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Superseding AIR1752

Aircraft Nosewheel Steering/Centering Systems

RATIONALE

AIR1752A has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

AIR1752A is an SAE Aerospace Information Report (AIR) prepared and maintained by SAE Committee A-5. The report documents steering system problems encountered and "lessons learned" by aircraft manufacturers and users. The document presents descriptive summaries of steering and centering systems used in a wide range of current commercial and military aircraft, including fighters, bombers, commercial, commuter, business aircraft, military trainers, and special-purpose aircraft.

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1. SCOPE:

The intent of this AIR is twofold: (1) to present descriptive summary of aircraft nosewheel steering and centering systems, and (2) to provide a discussion of problems encountered and “lessons learned” by various airplane manufacturers and users.

This document covers both military aircraft (land-based and ship-based) and commercial aircraft. It is intended that the document be continually updated as new aircraft and/or new “lessons learned” become available.

2. REFERENCES:

Currey, Norman S., Aircraft Landing Gear Design: Principles and Practices, AIAA Education Series, 1988

Currey, Norman S., Landing Gear Design Handbook, Lockheed-Georgia

Young, Donald W. S., and Ohly, Burkhard, “European Aircraft Steering Systems,” SAE Technical Paper 851940

2.1 Definitions:

DAMPING COEFFICIENT: Hydraulic damping torque divided by the square of the angular velocity of the shock strut piston about its longitudinal centerline, except as noted.

ALLOWABLE FREE PLAY: Maximum allowable uncontrolled rotation of the wheels about the shock strut centerline due to tolerances and/or wear.

STEERING TORQUE: Steering unit output torque about strut centerline.

FAIL PASSIVE: A failure in the steering system will cause the nose gear to revert to a free castoring mode.

STRUT INCLINATION: Forward angle of strut centerline to the vertical.

MECHANICAL TRAIL: Distance of the axle aft of the strut centerline measured perpendicular to the shock strut centerline.

3. TECHNICAL DISCUSSION:

Appendix A contains, in tabular form, pertinent descriptions of the steering/centering systems for current aircraft. The tables cover military attack and fighter aircraft; commercial and heavy bomber/ transport military aircraft; small/medium commercial, commuter, business aircraft; and military trainers, special purpose aircraft.

3. (Continued):

Detailed descriptions of the various shock strut and steering mechanisms are not within the scope of this document. Detail drawings and functional diagrams are best obtained from various airframe manufacturers. The summary tables in Appendix A can be used as a guide for the types of systems in use.

3.1 Redundancy/Failure Intelligence:

The redundancy and failure detection provisions incorporated on some aircraft are discussed as follows:

a. T-38/F-5: No failure intelligence is provided. Failure of LH hydraulic system or both electrical systems inactivates steering which reverts to damping mode. Aircraft can be controlled easily using brakes under most conditions.

b. F-4: No display or protection of EHSV mechanical/hydraulic valve malfunctions. Electrical protection for opens and shorts in potentiometers, EHSV, and associated ships wiring. No back-up hydraulic power supply, however, aircraft can be controlled with rudder and/or brakes under most conditions.

c. A-7: No protection. An advisory light for steering active is provided.

d. F-14A: Double redundant-fails passive.

e. B-1: Reverts to free caster mode if failure detection and monitoring circuitry detects a failure which would otherwise result in a nosewheel hardover condition. Fail-safe signal activates caution light at crew station if automatic disengagement occurs. Provisions for override of fail-safe feature.

f. Dash 7 (DHC-7): Reversion of unpowered mode whenever duplicated electrical circuitry develops a significant mismatching. Failure light on caution panel. Aircraft is cleared to fly with steering off as long as pilot is aware.

g. NA265: Stand-by electrical, automatic switch-over.

4. SERVICE EXPERIENCE:

4.1 Steering Systems:

a. T-38: System operation is generally satisfactory. It is somewhat sensitive at high speed and is usually turned off above 65 knots. Basic airframe stability and flight control system effectiveness makes steering primarily a taxi maneuvering system. “Push and hold” system found to be best on trainer to prevent confusion between pilots on status of steering.

4.1 (Continued):

b. F-5E: System operation is generally satisfactory. Have been problems with steering unit output shaft breakage. Appears to be low cycle fatigue and believed to be caused by overloading during towing. The F-5E vane-type hydraulic actuator has had external leakage problems and is hard to overhaul due to use of matched parts.

c. F-4J: The system is very responsive but has had service problems primarily due to pin-to-ground and pin-to-pin moisture induced shorts at the potentiometers/servovalve and associated ships wiring.

d. A-7: System has had numerous linkage and amplifier problems, all of which have been solved.

e. EA-6B: System exhibits high cycle fatigue failures of original aluminum output shaft; no signs of overload.

f. B-1: System operation generally satisfactory, with ground handling characteristics reported as excellent. Some reliability problems in original control box due to hard potting compound exerting excessive stresses on soldered joints, causing false “fail-safe” disengagements. Later control box design has corrected problem.

g. L-1011: The original rudder-pedal-engage mechanism and actuator had short service life. Redesigned mechanism and actuator performing satisfactorily.

h. NA265: Biggest system problem is potentiometer failure.

