Motor Sizing Study for

JA23073 Flap System

Robert L Nuckolls III
Original issue 02-14-08
Revision -A- 02-14-08
Revision -B- 02-15-08
Revision -C- 02-16-08

PERFORMANCE AT 25°C	JA23073

BN23HS-28AB-02LHB

PARAMETER	SYMBOL	UNITS	TOLERANCE	VALUE
TERMINAL VOLTAGE	V	VOLTS DC	NOMINAL	28
PEAK TORQUE	T_P	OZ-IN	MAXIMUM	222
CONTINUOUS STALL TORQUE	$T_C{}^1$	OZ-IN	MAXIMUM	32
NO LOAD SPEED	S_{NL}	RPM	NOMINAL	11900
RATED SPEED	S_R	RPM	NOMINAL	11000
RATED TORQUE		OZ-IN	MAXIMUM	25
RATED CURRENT		AMPS	MAXIMUM	8.50
RATED POWER		WATTS	MAXIMUM	203
TORQUE SENSITIVITY	K_T	OZ-IN/AMP	±10%	3.10
BEMF CONSTANT	K_E	VOLTS/KRPM	±10%	2.29
TERMINAL RESISTANCE	R_M	OHMS	±12%	0.190
TERMINAL INDUCTANCE	L_M	mH	±30%	0.440
MOTOR CONSTANT	K_M	OZ-IN/√WATTS	NOMINAL	7.11
ROTOR INERTIA	JM	(OZ-IN-SEC2)X10-3	NOMINAL	1.90
WEIGHT		OZ	Approximate	26.0

Max torque at outboard ballscrew:

T_{obbs} = F(Lead/2∏μ) = 650*(0.125/6.28*0.9)
T_{obbs} = 14.4lb-in

Max torque at inboard ballscrew:

T_{ibbs} = F(Lead/2∏μ) = 750*(0.125/6.28*0.9)
T_{ibbs} = 16.6lb-in

Max Torque on outboard flex shaft:

T_{obfs} = T_{obbs}/(Ratio * μ) = 14.4/(12.15*0.9) = 1.3lb-in

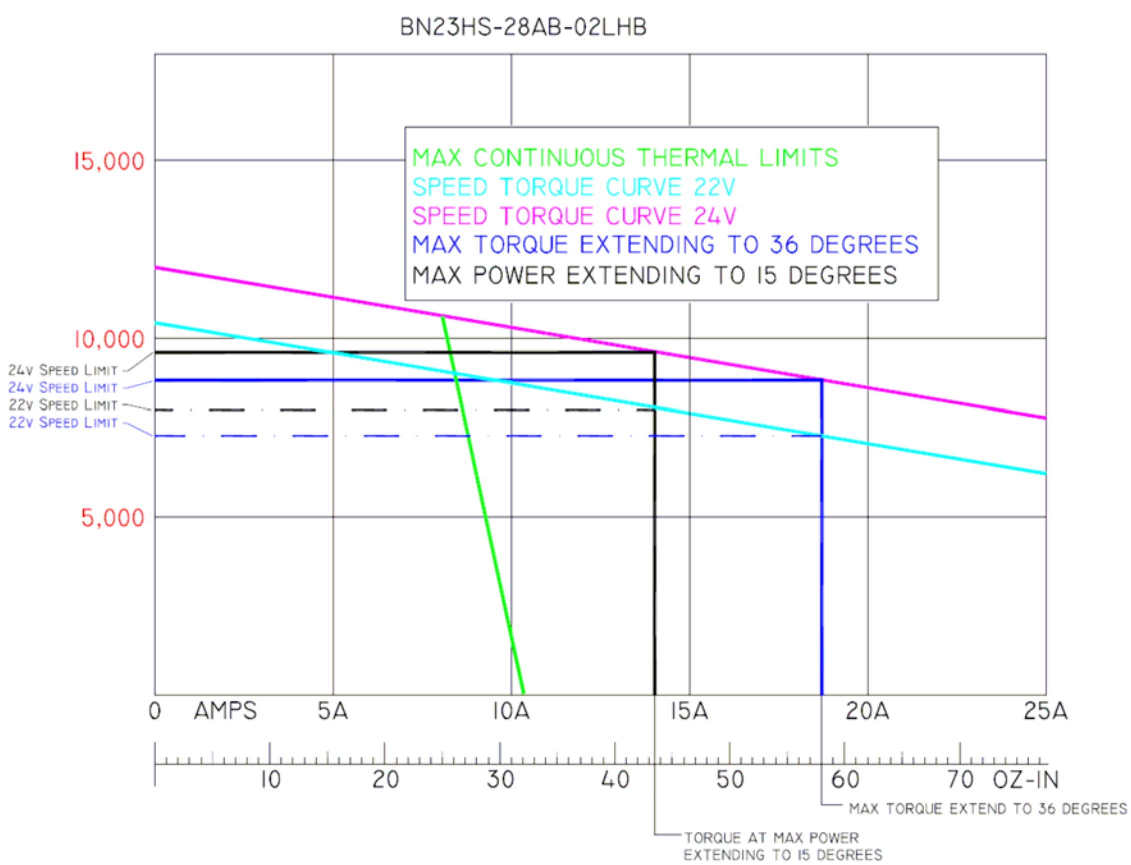
Max Torque on inboard flex shaft:

