9. CHARACTERISTICS OF VTOL-STOL AIRCRAFT

The interest in a wide variety of aircraft having VTOL-STOL capability has created the need for establishing preliminary-design methods for the prediction of the aerodynamic characteristics of such vehicles.

The terms VTOL, STOL, and V/STOL appear many times in the literature. VTOL means "vertical take-off and landing." STOL means "short take-off and landing," and vehicles of this classification do not have vertical take-off and landing capability. V/STOL means the capability to perform both vertical and short take-offs and landings. The many ways of achieving VTOL-STOL capability are exhibited in the proposed and existing vehicles of this family. There are four basic VTOL-STOL principles involved for accomplishing the conversion from hovering to cruise flight; namely, aircraft tilting, thrust tilting, thrust deflection, and dual-propulsion. These four conversion principles are coupled with four different propulsion methods; namely, rotor, propeller, fan, and jet, to give the family of basic V/STOL types. In the broad sense the material presented in this section does not include all V/STOL concepts. Specifically, the methods presented in Section 9 are applicable to predicting the forces and moments on free propellers (Section 9.1), power-on lift and drag forces of propeller-wing combinations (Section 9.2), and the forces and moments on isolated ducted propellers as functions of power and angle of attack (Section 9.3). No discussion or methodology is presented for rotor-type V/STOL aircraft. In addition to the material presented in this section, there are additional methods pertaining to STOL aircraft given in Section 6. Specifically, these methods pertain to jet-flap configurations; i.e., both internally-blown flaps (IBF) and externally-blown flaps (EBF).

Because of the unusual low-speed configurations and the effects of power and high angles of attack in the low-speed flight regime, which are typical of VTOL-STOL vehicles, conventional methods of predicting aerodynamic characteristics at low speeds are not applicable in most cases. In cruise flight, VTOL-STOL vehicles can usually be analyzed by conventional methods. Therefore, the primary problem is the prediction of characteristics that exist as a result of high-velocity slipstreams, high angles of attack, and geometry variations in the hover and transition flight regimes.

Because of the scope of VTOL-STOL aerodynamics and the scarcity of verified theoretical methods and design charts, a literature summary is presented as Table 9-A, accompanied by a subject index on page 9-34, a "key" to the summary table on page 9-35, and a bibliography on pages 9-3 through 9-33.

V/STOL aircraft are characterized by the following four basic and unique characteristics:

1. High power requirements in hover and transition
2. High-velocity slipstreams in hover and transition
3. Inherent deficiencies in aerodynamic stability and control in hover and low-speed flight
4. Special provisions for performing the conversion from the hovering to the cruise configuration

The high power required in hovering and transition is not of primary concern to the stability and control engineer and is not considered in the Datcom. However, it should be noted that the engine-operation problems are extremely significant in the design of a V/STOL vehicle. The high power required in hovering and transition results in both higher fuel consumption and greater noise.

The magnitude of these increases depends on the type of propulsion system used. Both fuel consumption and noise level progressively increase from the rotor to the propeller, the fan, and the jet.

The high-velocity slipstream required in hovering and transition flight introduces problems due to surface erosion, recirculation of dust and debris, ingestion of foreign objects, and slipstream recirculation, which can result in adverse aerodynamic effects and ingestion of hot gases into the engine, resulting in a serious reduction in engine thrust. Only the aerodynamic effects of the slipstream are considered in this section. Slipstream recirculation can affect the pressure on the airframe, which can cause significant changes in the vertical lift. When a single high-velocity slipstream exhausts in still air, suctions are generated on the surrounding surface because of the entrainment into the high-velocity slipstream. This "suckdown" effect is a pressure reduction and reduces the vertical lift. This lift loss is evident during hovering near the ground for a configuration with a single vertical slipstream or a close cluster of vertical slipstreams. On the other hand, when several vertical slipstreams are dispersed over the planform, the high-velocity slipstreams tend to meet on the ground between the exits, and the consequent upflow can produce positive-pressure regions between the exits to counterbalance the "suckdown" generated by the entrainment. Unfortunately, this upward flow of air is not very steady or symmetrical and can result in random upsetting motions. In addition, for configurations with a tail behind the slipstreams, additional interference effects on longitudinal trim and stability can occur during transition flight. (Strong downwash and sidewash fields can develop in the region aft of the exits as a result of the rearward deflection and distortion of the slipstreams together with the entrainment of the free-stream flow.) References pertaining to the aerodynamic effects of high-velocity slipstreams are listed under one or more of the following specialized categories in table 9-A:

5.5 Ground Effects

5.10 Jet-Wake or Propeller-Slipstream Effects

5.11 Jet-Induced Effects

An important aspect of V/STOL hovering and low-speed flight is the inherently low level of aerodynamic stability and control. Aerodynamic control and static and dynamic stability vary with dynamic pressure in the free stream, and they all drop off rapidly as the flight speed is decreased. In hovering there is no aerodynamic control effectiveness (unless the control surface is in a high-velocity slipstream), and it is usually necessary to provide an additional control system for hovering and low-speed flight. In hovering flight the static stability is neutral (no stability of attitude) for all V/STOL types. The dynamic stability in hover is about neutral for jet-V/STOL types, but other types are usually dynamically unstable in the form of unstable pitching and rolling oscillations. Almost any system that will provide control for the pilot under these conditions can also be used to augment stability. However, the way in which this should be accomplished has not been clearly settled for any V/STOL type. The cost, complexity, reliability, and maintainability of any augmentation system must be weighed against the improvements in handling qualities and the potential reductions in control requirements. The problem immediately becomes more complex, since there is still a great deal of controversy regarding control-system requirements and handling-quality criteria. References pertaining to the aerodynamic stability and control deficiencies in hovering and low-speed flight may be found under one or more of the following specialized categories in table 9-A:

