^3
MASS = 1.9424942e+00 KILOGRAM

CENTER OF GRAVITY with respect to _CAT_IIT_A_001_LOWERLEG coordinate frame:
X Y Z -7.8690992e-02 -2.4644061e-01 8.2178039e+01 MM

INERTIA with respect to _CAT_IIT_A_001_LOWERLEG coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 3.2432914e+04 2.0672713e-01 -8.5316108e+00
Iyx Iyy Iyz 2.0672713e-01 3.2660267e+04 -3.1827397e+01
Izx Izy Izz -8.5316108e+00 -3.1827397e+01 9.6125136e+02

INERTIA at CENTER OF GRAVITY with respect to _CAT_IIT_A_001_LOWERLEG coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 1.9314686e+04 2.4439725e-01 -2.1093082e+01
Iyx Iyy Iyz 2.4439725e-01 1.9542145e+04 -7.1166801e+01
Izx Izy Izz -2.1093082e+01 -7.1166801e+01 9.6112136e+02

PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 9.6082455e+02 1.9314710e+04 1.9542418e+04

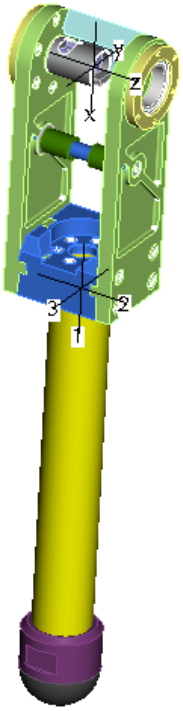
ROTATION MATRIX from _CAT_IIT_A_001_LOWERLEG orientation to PRINCIPAL AXES:
0.00115 1.00000 0.00143
0.00383 -0.00143 0.99999
0.99999 -0.00114 -0.00383

ROTATION ANGLES from _CAT_IIT_A_001_LOWERLEG orientation to PRINCIPAL AXES (degrees):
angles about x y z -90.220 0.082 -89.934

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 2.2240379e+01 9.9715859e+01 1.0030193e+02 MM

KFE (knee flexion/extension, with non compliant foot)

for Leg LF and RF



VOLUME = 2.5718473e+05 MM^3
SURFACE AREA = 1.3439259e+05 MM^2
AVERAGE DENSITY = 3.1260069e-06 KILOGRAM / MM^3
MASS = 8.0396125e-01 KILOGRAM

CENTER OF GRAVITY with respect to ACS0 coordinate frame:
X Y Z 1.2222975e+02 5.8620521e-01 -1.1923504e-01 MM

INERTIA with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 4.2080751e+02 -2.6595872e+00 4.3341665e-02
Iyx Iyy Iyz -2.6595872e+00 2.2015142e+04 0.0000000e+00
Izx Izy Izz 4.3341665e-02 0.0000000e+00 2.1827875e+04

INERTIA at CENTER OF GRAVITY with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 4.2051981e+02 5.4945614e+01 -1.1673645e+01
Iyx Iyy Iyz 5.4945614e+01 1.0003861e+04 -5.6180076e-02
Izx Izy Izz -1.1673645e+01 -5.6180076e-02 9.8163285e+03

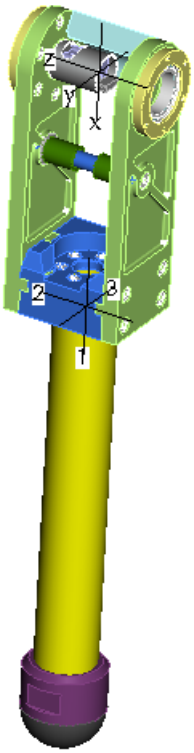
PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 4.2019029e+02 9.8163429e+03 1.0004176e+04

ROTATION MATRIX from ACS0 orientation to PRINCIPAL AXES:
0.99998 -0.00124 -0.00573
-0.00573 0.00066 -0.99998
0.00124 1.00000 0.00066

ROTATION ANGLES from ACS0 orientation to PRINCIPAL AXES (degrees):
angles about x y z 89.962 -0.329 0.071

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 2.2861538e+01 1.1049873e+02 1.1155090e+02 MM

for Leg LH and RH



VOLUME = 2.5718473e+05 MM^3
SURFACE AREA = 1.3439259e+05 MM^2
AVERAGE DENSITY = 3.1260069e-06 KILOGRAM / MM^3
MASS = 8.0396125e-01 KILOGRAM

CENTER OF GRAVITY with respect to ACS0 coordinate frame:
X Y Z -1.2222975e+02 -5.8620521e-01 -1.1923504e-01 MM

INERTIA with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 4.2080751e+02 -2.6595872e+00 -4.3341665e-02
Iyx Iyy Iyz -2.6595872e+00 2.2015142e+04 0.0000000e+00
Izx Izy Izz -4.3341665e-02 0.0000000e+00 2.1827875e+04

INERTIA at CENTER OF GRAVITY with respect to ACS0 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:
Ixx Ixy Ixz 4.2051981e+02 5.4945614e+01 1.1673645e+01
Iyx Iyy Iyz 5.4945614e+01 1.0003861e+04 5.6180076e-02
Izx Izy Izz 1.1673645e+01 5.6180076e-02 9.8163285e+03

PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)
I1 I2 I3 4.2019029e+02 9.8163429e+03 1.0004176e+04

ROTATION MATRIX from ACS0 orientation to PRINCIPAL AXES:
0.99998 0.00124 -0.00573
-0.00573 -0.00066 -0.99998
-0.00124 1.00000 -0.00066

ROTATION ANGLES from ACS0 orientation to PRINCIPAL AXES (degrees):
angles about x y z 90.038 -0.329 -0.071

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 2.2861538e+01 1.1049873e+02 1.1155090e+02 MM

Document Revision History:

Version	Date	Author	Changes/Comments
V1.0	30/6/2010	Semini	initial version for one leg only.
V2.0	9/7/2010	Semini	corrected version to agree with SL software standard, added all combinations to obtain the parameters for all four legs.
V2.1	5/8/2011	Goldsmith	Updated to current leg version 2.3, (Moog E024 Valve on the cylinder) added both versions of foot. Compliant and noncompliant.
V2.2	10/8/2011	Goldsmith	Updated to current leg version 2.4 (Added Moog Protection Assemblies).
V2.3	22/11/2011	Goldsmith	Updated to current Leg Version (Added Stiffness plates) Added all data in text format rather than image