T_{ibfs} = T_{obfs} + $T_{ibs/}$(Ratio * μ) = 1.4 + 16.6/(10.0*0.9) = 3.2lb-in

Max Torque on Motor = (2*3.2*16)/1.77 = 58oz-in

Max Motor Current:

Max I_m = (58oz-in)/(3.1oz-in/A) = 18.6A



From the data table, we can deduce the speed/torque characteristics for the BN23HS-28AB-02LHB Motor which have been plotted above. The green line represents max continuous conditions based on thermal limits for the motor within the environment where the data were developed. In this case upper end of the green line is bounded by a 25 oz-in max continuous torque for full power output at about 11,000 RPM. The lower end is at max-continuous no-output torque of 32 oz-in and zero RPM. The 32 oz-in value assumes that electronics associated with the operation of this motor will be crafted to insure this condition. The magenta line is the motor's speed torque curve for 24 volts bounded at one end by 11,000 RPM no load and 222 oz-in at stall at the far end (off the page). The cyan line is speed torque at 22 volts . . . 24 v simply translated downward to a new top-speed value. The black trace is the envelope for max power operations extending to 15 degrees in 12 seconds. The blue trace is the max force envelope for extending 15-36 degrees at approximately 1/10th the motor speed of the 0-15 degree segment.

At the time we need 18.6 amps of "push", flap speeds are so low as to drop motor RPM to approximately 1/10th of the 8800 RPM operating point on the speed torque curve for that torque value. This means that the 18.6 amps will be duty cycle switched to an average value on the order of 1.9 amps (assuming 100% electrical efficiency). In practice, this number will probably be on the order of 4 amps due to the losses in the electronics at this extreme corner of the operating envelope. However, we'll still see a peak current on the order of 18+ amps reflected to the bus at a repetition rate equal to the switching frequency of the controllers pulse-width modulation oscillator. This is a portent of the EMC filtering task before us.

The second case to be considered is the fast, max power deployment extending from 0-15 degrees in 15 seconds. This calls for a motor speed of 8600 RPM. Max loads on inboard actuator out to 15 degrees are 550#; the outboard actuator sees 460#. These lower force figures drop the motor torque requirements to no lower than 75% of max torque for extension to 36 degrees. If we plot another envelope on the speed torque curve at 75% of max torque (black), we get the max power limits for extending to 15 degrees. This shows that we can get about 8800 RPM from the motor.

This says that we're right at the limits for meeting extension speeds to 15 degrees and 24v on the motor. In operation we'll probably see a tad more voltage at the motor so we're probably okay for normal, generator-on-line ops. Battery only down to 22v can be predicted by the cyan speed torque curve. Taking the torque values up to the cyan line and extending left will show the new speed limits at which operation will proceed with reduced bus voltage.