5.1 General Static Stability and Control

5.2 Dynamic Stability

5.3 Handling Criteria

5.4 Handling Qualities

5.7 Stabilization

5.8 Zero or Low-Airspeed Control and/or Control Systems

Although wind-tunnel tests cover a wide variety of V/STOL configurations, they are often of questionable accuracy because of wall interference effects and/or data-accuracy limitations at the low tunnel velocities required to simulate low-speed flight. Large flow-deflection angles are required for flight at very low speeds, and when these conditions are duplicated by a powered model in a wind tunnel, the presence of the tunnel walls have a first-order effect on tunnel flow conditions. Most existing low-speed wind tunnels are inadequate for the simulation of powered-lift low-speed flight because of their size limitations. The test section must be large compared to model dimensions to minimize the adverse effects of the wind-tunnel walls on the flow field. Simply testing models of smaller scale in an effort to avoid wall-interference effects often has not proved satisfactory, because of the significant errors in test data associated with low Reynolds number and the problems encountered in the design and manufacture of a powered model to a small scale. There appears to be a limit, which is a function of the tunnel test-section size and shape, model size, flow deflection angle, and model configuration, at which the tunnel-wall constraint causes a complete flow breakdown. The effects of all these variables on the accuracy of the wind-tunnel data are quite complex and some are not yet clearly understood. However, one fact has become very clear, and that is that most existing wind tunnels are simply too small for simulation of V/STOL flight.* References pertaining to wind-tunnel test techniques are listed under category 5.12 in table 9-A.

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KEY TO VTOL-STOL SUMMARY TABLE

Column Heading	Abbreviation	Definition
V/STOL Concept	BLC	Boundary-Layer Control
	DJ	Deflected Jet (Vectored Jet)
	DP	Ducted Propeller
	DSS	Deflected Slipstream
	FIF	Fan in Fuselage
	FIW	Fan in Wing
	FP	Free Propeller
	HL	High Lift (Flaps, Slots, Slats)
	JF	Jet Flap or Jet-Augmented Flap
	L+P	Lift-Plus-Propulsion Engine
	RF	Rotating Flap
	S	Several
	TE	Tilting Engine
	TP	Tilting Propeller
	TS	Tailsitter
	TW	Tilting Wing
Nature of Report Material	A	Analytical
	BIB	Bibliography
	D	Description
	DS	Design Study
	E	Experimental
	PR	Pilot Report
	R	Research Summary
	S	Several
	T	Theoretical
Flight Regime or Air Flow	Ax	Axial Flow
	C	Cruise
	H	Hover
	LS	Low Speed
	N-Ax	Nonaxial Flow
	S	Several
	St	Static
	T	Transition
Test Article	C	Component
	E	Existing Aircraft (Production Aircraft)
	M	Model
	P	Prototype
	PM	Prototype Model
	S	Several
	Sim	Simulator
Type of Test	F	Flight Test
	S	Several
	Sim	Simulator
	St	Static
	T	Princeton Dynamic Model Track
	WT	Wind Tunnel

TABLE 9-A*

VTOL-STOL SUMMARY

								AREAS OF INVESTIGATION OR ANALYSIS																			
																	STABILITY AND CONTROL										
SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Slowdown	Gyroscopic Effects	Zero or Low Airspeed Control Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.1	94	59	BLC/DP	D	S	–	–	X								X											
	157	60	BLC/DSS	R/D	LS	–	–																				DEVELOPMENT PROGRAM FOR LOCKHEED BLC C-130
	159	60	BLC	E/D	LS	M	WT																				LIFT AUGMENTATION BY SPANWISE BLOWING OVER A LIFTING SURFACE
	244	58	BLC/DSS	E/A	LS	M	WT	X																			LIFTING EFFECTIVENESS, FLOW REQ OF BLOWING BLC APPLIED TO PROPELLER-DRIVEN AIRPLANE
	256	61	BLC	E/A	LS	E	F	X																			LIAISON AIRCRAFT
	291	65	BLC/DSS	E/PR/A	LS	PM	F/SIM											X	X	X		X		X	X		HANDLING QUALITIES OF STOL SEAPLANE
	443	63	BLC/DSS	E/A	LS	M	WT/ST	X							X		X										TEST OF FLAPPED WING IMMERSED IN SLIPSTREAM OF 4 PROPELLERS, GRD PROXIMITY, BLC
	502	63	BLC/DSS	E/A/PR	LS	P	F											X	X	X				X	X		MODIFIED C-130. STOL PERFORMANCE: BLC FLAP, AILERONS, ELEVATOR, RUDDER
	503	63	BLC/HL	E/A/PR	LS	SIM	SIM												X	X		X			X		C-130
	562	58	BLC/DSS	E/A	ST	C	ST	X	X	X				X													WING PLUS PROPELLERS
	567	56	BLC/DSS	E/A	ST	C	ST	X	X	X					X												WING PLUS PROPELLERS. SLAT, END PLATES, PROPELLER-POSITION VARIATIONS
	568	57	BLC/DSS	E/A	ST	C	ST	X	X	X				X													WING PLUS PROPELLERS
	573	57	BLC	E/A	LS	M	WT	X																			CIRCULATION-CONTROL RESEARCH MODEL
	597	62	BLC/JF	T/E/A	LS	M	WT	X				X	X														INCR OF LIFT DUE TO BLOWING BLC. JET MOMENTUM REQ TO PREVENT SEP. SURVEY ON SYSTEMATIC MEAS.
	637	59	BLC	E/A	LS	M	WT	X					X					X									45-FT-SPAN MODEL LIKE C-143 BUT 4 PROPELLERS, BLOWING FLAPS
	638	58	BLC	E/A	LS	M	WT	X					X														45-FT-SPAN MODEL LIKE C-143. AREA SUCTION FLAPS. LE FLAP
	639	61	BLC/TW	E/A	T/C	M	WT	X							X												LARGE MODEL, 4 PROPELLERS, BLC TRAILING-EDGE FLAP
	641	61	BLC	E/A	S	M	WT	X										X	X					X			AR-10 WING, DUAL ROTATION PROPELLERS LIKE C-143 BUT 4 PROPELLERS
1.2	25	59	TW	E/A	H/T	P	F	X																			VZ-2
	31	62	TW	E/A	LS	M	F											X	X	X							FREE-AIR TESTS, 4-PROPELLER MODEL
	69	66	TW/DSS	A	T	–	–																				ANALYTICAL METHOD FOR PREDICTING STABILITY CHAR OF TILT-WING VTOL AIRCRAFT
	74	69	TW/DSS	R/A	H/T/C	M/PM	WT/F																				WT – FLIGHT-TEST CORRELATION PROGRAM TO DETERMINE STATIC WT TEST TECHNIQUES
	80	68	TW	E/A	T	M	WT												X	X							4-PROPELLER TILT-WING VTOL. STATIC AND DYNAMIC DERIVATIVES
	86	63	TW	E/D/PR	H/T	SIM	SIM											X	X	X		X		X	X	X	SIMULATOR STUDY OF TILT-WING HANDLING QUALITIES, 2 DEGREES OF FREEDOM