4.2 Centering Systems:

a. T-38: Failure to remain centered after retraction caused several incidents involving nose-gear-up landings. This was caused by a combination design error and improper servicing which allowed extended air pressure to drop to level which allowed gear to come out of cams.

b. C-130, C-141: Systems have had centering cam failures. C-130 upper cam was changed to beryllium copper, C-141 cam changed to steel and lightening hole removed.

c. H-3: The aircraft has had a centering problem because the internal pressure and centering cams are not exerting sufficient force to override the resisting torque of the shimmy damper which is connected to the nose gear piston via the torque arms. The problem is still under investigation.

d. F-100 has a hydromechanical centering system. Failures of the NLG to extend have been experienced as a result of the nosewheels contacting the wheel well sidewall structure. The failure of the NLG to properly center and/or stay centered is alleged to have been caused by latent system conditions.

4.3 Shimmy/Damping:

a. T-38/F-5: Nose gear shimmy occurred on occasions when wheel revolutions per minute matched strut/structure lateral bending natural frequency. Cured problem by adding weight (mass) to apex of forward-mounted torque links.

b. C-140 (Jet Star): Shimmy occurred in original testing. (Gear had dual wheels and 1.5 in (38 mm) trail.) Corrected problem by making wheels corotating (live axle). Corotation cannot be considered a shimmy fix for all dual wheel nose gears. Some aircraft are more stable with independent wheels. A computer or actual test simulation of a new gear design should be conducted, utilizing various values for damping and considering lateral and torsional stiffness (including backup structure), the arrangement geometry, various airplane speeds, and field roughness characteristics.

c. C-130: Shimmy encountered in original testing. Friction collar added as temporary fix. Permanent fix was to change mechanical trail from 6 to 3 in (152.4 to 76.2 mm).

5. LESSONS LEARNED:

5.1 Steering Systems:

Some aircraft cannot be controlled safely on the ground without steering operative and thus may require a full-time, redundant fail-operate system. Some aircraft (T-38/F-5 for example) only need steering at low speeds and for maneuvering/parking. A fail-passive system is adequate. A dynamic analysis of any new aircraft will help resolve which type of steering system is required.

Systems employing electrohydraulic servovalves often need to be designed to safety and performance criteria similar to those imposed on flight control systems. Fail-operate requirements, failure warning systems, and strict performance requirements for phase lag, frequency response, control increment, etc., should be considered. Electrical systems must be tolerant of variable resistances to ground and wire-to-wire as experienced in electrical connectors and wire bundles in adverse environments.

Electrohydraulic servovalves can fail from neutral shift to hardover which can be caused by external blows to the case.

Steering systems response is tied to tire cornering power, steering actuator rates, input/output ratio, rudder authority, input forces, steering power, aircraft geometry: all should be addressed in the design.

Steering systems generally operate in more exposed areas than other control systems. The design should be compatible with environmental effects (corrosion, cold temperature, sand and dust, etc.) and should also preclude mechanical damage from towing or tow bar attachment, possible ground handling towing rates, damage from tires and runway debris, and damage from tie-down equipment. Protection should be provided for steering system hydraulic lines and hoses and electrical wiring on the strut as well as power units, valves, actuators, etc.

5.1 (Continued):

Steering systems which do not mechanically disengage for gear retraction are preferred. Systems which disengage should automatically engage and should not require pilot action to perform the engagement.

Particular attention should be given to the nose gear steering system disconnects. Typical problem areas include: bent pins that cannot be reinserted, loose nuts that may be lost, and complicated procedures that take time and are often done incorrectly.

Adaptation of an existing steering system specifically designed for one airplane for use on a different aircraft should be avoided because the two aircraft will experience different service conditions and problems. Initial cost savings will be reduced by increased component failure rates and possible aircraft damage, and hardware commonality will be lost through modifications as the aircraft matures.

Shipboard catapult-launched aircraft have special nose landing gear design requirements which affect steering. The nose gear strut must incorporate a launch bar that connects the airplane to the catapult shuttle. As the airplane approaches the catapult during initiation of the hookup procedure, the launch bar is lowered and enters a recessed portion of the deck immediately aft of the catapult. As the aircraft continues to taxi forward, it is automatically steered into position on the catapult. The nosewheel steering must be disengaged after the launch bar is properly positioned in the entry wye. (This can be tied to launch bar position.) Free swivel (360°) is required for deck handling (towing) of carrier based aircraft. One fighter with mechanical stops at 120° left or right experienced nose gear strut/steering system damage when the tow bar or spotting dolly exceeded these limits, requiring the aircraft to be put on jacks and the nose strut removed for repair.

5.2 Centering Systems:

Centering cams should be designed to withstand high impact loads caused by sudden strut extension while the wheel is not on center (example: sudden release of brakes with nosewheel still turned from last taxi-turn).

Cams should be designed to operate without damage when torque is applied from steering actuation or towing with the cams partially engaged.

If centering cams are used, strut extended pressure must be adequate to center the gear against internal strut friction, O-ring friction, steering unit friction, and gyroscopic precession during retraction. An adequate pressure margin must be available to accommodate some air and/or oil leakage or improper strut servicing.

If hydraulic centering is used, the wheel(s) must remain centered while the system is depressurized or after a system failure.

5.2 (Continued):

Systems utilizing the steering actuator to center the tire for gear retraction and a nose gear sensor to indicate an airborne condition must be designed to preclude any false indication that results in unwanted wheel centering on the ground.

5.3 Shimmy/Damping:

Dynamic analysis of nose gear shimmy must be made to determine basic stability characteristics and the required amount of damping. This must include the following:

a. Structural stiffness matrix of nose gear lateral/torsional modes
b. Detailed modeling of nosewheel steering
c. Appropriate lateral/torsional characteristics of nosewheel tires
d. All nonlinearities, friction, torsional free play, etc.