Motor Power Breaker Sizing:

This study gives us pause for considering the size of breaker and feeder for motor power. Internal current limiting for the system cannot be set at a lesser value than the value that produces the maximum expected torque. In this case, max torque is experienced near the end of stroke extending to 36 degrees. With an expected value of 18 or so amps, electronic current limiting should be set for something on the order of 20A.

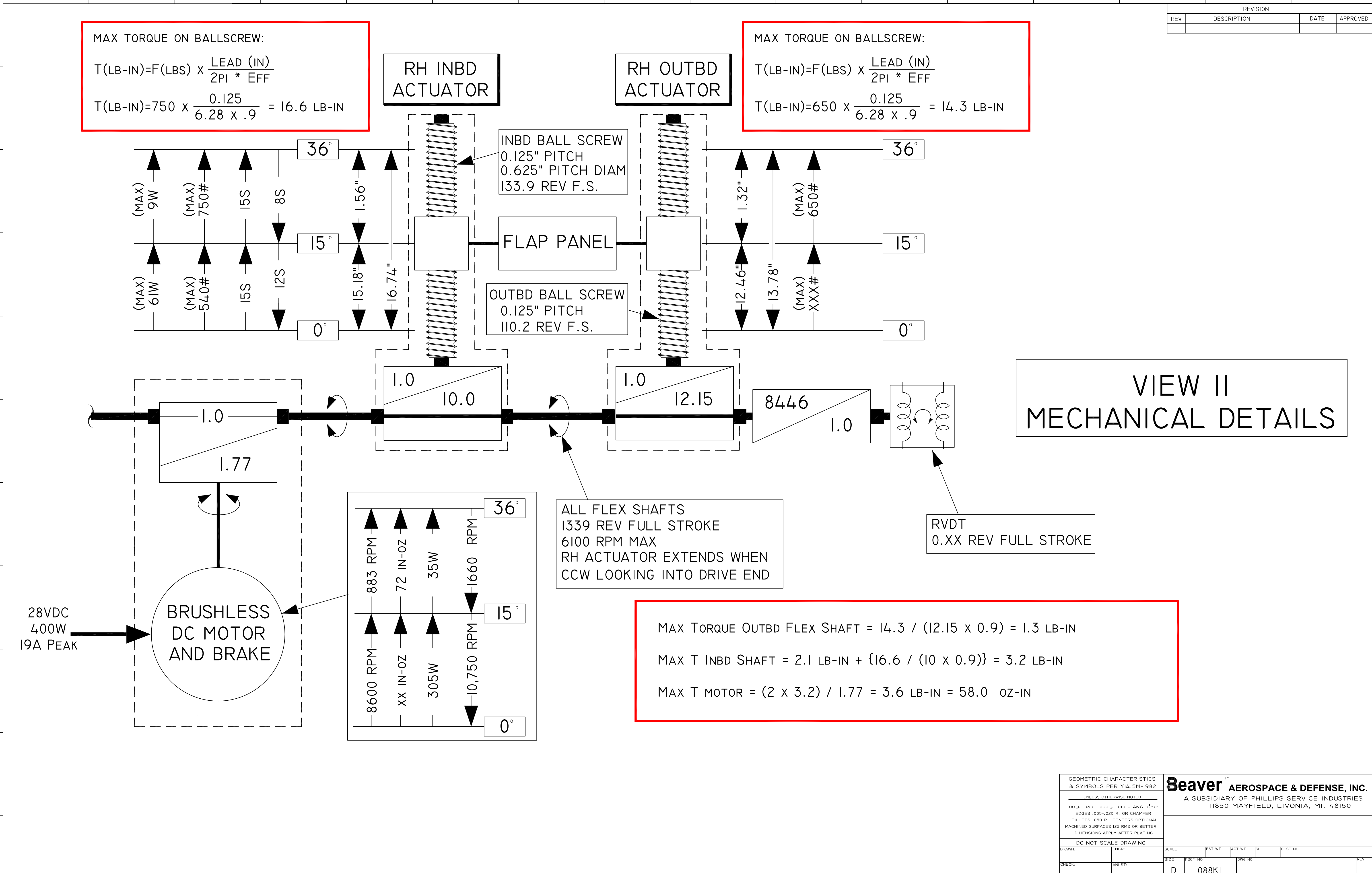
As long as the system is in a speed-regulated mode of operation, pulse width modulation (PWM) of motor power will cause average currents to stay well below the peak values required for max torque. In case of a jam at ANY speed, the motor will stop, speed control PWM goes to 100% duty cycle and the system goes into current limit PWM at 20A. Further, during a battery-only approach to landing, the system may drop out of speed regulation toward the end of 0-15 segment of travel. PWM limiting for speed goes to 100%, PWM for current limit is not yet in operation. There is risk that a 10A breaker for motor supply will nuisance trip. Flight and lab testing of the full-up system will allow us to confirm/refine the force values required of the flap extension system for operation at all edges of the performance envelope and validate the hypothetical analysis offered in this document.