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Tare or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.2 (CONT)	89	61	TW/DSS	E/A	T/C	PM	WT	X																			KAMAN K-16B MODEL
	101	68	TW	A	T	–	–											X		X							IMPORTANT FACTORS INFLUENCING DYNAMIC LONG STAB OF TILT-WING V/STOL AIRCRAFT
	103	66	TW	E/A	H/T/C	M	WT	X		X								X		X							STATIC AND DYNAMIC LONG STAB DERIVATIVES
	128	60	TW/DSS	T/A	H/T/C	–	–										X										METHODS FOR PREDICTING AERO STAB DERIVS OF PROPELLER-DRIVEN TILT-WING V/STOL AIRCRAFT
	130	68	TW	A	H/T	M	WT											X		X							EXPERIMENTAL VALUES OF LONG STAB DERIVS OF 3 TILT-WING AIRCRAFT VARIED TO ANALYZE CHARACTERISTIC ROOTS AND TRANSIENT RESPONSE
	131	60	TW	A	T	M	WT	X					X														DISCUSSION OF SLIPSTREAM EFFECTS
	135	69	DP/TW	A	LS	–	–	X									X	X		X							ASPECTS OF LONG DYNAMIC STAB CHAR OF PROPELLER-DRIVEN V/STOL AIRCRAFT ANALYZED
	136	67	TW/DSS	E/A	T	M	T											X		X							XC-142A MODEL. LONGITUDINAL DYNAMICS AT HIGH WING INCIDENCE
	139	61	TW	A/E	T	M/E	F											X		X							PRINCETON FREE-FLIGHT FACILITY (VZ-2)
	149	64	TW/DSS	E/A	T	M	WT	X									X	X									TILT-WING V/STOL TRANSPORT. STALL, PERFORMANCE, LONGITUDINAL STAB AND CONTROL CHARACTERISTICS
	156	66	TW/DSS	T	H/T	–	–								X		X										WING LOADING OF ARBITRARY PLANFORM EQUAL TO OR LESS THAN SPAN OF PROPELLER JET
	158	68	TW/DSS	E/A	LS	M	WT	X							X		X										AERO CHAR OF LARGE-SCALE MODEL OF 4-PROPELLER TILT-WING CONFIG. GROUND EFFECTS
	163	68	TW/DSS	E/PR/A	—	PM	F										X										RESULTS OF CATEGORY II FLT TESTS OF XC-142. CATEGORY I DATA INCLUDED
	164	54	TW	E/A	H/T/C	M	WT	X	X	X								X									AERO CHARACTERISTICS OF WING - PROPELLER, WING ALONE, AND PROPELLER ALONE
	168	59	TW	E/A	T	M	WT	X					X														TWIN-ENGINE MODEL
	174	62	TW	E/A	T	M	WT	X																			
	178	63	TW	D/A/E	S	S	S	X							X									X			REVIEW STUDY (VZ-2)
	183	69	TW/DSS	E/A	LS	M	WT									X		X									LONG AERO CHARACTERISTICS. EFFECT OF PROPELLER-ROTATION DIRECTION
	184	66	TW	E	LS	M	WT	X	X							X	X	X									EFFECT OF PROPELLER-ROTATION DIRECTION, FLAPS, SLATS, FENCES, ON AERO AND FLOW CHARACTERISTICS
	185	66	TW	E	LS	M	WT	X	X							X	X	X									EFFECT OF PROPELLER-ROTATION DIRECTION, FLAPS, SLATS, FENCES, ON AERO AND FLOW CHARACTERISTICS
	186	67	TW	E	LS	M	WT	X	X							X	X	X									EFFECT OF PROPELLER-ROTATION DIRECTION, FLAPS, SLATS, FENCES, ON AERO AND FLOW CHARACTERISTICS
	187	67	TW	E	LS	M	WT	X	X							X	X	X									EFFECT OF PROPELLER-ROTATION DIRECTION, FLAPS, SLATS, FENCES, ON AERO AND FLOW CHARACTERISTICS
	188	67	TW	E	LS	M	WT	X	X							X	X	X									EFFECT OF PROPELLER-ROTATION DIRECTION, FLAPS, SLATS, FENCES, ON AERO AND FLOW CHARACTERISTICS
	189	64	TW/DSS	E	LS	M	WT	X										X									LONG AERO CHARACTERISTICS. WING STALLING CHARACTERISTICS