The combined effect of positive geometric trail and positive strut inclination angle (swivel axis ahead of tire contact area center) has proved to be shimmy-stable on many gears, but must be verified by suitable analysis.

6. KEY WORDS:

Live axle, design steering load, mechanical trail, strut inclination, rudder effective velocity, control input, feedback, pilot input, steer angle, steer torque, steering rate, damping, free play, stiffness, tow angle, tow disconnect, failure provisions, redundancy, transducers, centering provisions, actuators

PREPARED UNDER THE JURISDICTION OF
SAE COMMITTEE A-5, AEROSPACE LANDING GEAR SYSTEMS

APPENDIX A
AIRCRAFT STEERING SYSTEM DESCRIPTIONS

A.1 SCOPE:

Tables A1 through A5 contain steering system description and information for the following aircraft:

a. Table A1 - Attack and Fighter Aircraft

(1) F-4J
(2) F-5E
(3) A-6E
(4) A-7E
(5) AV-8B
(6) A-10
(7) F-14 A/F,D
(8) F-15 C/D
(9) F-16 C/D
(10) F-18
(11) F-111
(12) ALPHA JET[1]
(13) JAGUAR[1]
(14) MIRAGE 2000[1]
(15) MIRAGE 4000[1]
(16) TORNADO[1]
(17) VIGGEN[1]

b. Table A2 - Commercial, Heavy Bomber Aircraft

(1) B-1B
(2) C-5
(3) DC-8
(4) DC-9
(5) DC-10
(6) MD-11
(7) C-17
(8) MD-80
(9) F-100
(10) C-130
(11) 707 AWACS

[1] Confirmation of data was not obtained for the latest version of this document.

A.1 (Continued):

(12)727
(13) 737
(14) 737-300
(15) 747
(16) 757
(17) 767
(18) L-1011

c. Table A3 - Small/Medium Commercial, Commuter, Business Aircraft

(1) DHC-7
(2) DHC-8
(3) F-27[2]
(4) F-50
(5) P-180
(6) NA-265[2]
(7) SAAB 340
(8) CL 600,601
(9) BEECH 1900
(10) SAAB 2000
(11) BAC ATP
(12) REGIONAL JET

d. Table A4 - Military Trainer, Special-Purpose Aircraft

(1) C2A/E2C
(2) S-3A
(3) EA-6B
(4) T-38
(5) T-45
(6) SPACE SHUTTLE

e. Table A5 - Additional Pilot Steering Input/Output Data

(1) F-4J
(2) F-15 C/D
(3) C-5
(4) SAAB 340
(5) CL 600,601
(6) F-5E
(7) F-16 C/D

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2 See Footnote 1.

A.1 (Continued):

(8) MD-11
(9) SAAB 2000
(10) A-6E
(11) F-18
(12) C-17
(13) REGIONAL JET
(14) AV-8B
(15) B-1B
(16) DHC-8
(17) T-38

A.2 ABBREVIATIONS:

Definitions for the abbreviations used in Tables A1 through A5 are listed as follows:

Accum	accumulator
Act.	actuator
FCS	flight control system
HWHL	handwheel
Hyd	hydraulic
Hyd. Ser. Orif	hydraulic series orifices
L	land-based
Lin	linear
N.L.	nonlinear
NWS	nosewheel steering
Prov	provisions
Pneum	pneumatic
Redund	redundancy
R. Ped	rudder pedal
S	shipboard
SC	strut compression
SW	switch
TDX	transducer
TLR	tiller
visc	viscous
vlv	valve

TABLE A1 - Steering System Descriptions: Attack and Fighter Aircraft

General Data		Aircraft	F-4J	F-5E	A-6E
Weight Maximum T.O.		(lb)	56-58 000	22-26 000	54 000
Weight Des. Landing		(lb)	40-46 000	13-15 000	36 000
Nosewheel Arrangement			Dual	Single	Dual
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	18 x 5.7	18 x 6.5	20 x 5.5
Tire Rated Load		(lb)	6200	5000	6150
Tire Rated Pressure		(psi)	215		180
Max. Static NLG Load, Vert.		(lb)	8000	5000	5250
Design Steering Load, Vert.		(lb)	8000		
Tire Oper. Pressure		(psi)	150 L / 350 S	145	175 L / 290 S
Mechanical Trail		(in)	3.5	1.5	3.0
Strut Inclination		(deg)	0	7	1.5 Aft, Static
Rudder Effective Vel.		(knots)	70	50-60	50
Steering System Data					
Type Actuator			Hyd/Motor	Hyd/Rotary	Hyd/Rotary
Type Control	Input		Elect	Mech	Mech
	Feedback		Elect	Mech	Mech
Pilot Input	Input		Rud. Ped.	Rud. Ped.	Rud. Ped.
	Δin/Δout		See Table A5	See Table A5	See Table A5
Maximum Steer Angle		(deg)	±70	±40	±56
Maximum Steer Torque		(in/lb)	12 000	5000	12 000
Max Steer Rate (No Load)		(deg/s)	40	15	
Type Damping			Hyd	Hyd	Hyd
Damp While Steer?		(Yes/No)	Yes	No	Yes
Damp. Coef.		(in-lb/rad^2/s^2)	14 440	3000	
Allow Free-Play		(deg)	0.333		
Stiffness		(in-lb/rad)	650 000 min		
Maximum Tow Angle		(deg)	360	360	360
Tow Disconnect Type			None Reqd.	Manual	Auto Tog Lock
Pilot Select	How		Push Hold SW	Push Hold SW	Push Hold SW
or	Dual Range		No	No	No
Full Time					
Failure Provisions	Power		None	None	None
(Redundancy)	Controls		None		
	Warning		Monitor Only	None	None
Type Transducers			Plastic/Carbon Pots		
Centering Provisions			Strut Cams	Strut Cams	Torsion Spring