To avoid nuisance tripping during flight tests, I'll suggest that the motor supply breaker be up-sized to 15A. The feeder can safely remain at 16AWG or the installer may opt for trimming a few strands from a 14AWG feeder to accommodate wire size limits on the present connector pins.

The foregoing analysis suggests that the BN23HS-28AB-02LHB motor from Moog is suited to the task of operating the flaps to Piper's requested speeds . . . assuming PDU gear ratios are changed 1.77:1

For IB, suggest we leave the 4.95:1 gears in place, adjust the 0-15 segment speeds to wide open and then calibrate the 15-36 segments to the requested speeds.

-----*****-----


MAX TORQUE ON BALLSCREW:
T(LB-IN)=F(LBS) X LEAD (IN) / 2PI * EFF
T(LB-IN)=750 X 0.125 / 6.28 X .9 = 16.6 LB-IN
RH INBD ACTUATOR
RH OUTBD ACTUATOR
MAX TORQUE ON BALLSCREW:
T(LB-IN)=F(LBS) X LEAD (IN) / 2PI * EFF
T(LB-IN)=650 X 0.125 / 6.28 X .9 = 14.3 LB-IN
36°
15°
0°
(MAX) 9W
(MAX) 750#
15S
8S
(MAX) 61W
(MAX) 540#
15S
12S
1.56"
15.18"
16.74"
INBD BALL SCREW
0.125" PITCH
0.625" PITCH DIAM
133.9 REV F.S.
FLAP PANEL
OUTBD BALL SCREW
0.125" PITCH
110.2 REV F.S.
1.32"
12.46"
13.78"
(MAX) 650#
(MAX) XXX#
1.0
10.0
1.0
12.15
8446
1.0
1.0
1.77
VIEW II
MECHANICAL DETAILS
883 RPM
72 IN-OZ
35W
1660 RPM
8600 RPM
XX IN-OZ
305W
10,750 RPM
ALL FLEX SHAFTS
1339 REV FULL STROKE
6100 RPM MAX
RH ACTUATOR EXTENDS WHEN
CCW LOOKING INTO DRIVE END
RVDT
0.XX REV FULL STROKE
28VDC
400W
19A PEAK
BRUSHLESS DC MOTOR AND BRAKE
MAX TORQUE OUTBD FLEX SHAFT = 14.3 / (12.15 X 0.9) = 1.3 LB-IN
MAX T INBD SHAFT = 2.1 LB-IN + {16.6 / (10 X 0.9)} = 3.2 LB-IN
MAX T MOTOR = (2 X 3.2) / 1.77 = 3.6 LB-IN = 58.0 OZ-IN
REVISION
REV
DESCRIPTION
DATE
APPROVED
GEOMETRIC CHARACTERISTICS & SYMBOLS PER Y14.5M-1982
UNLESS OTHERWISE NOTED
DO NOT SCALE DRAWING
Beaver AEROSPACE & DEFENSE, INC.
A SUBSIDIARY OF PHILLIPS SERVICE INDUSTRIES
11850 MAYFIELD, LIVONIA, MI. 48150
SIZE D
088KI