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.2 (CONT)	190	64	TW/DSS	E	LS	M	WT	X										X									LONG AERO CHARACTERISTICS. WING STALLING CHARACTERISTICS
	191	64	TW	E	LS/H	M	WT	X	X								X	X									EFFECT OF SLATS AND LE AND TE FLAPS ON AERO AND FLOW CHARACTERISTICS
	192	69	TW/DSS	E	LS	M	WT						X			X											SEMISPAN MODEL. WING SURFACE PRESSURES OVER α FROM 6° TO 80° FOR THRUST COEFF .3, .6, .8, .9 AND δ_f = 0, 20°, 40°, 60°. PROP-ROTATION-DIRECTION EFFECTS.
	197	61	TW/DSS	E/A	T	PM	WT											X									KAMAN K-16B MODEL
	230	67	TW/DSS	E/A	LS	M	WT	X							X			X	X					X			LONG., LAT AND CONTROL CHAR OF 4-PROPELLER TW MODEL IN GRD EFF. RECIRCULATION EFFECTS MOVING-BELT GROUND PLANE. THOROUGH REPT
	231	67	TW	E/A	T	M	WT	X							X		X	X									GROUND EFFECTS ON TILT-WING AIRPLANE
	232	66	TW/DSS	E/A	T	M	WT								X		X	X									EXPERIMENTAL STUDY OF LONG AERO PROBS OF FLAPPED 4-PROPELLER V/STOL TRANSPORT
	247	61	TW	E/A	H/T	M	WT	X							X				X	X							AO-1 CONVERSION TO 4-PROPELLER TILT WING (MOHAWK)
	253	55	TW	T/A/E	N–Ax	C	WT	X	X	X																	WING PLUS PROPELLERS
	254	60	TW/DP	D/E	H/T	P	F	X							X		X										VZ-2, VZ-4
	262	61	TW	T/A	T	–	–											X		X							
	295	60	TW/DSS	E/A	ST	M	ST	X					X		X												
	296	63	TW/DSS	E/A	T	M	WT	X					X														WING AND FLAP LOADS
	313	59	TW	E/A	T	M	U										X							X			4-POINT CONTROL
	327	61	TW/DSS	R/D/A	H/T	–	–	X									X	X									DISCUSSION OF TW AND DSS, PROPELLER-DRIVEN VTOL AIRCRAFT
	329	64	TW/DSS	E/A	T	M	WT											X									VZ-2. FORCE TEST TO DETERMINE LONG AERO CHAR AND AILERON CONTROL CHAR. EFF OF LE DROOP
	354	56	TW	E/A	0-90°	C	WT	X	X	X																	WING PLUS PROPELLER, AND SEPARATELY
	368	60	TW/DSS	E	T	M	WT	X	X						X			X									AERO CHAR OF TILT-WING, DEFLECTED SLIPSTREAM, AND TW + DSS VTOL AIRCRAFT
	369	68	TW	–	LS	M	WT													X					X		RESULTS OF DYNAMIC STAB TESTS. EFFECT OF STAB DERIVS ON DYNAMIC STAB
	377	68	TW/TP	T	T/C	–	–											X									LARGE TILT-ANGLE LIFTING-SURFACE THEORY. DOWNWASH ANGLES AT TAIL NOT ACCURATELY PREDICTED AT HIGH ANGLES.
	385	66	TW	R	H/T/C	–	–											X	X			X			X	X	SUMMARY OF TEST PROGRAM ON CL-84 V/STOL PROTOTYPE AND 2 TYPES OF SIMULATORS TO ASSESS QUALITATIVELY HANDLING QUALITIES
	387	57	TW	E/A	T	M	F										X										4-PROPELLER MODEL
	388	56	TW	E/A	H	M	F											X	X	X							4-PROPELLER MODEL
	389	56	TW	E/A	T	M	F											X	X	X							4-PROPELLER MODEL

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control Systems	Handling Qualities / Handling Qualities Criteria	COMMENTS
1.2 (CONT)	413	63	TW	A/D/E	S	S	S	X							X		X	X	X	X				X		REVIEW STUDY OF TILT-WING V/STOL AERODYNAMICS
	432	63	TW/DSS	E/A	T	M	WT	X										X							X	VZ-2 WING STALLING PHENOMENA STUDIED. LIFT AND DRAG CORRELATED WITH FLT-TEST RESULTS. FLYING QUALITIES PROBLEMS CORRELATED WITH WING STALL. TUFT STUDY
	441	60	TW	E/A	T	M	WT											X	X					X		DAVID TAYLOR MODEL BASIN, STOL MODEL
	446	57	TW	E/A	ST	M	ST	X							X											4-PROPELLER MODEL
	450	58	TW/DSS	E/A	T	M	WT	X											X							4-PROPELLER MODEL
	451	62	TW	E/A	H/T	M	F											X		X						4-PROPELLER MODEL WITH PROGRAMMED FLAPS (FLT TEST)
	452	64	TW	E/A	H/T/C	M	WT/ST								X			X	X	X		X		X		FREE-FLIGHT TESTS OF 1/9-SCALE MODEL OF 4-PROPELLER V/STOL TRANSPORT
	454	62	TW	E/A	S	M	WT											X	X							4-PROPELLER MODEL WITH PROGRAMMED FLAPS (FORCE TEST)
	455	58	TW	E/A	T	PM	WT	X										X	X							VZ-2
	456	62	TW	E/A	H	M	ST								X											SLIPSTREAM FLOW AROUND VZ-2, X-18, AND ARB CONFIG MODELS
	480	65	TW	PR/A	H/LS	PM	F								X			X	X	X				X	X	FULL-SCALE FLIGHT INVESTIGATION OF MODIFIED VZ-2. OPERATIONAL AND AERO ASPECTS
	481	62	TW	E/A	H/T	P	F																	X		AILERON FOR YAW CONTROL INVESTIGATION (VZ-2)
	482	62	TW	E/A	S	P	F	X							X			X	X	X				X	X	FLIGHT-TEST RESULT SUMMARY (VZ-2)
	494	68	TW/DSS	E/A	T	M	T/WT	X							X											XC-142A MODEL. GROUND EFFECTS ON LONG. FORCES AND PITCHING MOMENT
	496	69	TW	E/A	T	M	T	X											X	X						XC-142A MODEL TESTED IN 3° OF LAT-DIR FREEDOM IN MID-TRANSITION FLT COND. CONTROL EFFECTIVENESS. CONTROL MIXING REQUIREMENTS.
	499	61	TW	E/A	T	M	T	X										X		X						PRINCETON UNIV FORWARD FLIGHT FACILITY
	518	59	TW/DSS	D	S	P	–																			KAMAN K-16B DESCRIPTION
	531	64	TW/DSS	E/A	T	M	SIM									X		X	X	X						DYNAMIC LAT STAB AND CONT CHAR OF THE VZ-2. SIM FLT-TEST EVALUATION. TRANSITION RANGE WHERE WING STALLING OCCURS.
	570	63	TP/TW	E/A	T/LS/C	M	WT	X								X	X									DETERMINATION OF LIMITING VALUES ON TRANSITION STALLING CHAR. RATIO OF WING CHORD TO PROP DIAM VARIED
	578	64	TW/DSS	E/A	T	SIM	SIM												X	X		X				PROB AREAS IN SIM OF LAT-DIR DYN BEHAVIOR OF STOL AIRCRAFT. EQ OF MOTION. TURBULENCE EFFECTS
	591	59	TW	E/A	T	C	WT	X	X	X								X								WING CHORD TO PROPELLER DIAMETER RATIO. WING PLUS PROPELLER. SLATS
	598	58	TW	E/A	S	P	F	X																		VZ-2 CONVERSION MANEUVER
	600	60	TW	E/A	T	PM	WT	X										X	X	X						VZ-2
	601	60	TW	E/A	S	PM	F								X			X	X	X				X		X-18 MODEL (FLIGHT TEST)