TABLE A1 (Continued)

General Data		Aircraft	A-7E	AV-8B	A-10
Weight Maximum T.O.		(lb)	42 000	29 750	50 000
Weight Des. Landing		(lb)	33 800	25 000	32 334
Nosewheel Arrangement			Dual	Single	Single
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	22 x 5.5	26 x 8.75 - 11	24 x 7.7
Tire Rated Load		(lb)	7100	11 070	8200
Tire Rated Pressure		(psi)	100 L / 265 S	125	135
Max. Static NLG Load, Vert.		(lb)		11 070	8200
Design Steering Load, Vert.		(lb)		11 070	
Tire Oper. Pressure		(psi)		125	145
Mechanical Trail		(in)	14.5 Trail Arm	16.4 Trail Arm	0
Strut Inclination		(deg)	0	1.8 FWD	7.49 FWD
Rudder Effective Vel.		(knots)		60	
Steering System Data					
Type Actuator			Hyd/Linear	Hyd/Linear	Hyd
Type Control	Input		Elect	Mech	Elect
	Feedback		Elect	Mech	None
Pilot Input	Input		Rud. Ped.	Rud. Ped.	360° Button
	Δin/Δout			See Table A5	
Maximum Steer Angle		(deg)	±60	±45	±55
Maximum Steer Torque		(in/lb)	39 600	60 000	15 000
Max Steer Rate (No Load)		(deg/s)	46	20	60
Type Damping			Hyd	Hyd	Hyd
Damp While Steer?		(Yes/No)		Yes	Yes
Damp. Coef.		(in-lb/rad^2/s^2)			
Allow Free-Play		(deg)			
Stiffness		(in-lb/rad)			
Maximum Tow Angle		(deg)	360	179	±130
Tow Disconnect Type				None	Manual
Pilot Select	How			Press Hold or Auto	Button On/Off
or	Dual Range			Full Time Anti-Skid Off	No
Full Time					
Failure Provisions	Power			Backup Hyd	No
(Redundancy)	Controls			No	
	Warning			No	Light
Type Transducers				None	Linear Pot
Centering Provisions			Strut Roller Whl Well Cams	Hyd Steer and Mech Lock	Strut Cam

TABLE A1 (Continued)

General Data		Aircraft	F-14 A/F/D	F-15 C/D	F-16 C/D
Weight Maximum T.O.		(lb)	74 349	68 000	48 000
Weight Des. Landing		(lb)	51 830/54 000 S 60 029 L	35 072	31 000
Nosewheel Arrangement			Dual	Single	Single
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	20 x 6.6	22 x 6.6 - 10	18 x 5.7 - 8
Tire Rated Load		(lb)	12 000	10 700	8600
Tire Rated Pressure		(psi)	270	260	300
Max. Static NLG Load, Vert.		(lb)	10 000	10 700	10 789
Design Steering Load, Vert.		(lb)	10 000	10 700	
Tire Oper. Pressure		(psi)	150 L / 350 S	260	300-310
Mechanical Trail		(in)	3.0	3.0	-0.6
Strut Inclination		(deg)	0	1.0	14.5
Rudder Effective Vel.		(knots)		50	50-60
Steering System Data					
Type Actuator			Hyd/Rotary	Hyd/Linear	Hyd/Linear
Type Control	Input		Elect	Mech	Elect
	Feedback		Mech	Mech	Elect
Pilot Input	Input		Rud. Ped.	Rud. Ped.	Rud. Ped.
	Δin/Δout			See Table A5	See Table A5
Maximum Steer Angle		(deg)	±70	±15 / ±45	±32
Maximum Steer Torque		(in/lb)	17 000	13 200	12 548
Max Steer Rate (No Load)		(deg/s)	50	60	16
Type Damping			Hyd	Hyd	Hyd & Frict
Damp While Steer?		(Yes/No)	Yes	Yes	Yes
Damp. Coef.		(in-lb/rad^2/s^2)		6124Pwr/17344 Damp	300 min
Allow Free-Play		(deg)	2	±0.583	0.5
Stiffness		(in-lb/rad)		240 000	340 000
Maximum Tow Angle		(deg)	±120	360	360
Tow Disconnect Type			None	None Reqd	Manual
Pilot Select or	How		Push On/Off Holding Relay	Press Hold for ±45	Press On/Off
Full Time	Dual Range		No	Auto for ±15 and SC	No
Failure Provisions	Power		None	None	None
(Redundancy)	Controls			None	
	Warning		Light	None	Light
Type Transducers			Linear Pot	None	Wire Wound
Centering Provisions			Hyd Steer	Strut Cams	Strut Cams

TABLE A1 (Continued)

General Data		Aircraft	F-18	F-111	Alpha Jet
Weight Maximum T.O.		(lb)	50 000	100 000	15 430
Weight Des. Landing		(lb)	32 200	80 000	9920
Nosewheel Arrangement			Dual	Dual	Single
Live Axle		(Yes/No)	No	No	
Nose Tire Size		(in x in)	22 x 6.6 - 10	21 x 7.25 - 10	380 x 15 - 4
Tire Rated Load		(lb)	12 000	12 000	
Tire Rated Pressure		(psi)	290	320	
Max. Static NLG Load, Vert.		(lb)	8900	12 000	1260
Design Steering Load, Vert.		(lb)	8900		
Tire Oper. Pressure		(psi)	150 L / 350 S	320	
Mechanical Trail		(in)	3.0	2.575	
Strut Inclination		(deg)	0	6.5	
Rudder Effective Vel.		(knots)	65	50-60	
Steering System Data					
Type Actuator			Hyd/Motor	Hyd	Hyd/Rack & Pinion
Type Control	Input		Elect	15 in-lb max	Elect FCS Comp
	Feedback		Elect	15 in-lb max	Elect
Pilot Input	Input		Rud. Ped.	Push/Pull Rods	Rud. Ped.
	Δin/Δout		See Table A5		Nonlinear
Maximum Steer Angle		(deg)	±75, ±15	±40	±45
Maximum Steer Torque		(in/lb)	14 000	25 000	15 000
Max Steer Rate (No Load)		(deg/s)	20, 55	25	15
Type Damping			Hyd	Hyd	Hyd
Damp While Steer?		(Yes/No)	Yes	Yes	Hyd Lock
Damp. Coef.		(in-lb/rad^2/s^2)	10 000		
Allow Free-Play		(deg)	0.25		
Stiffness		(in-lb/rad)	700 000		
Maximum Tow Angle		(deg)	360	360	360
Tow Disconnect Type			None Reqd.	Manual	Manual
Pilot Select	How		Auto ±15°	Press On/Off	Auto/Manual
or	Dual Range		Paddle SW ±75°	No	
Full Time					
Failure Provisions	Power		Yes	None	
(Redundancy)	Controls		Yes, TDX + LVDTS		
	Warning		Yes	Light	Light
Type Transducers			RVDT/LVDT	None	
Centering Provisions			Strut Cams	Hyd Steer	Strut Cams

TABLE A1 (Continued)

General Data		Aircraft	Jaguar	Mirage 2000	Mirage 4000
Weight Maximum T.O.		(lb)	33 070	36 370	61 730
Weight Des. Landing		(lb)	18 730	21 820	34 170
Nosewheel Arrangement			Single	Dual	Dual
Live Axle		(Yes/No)		No	Yes
Nose Tire Size		(in x in)	550 x 250 - 6	360 x 135 - 6	
Tire Rated Load		(lb)			
Tire Rated Pressure		(psi)	57		
Max. Static NLG Load, Vert.		(lb)	2860	5120	5530
Design Steering Load, Vert.		(lb)			
Tire Oper. Pressure		(psi)			
Mechanical Trail		(in)			
Strut Inclination		(deg)			
Rudder Effective Vel.		(knots)			
Steering System Data					
Type Actuator			Hyd Rack & Pinion	Hyd Rack & Pinion	Hyd Rack & Pinion
Type Control	Input Feedback		Mech	Elect	Elect
Pilot Input	Input Δin/Δout				
Maximum Steer Angle		(deg)	±55	±45	±70
Maximum Steer Torque		(in/lb)	22 850	8500	41 420
Max Steer Rate (No Load)		(deg/s)			
Type Damping					
Damp While Steer?		(Yes/No)			
Damp. Coef.		(in-lb/rad^2/s^2)			
Allow Free-Play		(deg)			
Stiffness		(in-lb/rad)			
Maximum Tow Angle		(deg)	360	360	No Swivel
Tow Disconnect Type				Manual	
Pilot Select or Full Time	How Dual Range				
Failure Provisions (Redundancy)	Power Controls Warning				
Type Transducers					
Centering Provisions					

TABLE A1 (Continued)

General Data		Aircraft	Tornado	Viggen
Weight Maximum T.O.		(lb)	60 500	49 600
Weight Des. Landing		(lb)	30 800	
Nosewheel Arrangement			Dual	Dual
Live Axle		(Yes/No)	No	Yes
Nose Tire Size		(in x in)	18 x 5.5	18 x 5.5
Tire Rated Load		(lb)		
Tire Rated Pressure		(psi)	160	155
Max. Static NLG Load, Vert.		(lb)	6000	
Design Steering Load, Vert.		(lb)		
Tire Oper. Pressure		(psi)		
Mechanical Trail		(in)	58 mm	
Strut Inclination		(deg)	6	
Rudder Effective Vel.		(knots)		
Steering System Data				
Type Actuator			Hyd Motor	Hyd
Type Control	Input		FBW (FCS) Computer	Mech
	Feedback		Yaw Gyro	
Pilot Input	Input		Rud. Ped.	
	Δin/Δout		Nonlinear	
Maximum Steer Angle		(deg)	30/60	±30
Maximum Steer Torque		(in/lb)	16 200	
Max Steer Rate (No Load)		(deg/s)	20	
Type Damping			Hyd	
Damp While Steer?		(Yes/No)	Hyd Lock	
Damp. Coef.		(in-lb/rad^2/s^2)		
Allow Free-Play		(deg)		
Stiffness		(in-lb/rad)		
Maximum Tow Angle		(deg)	360	360
Tow Disconnect Type			None	
Pilot Select	How		Auto Low Range	
or	Dual Range		Pilot Select ±60°	
Full Time				
Failure Provisions	Power		Damping Mode	
(Redundancy)	Controls		Manual Mode	
	Warning		Light & Sound	
Type Transducers				
Centering Provisions			Elect	