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.2 (CONT)	602	58	TW	E/A	S	PM	F											X	X	X				X			VZ-2 MODEL FLIGHT TEST
	603	60	TW	E/A	S	PM	WT	X							X			X	X								X-18 MODEL (FORCE TEST)
	605	61	TW	E/A	H/T	PM	F											X		X					X		VZ-2, 1/4-SCALE MODEL, RIGID AND FLAPPING PROPELLER BLADES
	606	61	TW	E/A	T	PM	F											X		X				X			VZ-2, 1/4-SCALE MODEL
	608	68	TW	E	H/T	M	WT	X									X	X									PRINCETON DYNAMIC MODEL TRACK FACILITY. A GENERAL TILT-WING-PROPELLER MODEL
	632	69	TW	R/D	H/T/C	–	–								X		X										TECH AND OPERATIONAL LESSONS FROM XC-142 PROGRAM. WT AND FLT-TEST RESULTS COMPARED. PROP PITCH MOM AT HIGH INFLOW ANGLES
	639	61	TW/DSS	E	T	M	WT	X							X		X										LARGE-SCALE WT TEST OF TILT-WING AND DEFLECTED-SLIPSTREAM MODEL
	640	64	TW/DSS	E/A	LS	M	WT	X								X	X										EFFECTS OF HIGH-LIFT DEVICES ON FLOW SEPARATION, BUFFET, AND DESCENT CHAR
	642	65	TW	E	T/H	M	WT/ST	X									X	X	X								PERFORMANCE AND CONTROL CHAR OF VTOL AIRPLANE
	644	63	TW	E/A	LS	M	WT	X										X									VTOL CONFIG WITH FREE-PIVOTED TILTING WING WITH AERODYNAMICALLY CONTROLLED TILT ANGLE. EFF OF PIVOT LOC ON ABILITY TO TRIM
	658	62	TW/DSS	E/A	ST	M	ST						X														6-PROPELLER MODEL. PROPELLER SLIPSTREAM EFFECTS INVESTIGATED
	662	62	TW	T/A/E	S	PM	F/WT											X		X							VZ-2 STABILITY DERIVATIVES
	670	63	TW/DSS	T	H/T	–	–				X			X													METHOD FOR ASSESSING NONUNIFORM FLOW FIELDS OF WING-PROPELLER SLIPSTREAM AERODYNAMICS. METHODS FOR SPANWISE LIFT DISTRIBUTION AND INDUCED DRAG
[illegible]	11	62	DSS	D	LS	P	F	X																			BREGUET 941 DESCRIPTION
	61	58	DSS	E/A	T	C	U	X	X	X																	WING PLUS PROPELLERS (VARIOUS COMBINATIONS)
	69	66	TW/DSS	A	T	–	–																				ANALYTICAL METHOD PREDICTING STAB CHAR OF VTOL AIRCRAFT
	74	66	TW/DSS	R/A	H/T/C	M/PM	WT/F																				WT-FLT-TEST PROGRAM TO DETERMINE STATUS OF WT TEST TECHNIQUES
	89	61	TW/DSS	E/A	U	PM	WT	X																			KAMAN K-16B
	106	58	DSS	T/A/E	H/T	M	WT	X												X							STATIC AND DYNAMIC STABILITY (VZ-3)
	128	60	TW/DSS	T/A	H/T/C	–	–										X										METHODS PREDICTING AERO STAB DERIVS OF PROPELLER-DRIVEN V/STOL AIRCRAFT
	141	64	DSS	A	C	–	–										X	X	X	X					X	X	BREGUET 941. LOW-SPEED FLYING QUALITIES COMPARED WITH AGARD REQUIREMENTS FOR V/STOL
	149	64	TW/DSS	E/A	T	M	WT	X									X	X									STALL PERFORMANCE AND LONG STAB AND CONTROL CHAR OF V/STOL TRANSPORT
	151	60	DSS	D	S	P	F	X																			BREGUET 941 AND 942
	152	61	DSS	D	H/T/C	M/PM/SIM	W/F/SIM													X							DISCUSSION OF COORDINATED METHODS USED TO PERFECT DYNAMIC BEHAVIOR OF BREGUET 940