TABLE A2 - Steering System Descriptions: Heavy Commercial and Bomber Aircraft

General Data		Aircraft	B-1B	C-5	DC-8
Weight Maximum T.O.		(lb)	477 000	769 000	353 000
Weight Des. Landing		(lb)	346 500	635 850	245 000
Nosewheel Arrangement			Dual	Dual Twin	Dual
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	35 x 11.5 - 16	49 x 17	34 x 11
Tire Rated Load		(lb)	23 000	39 600	20 500
Tire Rated Pressure		(psi)	210	170	185
Max. Static NLG Load, Vert.		(lb)	40 700	99 700	30 500
Design Steering Load, Vert.		(lb)		99 700	
Tire Oper. Pressure		(psi)	210	155	147
Mechanical Trail		(in)	5.0	4.5	0
Strut Inclination		(deg)	0	0	8.5
Rudder Effective Vel.		(knots)	60	55	
Steering System Data					
Type Actuator			3 Cycle Hyd/Rotary	Hyd/Linear	Hyd/Linear
Type Control	Input		Elect	Mech	Mech
	Feedback			Mech	Mech
Pilot Input	Input		Rud. Ped.	Rud. Ped & HWHL	R. Ped & Tiller
	Δin/Δout		See Table A5	See Table A5	Nonlinear
Maximum Steer Angle		(deg)	±30, ±75	±60	±67 TLR/±10 PED
Maximum Steer Torque		(in/lb)	180 000	1 128 816	
Max Steer Rate (No Load)		(deg/s)	20	12	7.5
Type Damping			Hyd + Friction	Hyd Ser Orif	Hyd Ser Orif
Damp While Steer?		(Yes/No)	Yes, Bypass	Yes	
Damp. Coef.		(in-lb/rad^2/s^2)	100 000		
Allow Free-Play		(deg)	0.167		
Stiffness		(in-lb/rad)		190 972	
Maximum Tow Angle		(deg)	360	±60	360
Tow Disconnect Type				Manual Unbolt	Manual
Pilot Select	How		Up Hold Engage	Full Time	Auto
or	Dual Range		Yes	No	Yes
Full Time					
Failure Provisions	Power		Failure Monitor	Alt. System	Hyd Accum
(Redundancy)	Controls		Free Castor	Free Castor	None
	Warning		Light	No	No
Type Transducers			LVDT	Synchro	
Centering Provisions			Strut Cams	Mech Cams	

TABLE A2 (Continued)

General Data		Aircraft	DC-9	DC-10	MD-11
Weight Maximum T.O.		(lb)	121 000	555 000	618 000
Weight Des. Landing		(lb)	110 000	403 000	480 000
Nosewheel Arrangement			Dual	Dual	Dual
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	26 x 6.6	40 x 15.5	40 x 15.5
Tire Rated Load		(lb)	8600	36 300	39 500
Tire Rated Pressure		(psi)	185	180	195
Max. Static NLG Load, Vert.		(lb)	11 773	68 250	57 612
Design Steering Load, Vert.		(lb)			
Tire Oper. Pressure		(psi)	157	190	187
Mechanical Trail		(in)	0	0	0
Strut Inclination		(deg)	8	9.5	9.5
Rudder Effective Vel.		(knots)	60		
Steering System Data					
Type Actuator			Hyd/Linear	Hyd/Linear	Hyd/Linear
Type Control	Input		Mech	Mech	Mech
	Feedback		Mech	Mech	Mech
Pilot Input	Input		R. Ped & Tiller	R. Ped & Tiller	R. Ped & Tiller
	Δin/Δout				See Table A5
Maximum Steer Angle		(deg)	82 (Tiller)	±68	70 Tiller/8 Ped.
Maximum Steer Torque		(in/lb)	32 000		337 000
Max Steer Rate (No Load)		(deg/s)	16.4	30	30
Type Damping			Hyd Ser Orif	Hyd Orifice	Hyd Orifice
Damp While Steer?		(Yes/No)	Yes	Yes	Yes
Damp. Coef.		(in-lb/rad^2/s^2)			
Allow Free-Play		(deg)		±0.75	±0.75
Stiffness		(in-lb/rad)	1 300 000	7 840 000	7 840 000
Maximum Tow Angle		(deg)	102 in Bypass	±78 Bypass 360 PIN	±78 Bypass ±360 PIN
Tow Disconnect Type			Bypass VLV or PIN	Bypass VLV or PIN	Bypass VLV or PIN
Pilot Select	How		Auto	Auto	Auto
or	Dual Range		Yes	Yes	Yes
Full Time					
Failure Provisions	Power		Yes	#3 Sys Norm 1 Sys Emer	2 Hyd System
(Redundancy)					
	Controls				
	Warning		No	No	No
Type Transducers					
Centering Provisions				Mech Cams	Mech Cam

TABLE A2 (Continued)

General Data		Aircraft	C-17	MD-80	F-100
Weight Maximum T.O.		(lb)	580 000	161 000	98 000
Weight Des. Landing		(lb)	502 100	139 500	88 000
Nosewheel Arrangement			Dual	Dual	Dual
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	40 x 16	26 x 6.6	24 x 7.7 - 10
Tire Rated Load		(lb)	29 200	8600	5400
Tire Rated Pressure		(psi)	155	185	90
Max. Static NLG Load, Vert.		(lb)	54 540	15 000	10 276
Design Steering Load, Vert.		(lb)			10 276
Tire Oper. Pressure		(psi)	155	170	90
Mechanical Trail		(in)	0	0	3.0
Strut Inclination		(deg)	6.117	8	0
Rudder Effective Vel.		(knots)			
Steering System Data					
Type Actuator			Hyd/Linear	Hyd/Linear	Hyd Rack & Pinion
Type Control	Input		Mech	Mech	Mech
	Feedback		Mech	Mech	Mech
Pilot Input	Input		R. Ped & Tiller	R. Ped & Tiller	Handwheel
	Δin/Δout		See Table A5		Nonlinear
Maximum Steer Angle		(deg)	65 Tiller/12 Ped	82 Tiller	±76
Maximum Steer Torque		(in/lb)	440 000	32 000	30 184
Max Steer Rate (No Load)		(deg/s)		16.4	18
Type Damping			Hyd Orifice	Hyd Orifice	Hyd-Mech
Damp While Steer?		(Yes/No)	Yes		Yes
Damp, Coef.		(in-lb/rad^2/s^2)			
Allow Free-Play		(deg)			
Stiffness		(in-lb/rad)	11 640 000	1 300 000	
Maximum Tow Angle		(deg)	±65 Bypass 360 PIN	±102 Bypass 320 PIN	±135
Tow Disconnect Type			Bypass VLV or PIN	Bypass VLV or PIN	Auto
Pilot Select	How		Auto		Select
or	Dual Range		Yes		Single
Full Time					
Failure Provisions	Power		2 Hyd Systems	yes	Damping Mode
(Redundancy)	Controls			No	
	Warning				
Type Transducers					
Centering Provisions			Mech Cams		Hyd Act.

TABLE A2 (Continued)

General Data		Aircraft	C-130	707 AWACS	727
Weight Maximum T.O.		(lb)	175 000	327 000	169 000
Weight Des. Landing		(lb)	130 000	207 000	150 000
Nosewheel Arrangement			Dual	Dual	Dual
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	12.5 x 16	39 x 13	32 x 11.5
Tire Rated Load		(lb)	12 800	17 200	11 200
Tire Rated Pressure		(psi)	75	115	120
Max. Static NLG Load, Vert.		(lb)	10 450	32 700	16 473
Design Steering Load, Vert.		(lb)	10 450		
Tire Oper. Pressure		(psi)	65		
Mechanical Trail		(in)	3.0	3.0	3.0
Strut Inclination		(deg)	0	0	0
Rudder Effective Vel.		(knots)		50	
Steering System Data					
Type Actuator			Hyd	Hyd/Linear	Hyd/Linear
Type Control	Input		Mech Cable	Mech	Mech
	Feedback				
Pilot Input	Input		Mech Cable & Steer Whl	Tiller	R. Ped & Tiller
	Δin/Δout			+66° Linear	Tlr 97° Linear
Maximum Steer Angle		(deg)	±60	+60	+78
Maximum Steer Torque		(in/lb)	78 628	15 528	13 872
Max Steer Rate (No Load)		(deg/s)		22	22.6
Type Damping			Hyd & Friction	Hyd Ser Orif	Hyd Ser Orif
Damp While Steer?		(Yes/No)	Yes		
Damp. Coef.		(in-lb/rad^2/s^2)		30 000	20 000 @ Null Varies @ Pos
Allow Free-Play		(deg)	2 max	+0.87	+2.14
Stiffness		(in-lb/rad)		777 000	3 610 000
Maximum Tow Angle		(deg)	90 W/Torque Arms Disc	±60	±78
Tow Disconnect Type			Pin		
Pilot Select	How		Full	Auto W/Strut SW	Auto W/Strut SW
or	Dual Range			No	No
Full Time					
Failure Provisions	Power		Hand or Elect Pump	No	No
(Redundancy)	Controls		Manual		
	Warning		Light		
Type Transducers					
Centering Provisions			Internal to VLV	Strut Cams	Strut Cams

TABLE A2 (Continued)

General Data		Aircraft	737	737-300	747
Weight Maximum T.O.		(lb)	117 500	139 000	875 000
Weight Des. Landing		(lb)	105 000	114 000	666 000
Nosewheel Arrangement			Dual	Dual	Dual
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	24 x 7.7	27 x 7.75	49 x 17
Tire Rated Load		(lb)	8200	7800	50 400
Tire Rated Pressure		(psi)	135	166	210
Max. Static NLG Load, Vert.		(lb)	17 000	15 000	100 800
Design Steering Load, Vert.		(lb)			
Tire Oper. Pressure		(psi)			
Mechanical Trail		(in)	2.0	2.0	5.0
Strut Inclination		(deg)	5.0	5.0	0
Rudder Effective Vel.		(knots)	50	50	60
Steering System Data					
Type Actuator			Hyd/Linear	Hyd/Linear	Hyd/Linear
Type Control	Input		Mech	Mech	Mech
	Feedback		Mech	Mech	Mech
Pilot Input	Input		R. Ped & Tiller	R. Ped & Tiller	R. Ped & Tiller
	Δin/Δout		95 deg	95 deg	150 deg
Maximum Steer Angle		(deg)	7 Ped/78 Tiller	7 Ped/78 Tiller	7.5 Ped/ 70 Tiller
Maximum Steer Torque		(in/lb)	90 084	90 084	604 032
Max Steer Rate (No Load)		(deg/s)	23.4	23.4	21
Type Damping			Hyd Ser Orif	Hyd Ser Orif	Hyd Ser Orif
Damp While Steer?		(Yes/No)	No	No	No
Damp. Coef.		$(in\text{-}lb/rad^2/s^2)$	4700 @ Null	4700 @ Null	60 000 @ Null
Allow Free-Play		(deg)	+0.66	±0.66	+1.02
Stiffness		(in-lb/rad)	2 060 000	2 060 000	21 600 000
Maximum Tow Angle		(deg)	±78	±78	±70
Tow Disconnect Type					
Pilot Select	How		Auto W/Strut SW	Auto W/Strut SW	Auto W/Strut SW
or	Dual Range		Yes	Yes	Yes
Full Time					
Failure Provisions	Power		No	No	No
(Redundancy)	Controls				
	Warning				
Type Transducers					
Centering Provisions			Strut Cams	Strut Cams	Strut Cams