* See table 9B for key to summary

TABLE 9-A (CONTD)*

								AREAS OF INVESTIGATION OR ANALYSIS									STABILITY AND CONTROL										
Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulators	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.3 (CONT)	156	66	TW/DSS	T	H/T	–	–								X		X										WING LOADING OF ARBITRARY PLANFORM EQUAL TO OR LESS THAN SPAN OF PROPELLER JET
	157	60	BLC/DSS	R/D	LS	–	–																				DESCRIPTION OF THE DEVELOPMENT PROGRAM FOR LOCKHEED BLC C-130 AIRCRAFT
	158	68	TW/DSS	E/A	LS	M	WT	X							X		X										AERO CHAR OF A LARGE-SCALE MODEL OF 4-PROPELLER CONFIG. GROUND EFF.
	163	68	TW/DSS	E/PR/A	–	PM	F										X										RESULTS OF CATEGORY II FLT TESTS OF XC-142. CATEGORY I DATA INCLUDED
	166	55	DSS	E/A	ST	C	ST	X	X	X				X													WING PLUS PROPELLERS
	183	69	TW/DSS	E/A	LS	M	WT									X		X									LONG AERO CHAR. EFFECT OF PROPELLER-ROTATION-DIRECTION EFFECTS
	189	64	TW/DSS	E	LS	M	WT	X										X									LONG AERO CHAR. WING STALLING CHAR
	190	64	TW/DSS	E	LS	M	WT	X										X									LONG AERO CHAR. WING STALLING CHAR
	192	69	TW/DSS	E	LS	M	WT						X			X											SEMISPAN MODEL. WING SURFACE PRESSURES OVER α FROM 5° TO 80° FOR THRUST COEFF .3, .6, .8, .9, AND δ_f = 0, 20°, 40°, 60°. PROP-ROTATION DIRECTION EFFECTS
	197	61	TW/DSS	E/A	T	PM	WT											X									KAMAN K-16B MODEL
	222	63	DSS/TS	PR	S	P	F	X							X			X		X	X		X				VZ-3 AND X-13
	230	67	TW/DSS	E/A	LS	M	WT	X							X			X	X					X			LONG., LAT., AND CONTROL CHAR OF 4-PROPELLER TW MODEL IN GRD EFF. RECIRCULATION EFFECTS. MOVING-BELT GROUND PLANE. THOROUGH REPT.
	232	66	TW/DSS	E/A	T	M	WT								X		X	X									EXPERIMENTAL STUDY OF LONG AERO PROBS OF FLAPPED 4-PROPELLER V/STOL TRANSPORT
	244	58	BLC/DSS	E/A	LS	M	WT	X																			LIFTING EFFECTIVENESS, FLOW REQ OF BLOWING BLC APPLIED TO PROPELLER-DRIVEN AIRPLANE
	261	61	BLC/DSS	E/A	S	M	WT								X			X	X								6 PROPELLERS, T-TAIL
	264	58	DSS	E/A	H	C	ST		X	X							X										WING PLUS PROPELLERS, PROPELLER POSITION EFFECTS
	291	65	DSS/BLC	E/PR/A	LS	PM	F/SIM											X	X	X		X		X	X		HANDLING QUALITIES OF A STOL SEAPLANE
	295	60	DSS/TW	E/A	ST	M	ST	X					X		X												6 PROPELLERS, 35-FT SPAN, AR=6, DOUBLE-SLOTTED FLAPS
	298	63	DSS/TW	E/A	T	M	WT	X					X														WING AND FLAP LOADS
	304	59	DSS	E/A	S	P/SIM	WT/SIM	X							X			X	X					X	X		AMES 40 x 80 WT TEST OF PROTOTYPE PLUS SIMULATOR (VZ-3)
	327	61	TW/DSS	R/D/A	H/T	–	–	X									X	X									DISCUSSION OF TW AND DSS, PROPELLER-DRIVEN VTOL AIRCRAFT
	329	64	TW/DSS	E/A	T	M	WT											X									VZ-2. FORCE TEST TO DETERMINE LONG AERO CHAR AND AILERON CONTROL CHAR. EFF OF LE DROOP
	331	55	DSS	E/A	LS	C	S																				SUMMARY OF NACA FLAP AND VANE INVESTIGATIONS
	355	58	DSS	E/A	H/T	C	WT	X	X	X				X													WING PLUS PROPELLERS, TURNING EFFECTIVENESS

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.3 (CONT)	356	57	DSS	E/A	ST	C	ST	X	X	X				X	X												WING PLUS PROPELLERS, TURNING EFFECTIVENESS
	357	56	DSS	E/A	ST	C	ST	X	X	X				X	X												WING PLUS PROPELLERS, PROPELLER POSITION EFFECTS
	358	54	DSS	E/A	0-90°	C	WT	X	X	X				X													4-PROPELLER MODEL. WING PLUS PROPELLERS, TURNING EFFECTIVENESS
	359	56	DSS	E/A	ST	C	ST	X	X	X								X						X			WING PLUS PROPELLERS, LE SLAT
	360	61	DSS	E/A	T	PM	WT	X							X				X								LARGE POWER EFFECTS ON DIR STAB. (VZ-5)
	361	60	DSS	E/A	S	M	WT	X							X			X									4 PROPELLERS, PROPELLER EFFECTS, SLAT, TAIL FAN OPERATION
	363	56	DSS	E/A	ST	C	ST	X	X	X				X	X												WING PLUS PROPELLERS, TURNING EFFECTIVENESS
	365	59	DSS	T/A/E	H/T	C	WT	X	X	X																	WING PLUS PROPELLERS, LIFT AND DRAG ESTIMATION METHODS
	367	57	DSS	E/A	T	M	WT	X																			LARGE WALL CORRECTIONS NOT REMOVED
	368	60	TW/DSS	E	T	M	WT	X	X						X			X									AERO CHAR OF TILT-WING, DEFLECTED SLIPSTREAM, AND TW + DSS VTOL AIRCRAFT
	399	66	DSS	E/A	LS	M	WT	X									X	X									STAB AND CONTROL DATA ON 2-PROPELLER STOL AIRCRAFT
	416	54	DSS	E/A	H	M	F													X							4 CASCADE WINGS, 4 PROPELLERS
	443	63	BLC/DSS	E/A	LS	M	WT/ST	X							X		X										TEST OF FLAPPED WING IMMERSED IN SLIPSTREAM OF 4 PROPELLERS. GRD PROXIMITY. BLC
	449	57	DSS	E/A	0-90°	C	WT	X	X	X																	WING PLUS PROPELLERS. PROPELLER LOCATION EFFECTS
	450	58	DSS or TW	E/A	T	M	WT	X											X					X			4 PROPELLERS
	457	67	DSS	E/A	H/T	M	WT		X		X																WING WITH DUCTED FANS AND DOUBLE-SLOTTED FLAP. DUCT POSITION AND DUCT EXIT CONFIG VARIED. FLAP TURNING EFFECTIVENESS
	465	66	DSS	E/A	LS	M	WT	X								X		X									LONG FORCE CHAR OF STOL MODEL. WING SPAN VARIED. PROP-ROTATION-DIRECTION EFFECTS. SPANWISE VARIATION OF PROP THRUST
	466	66	DSS	E/A	LS	M	WT	X					X			X		X									WING PRESSURE DISTRIBUTION DATA ON STOL MODEL. WING SPAN VARIED. PROP-ROTATION-DIRECTION EFFECTS. SPANWISE VARIATION OF PROP THRUST
	500	64	DSS	E/A	LS	P	F											X	X	X				X	X		BREGUET 941. RESULTS OF FLT TEST OF PERFORMANCE, HANDLING QUALITIES, AND OPERATIONAL CHAR
	502	63	BLC/DSS	E/A/PR	LS	P	F											X	X	X				X	X		MODIFIED C-130. STOL PERFORMANCE: BLC FLAP, AILERONS, ELEVATOR, RUDDER
	515	61	DSS	D	LS/C	P	F																				BREGUET STOL AIRCRAFT
	518	59	DSS/TW	D	S	P	–																				KAMAN K-16B, DESCRIPTION IN JAHS
	565	60	DSS/JF	E	H/LS	C	WT	X	X	X			X		X												SEMISPAN WING PLUS 2 PROPELLERS, WING TIP BEYOND SLIPSTREAM
	567	66	DSS/BLC	E/A	ST	M	F	X												X							4-ENGINE TRANSPORT

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.3 (CONT)	568	57	BLC/DSS	E/A	ST	C	ST	X	X	X				X													EFFECTS OF PROP DIAM ON ABILITY OF FLAPPED WING TO DEFLECT SLIPSTREAM DOWNWARD
	578	64	TW/DSS	E/A	T	SIM	SIM												X	X		X					PROB AREAS IN SIM OF LAT-DIR DYN BEHAVIOR OF STOL AIRCRAFT. EQ OF MOTION. TURBULENCE EFFECTS
	579	59	DSS	D/A/E	S	P	F	X									X				X			X			VZ-2
	604	55	DSS	E/A	H	M	F	X												X							4-ENGINE TRANSPORT. LARGE FLAP AND EXTENSIBLE VANES
	607	57	DSS	E/A	T	M	F	X										X	X	X							4-ENGINE TRANSPORT. LARGE FLAP AND EXTENSIBLE VANES
	614	62	DSS	E/A	T	P	F								X			X						X	X		VZ-3
	615	63	DSS	E/A	LS	PM	F																		X		FLIGHT TEST OF RYAN VZ-3RY V/STOL VEHICLE. EVALUATION OF DSS CONCEPT FOR VTOL AND STOL
	630	61	TW/DSS	E	T	M	WT	X							X		X										LARGE-SCALE WT TEST OF TILT-WING AND DEFLECTED SLIPSTREAM MODEL
	640	64	TW/DSS	E/A	LS	M	WT	X								X	X										EFFECTS OF HIGH-LIFT DEVICES ON FLOW SEPARATION, BUFFET, AND DESCENT CHAR
	655	61	DSS	T/A	T	–	–													X							6 EQUATIONS OF MOTION DEVELOPED AND EXAMINED
	668	62	TW/DSS	E/A	ST	M	ST						X														6-PROPELLER MODEL. SLIPSTREAM EFFECTS
	670	63	TW/DSS	T	H/T	–	–				X			X													METHOD FOR ASSESSING NONUNIFROM FLOW FIELDS OF WING-PROPELLER SLIPSTREAM AERODYNAMICS METHODS FOR SPANWISE LIFT DISTRIBUTION AND INDUCED DRAG
1.4	27	66	DP	E	C/T/H	M	WT	X									X	X						X			XV-5A. HOVER TO 100 KNOTS IN CONVENTIONAL AND FAN POWER MODES. SUMMARY OF AERO PERF
	56	63	DP	E	C/T/H	M	WT	X	X				X		X		X	X	X					X			XV-5A
	94	59	DP/BLC	D	LS/C	P	–	X																			
	107	63	DP	E/A	H/T/LS	–	–											X	X	X	X			X	X	X	CONTROL AND STAB AUGMENTATION REQUIREMENTS. THEOR AND ANALOG COMPUTER INVESTIGATIONS
	134	65	DP	E/A	H	PM	ST				X				X												DOWNWASH TESTS OF DUAL TANDEM DUCTED-PROP VTOL
	135	69	DP/TW	A	LS	–	–	X									X	X		X							LONG DYN STAB CHAR
	138	66	DP	R/A	T	–	–											X	X								LONG DYNAMICS ANALYZED TO DETERMINE STAB DERIVS
	144	64	DP	E/A	T	M	WT	X										X						X			TRANSITION CHAR OF DUAL TANDEM CONFIG. TRIM AND CONTROL
	194	66	DP	PR/A	H/T/C	E	F	X									X	X	X								XV-5A STAB AND CONTROL FLT-TEST EVALUATION
	223	67	DP	E/A	H/T/C	M	WT								X			X						X			LONG AERO CHAR IN GROUND EFFECT. 3 GROUND HEIGHTS. VTOL AND STOL OPERATION
	224	66	DP	E/A	H/T/C	M	WT	X									X	X	X					X			LONG AND LAT-DIR AERO CHAR. PERFORMANCE STAB AND CONTROL. EFF OF DUCT STALL
	229	62	DP	E/A	H/T	C	WT	X	X		X				X			X									VZ-4. 4 TAIL LOCATIONS, LIP MODIFICATION, WING PLUS DUCTED PROPELLER