TABLE A2 (Continued)

General Data		Aircraft	757	767	L-1011
Weight Maximum T.O.		(lb)	221 000	412 000	510 000
Weight Des. Landing		(lb)	198 000	320 000	368 000
Nosewheel Arrangement			Dual	Dual	Dual
Live Axle		(Yes/No)	No	No	No
Nose Tire Size		(in x in)	31 x 13	H37 x 14-15	37 x 13
Tire Rated Load		(lb)	17 200	26 700	22 200
Tire Rated Pressure		(psi)	155	180	165
Max. Static NLG Load, Vert.		(lb)	31 200	48 500	20 365
Design Steering Load, Vert.		(lb)			21 318
Tire Oper. Pressure		(psi)			165
Mechanical Trail		(in)	3.0	3.0	3.0
Strut Inclination		(deg)	0	0	0
Rudder Effective Vel.		(knots)	60	60	60
Steering System Data					
Type Actuator			Hyd/Linear	Hyd/Linear	Hyd/Linear
Type Control	Input		Mech	Mech	Mech
	Feedback		Mech	Mech	Mech
Pilot Input	Input		R. Ped & Tiller	R. Ped & Tiller	R. Ped & Tiller
	Δin/Δout		360 deg	360 deg	Tiller 156 deg N.L.
Maximum Steer Angle		(deg)	6 Ped/65 Tiller	7.5 Ped/ 65 Tiller	±10 Ped/ ±65 Tiller
Maximum Steer Torque		(in/lb)	277 800	375 600	100 000
Max Steer Rate (No Load)		(deg/s)	30	23.8	15
Type Damping			Orif + DLD	Orif + DLD	Hyd Ser Orif
Damp While Steer?		(Yes/No)	Yes	Yes	No
Damp. Coef.		(in-lb/rad^2/s^2)	50 000 @ Null	90 000 @ Null	39 000
Allow Free-Play		(deg)	+0.7	+1.13	0.6
Stiffness		(in-lb/rad)	13 500 000	19 200 000	3 880 000
Maximum Tow Angle		(deg)	±65	±65	±65
Tow Disconnect Type					
Pilot Select	How		Auto W/Strut SW	Full Time	Auto
or	Dual Range		Yes	Yes	Yes
Full Time					
Failure Provisions	Power		Yes	No	Yes, Emer Pwr
(Redundancy)	Controls				No
	Warning				No
Type Transducers					
Centering Provisions			Strut Cams	Strut Cams	Strut Cams

TABLE A3 - Steering System Descriptions: Small/Medium Commercial, Commuter, Business Aircraft

General Data		Aircraft	DHC-7	DHC-8	F-27
Weight Maximum T.O.		(lb)	43 500	43 200	45 000
Weight Des. Landing		(lb)	41 500	42 000	43 500
Nosewheel Arrangement			Dual	Dual	Single
Live Axle		(Yes/No)	No	No	
Nose Tire Size		(in x in)	21 x 6.5 - 18	6.5 - 10	9.25 x 12
Tire Rated Load		(lb)	4750	2800	5600
Tire Rated Pressure		(psi)	100	80	60
Max. Static NLG Load, Vert.		(lb)	5550	4800	
Design Steering Load, Vert.		(lb)			
Tire Oper. Pressure		(psi)			
Mechanical Trail		(in)	0.5	8.5	0
Strut Inclination		(deg)	+3.0	0	0
Rudder Effective Vel.		(knots)	40-45		
Steering System Data					
Type Actuator			Hyd/Linear	Hyd/Linear	Pneum/Linear
Type Control	Input		Elect	Elect (HWHL)	Mech Rack & Pinion
	Feedback			Elect	
Pilot Input	Input		R. Ped & Tiller	Elect HWHL & Ped	Tiller
	Δin/Δout		Tiller Const Ped N.L.	See Table A5	
Maximum Steer Angle		(deg)	±65 Tiller	±6 Ped/ ±60 HWHL	
Maximum Steer Torque		(in/lb)	2400 (Max 0 deg)	10 000	
Max Steer Rate (No Load)		(deg/s)	10	10	
Type Damping			Hyd Ser Orif	Hyd Orifice	Hyd Converter
Damp While Steer?		(Yes/No)		Yes	
Damp. Coef.		(in-lb/rad^2/s^2)			
Allow Free-Play		(deg)			
Stiffness		(in-lb/rad)			
Maximum Tow Angle		(deg)	±110	±120	360
Tow Disconnect Type				Not Reqd	
Pilot Select	How		Auto W/Strut SW		
or	Dual Range		Yes		
Full Time					
Failure Provisions	Power		Elect Mismatch		No
(Redundancy)	Controls		Auto Pwr Off		
	Warning		Light		No
Type Transducers			Plastic		
Centering Provisions			Hyd Plunger in Cam	Linear Spring	