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	Comments
1.4 (CONT)	238	65	DP	T	AX	–	–	X			X						X										INVISCID THEORY FOR STEADY AERO LOADING ON DUCTED PROPELLER IN FORWARD FLIGHT
	240	62	DP	E/A	H/T	M	WT	X	X		X																DIVISION OF AERO LOADS. WING PLUS DUCTED PROPELLER
	254	60	TW/DP	D/E	H/T	P	F	X							X		X								X		ANALYSIS OF FLT CHAR (VZ-4 AND VZ-2)
	258	63	DP	A	T	–	–				X									X							SIMPLIFIED ANALYTICAL APPROACH FOR EVALUATING DYN STAB CHAR OF VTOL CONFIG
	312	68	DP	E/A/PR	H/T	P	F										X										DEVELOPMENT FLT TESTS OF X-22A
	317	62	DP	E/A	H/T	P	F	X																	X		TRANSITION AND HOVER FLT CHAR (VZ-4)
	324	68	DP	A	T	–	–											X	X	X							X-22A DYNAMICS IN TRANSITION. EQ OF MOTION FOR FLT-TEST PARAMETER IDENTIFICATION
	336	61	DP	T	H/LS	–	–											X	X	X				X	X		HOVERING IN STILL AIR AND GUST COND, GLIDE APPROACHES AT LOW SPEED. DAMPING AND SENSITIVITY
	395	66	DP	D/R	T	–	–								X			X	X	X	X			X			REVIEW OF TEST RESULTS WITH EMPHASIS ON STAB AND CONT CHAR.
	418	62	DP	E/A	H/T/C	M	WT	X										X	X								STATIC STAB AND CONT CHAR OF CONFIG WITH 4 TILTING DUCTED PROPS, MOUNTED IN TANDEM PAIRS
	419	68	F(W)/ DP/DJ	D	H/T/C	–	–	X							X		X										PROBS ENCOUNTERED BY FAN V/STOL AIRCRAFT
	429	69	DP	R/PR/A	H/T	SIM	SIM										X					X			X		3 TYPES OF GROUND-BASED SIMULATORS OF THE X-22A EVALUATED AND COMPARED WITH ACTUAL FLIGHT
	438	62	DP	E/A	S	C	WT	X	X		X							X									WING PLUS DUCTED PROPELLERS, EXTENSIVE DUCT TESTS (VZ-4)
	445	63	DP	E/A	S	M	WT	X										X	X								4-DUCT TANDEM VTOL CONFIG
	453	66	DP	E/A	H/T/C	M	WT								X			X	X	X		X		X			FREE-FLT TESTS OF A 1/18-SCALE MODEL OF A 4-DUCT TANDEM V/STOL TRANSPORT
	469	61	DP	E/A	H/T	M	F											X	X	X	X						4-DUCT MODEL
	470	61	DP	E/A	H/T	M	F													X	X						2-DUCT MODEL
	472	60	DP	E/A	T	M	WT	X										X									JEEP-TYPE VEHICLE
	475	63	DP	D/E	S	M	WT	X									X										X-22A DESIGN DESCRIPTION
	492	64	DP	E	H	M	WT								X												FULL-SCALE, HALF-MODEL SIMULATION OF A DUAL TANDEM DUCTED PROPELLER AIRCRAFT. DOWNWASH ALLEVIATION
	495	68	DP	E/A	H	M	WT	X			X							X	X	X							MODEL SIMILAR TO X-22A. LONG AND LAT TRANSIENT RESPONSE USING A DYNAMIC MODEL. COMPARISON OF L, DRAG, PITCH MOM. OF ISOLATED DUCT
	496	68	DP	E/A	T	M	WT											X		X							MODEL SIMILAR TO X-22A. LONG TRANSIENT RESPONSE USING A DYNAMIC MODEL. TIME HISTORIES OF MODEL MOTION IN VARIOUS LONG DEGREES OF FREEDOM
	497	68	DP	E/A	LS	M	WT												X	X							X-22A. LAT-DIR DYN STAB OF DUCTED-PROP. QUAD CONFIG.TIME HISTORIES
	507	60	DP	E/D	S	P	F	X							X		X	X	X	X				X			FLIGHT-TEST REPORT (VZ-4)

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Stability and Control: Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
1.4 (CONT)	556	60	DP	E/A	T	M	WT	X										X									JEEP-TYPE VEHICLE
	561	63	DP	E/A	H	M	WT	X							X			X	X								TRENDS IN LIFT, PITCHING MOM, AND ROLLING MOM DUE TO GROUND EFFECT
	571	66	DP	E/A	T	M	WT												X					X			LAT AND DIR CHAR OF A 4-DUCT-PROPELLER VTOL MODEL IN GROUND EFFECT
	572	66	DP	E/A	H/T/C	M	WT	X			X						X	X	X					X			LONG AERO AND CONTROL CHAR OF DUCTED-PROP VTOL MODEL
	589	60	DP	E/A	S	P	F	X									X							X			CONVERSION MANEUVER (VZ-4)
	618	59	DP	D/E	S	P	ST/F	X									X										DESCRIPTION AND INITIAL FLT-TEST FINDINGS (VZ-4)
	663	63	DP	A/T/E	T/C	P/C	F/WT												X	X							LAT STAB DERIVS (VZ-4)
	664	63	DP	A/T/E	T/C	P/C	F/WT											X		X							LONG STAB DERIVS (VZ-4)
	673	61	DP	E/A	S	C	WT	X	X		X							X									WING PLUS DUCTED PROPELLER. GENERAL OVERALL DATA (VZ-4)
	674	61	DP	E/A	T	C	WT	X	X		X							X									WING PLUS DUCTED PROPELLER. TRANSITION CONDITIONS (VZ-4)
1.5	64	59	TP	A/E	S	–	–																		X		FLYING QUALITIES REPORT FOR KAMAN K-16B
	78	63	TP	D/A	S	P	-	X												X				X	X		X-19 (DUAL-TANDEM FREE-TILTING PROPELLERS)
	162	60	TP	D	LS	P/PM	F/WT																				DORNIER DO-29 (AGARD SYMPOSIUM PAPER)
	257	64	S	R/D	H/LS	-	-														X			X			LOW-SPEED CONT-SYS REQ FOR VTOL. GUIDANCE, FREQ, ATTITUDE CONT. GENERATION OF MOM DISCUSSED. STABILIZATION DEVICES. CONT SYS OF GER VJ101 TILT-ENGINE CONFIG DESCRIBED
	373	67	TP	T	H/T	–	–	X		X																	FORCES AND MOMENTS ON PROPELLER AT ANGLE OF ATTACK
	377	68	TW/TP	T	T/C	–	..											X									LARGE-TILT-ANGLE LIFTING-SURFACE THEORY. DOWNWASH ANGLES AT TAIL NOT ACCURATELY PREDICTED AT HIGH ANGLES
	570	63	TP/TW	E/A	T/LS/C	M	WT	X								X	X										DETERMINATION OF LIM VALUES ON TRANSITION STALLING CHAR. RATIO OF WING CHORD TO PROP DIAM VARIED
	679	59	TP	A/E	T	–	–													X					X		FLYING-QUALITIES REPORT FOR KAMAN K-16B. DYN STAB IN TRANSITIONAL FLT
1.6	65	61	TS	E/A	H	M	F													X				X			LOCKHEED "POGO" (XFV-1)
	66	61	TS	E/A	H	M	F													X				X			LOCKHEED "POGO" (XFV-1)
	294	58	TS	R/A	H/T	–	–	X									X					X		X		X	STAB. AND CONT CHAR. OF TAILSITTER AIRCRAFT
2.1	5	66	DJ/L+P	A/D	H/T/C	–	–																				COND NECESSARY FOR GOOD PERFORMANCE AND STAB AND CONTROL CHAR FOR JET V/STOL AIRCRAFT
	33	62	DJ	PR	S	P	F										X							X			HAWKER P-1127. HOVER TIME HISTORY
	59	68	DJ/L+P	T/A	H/T	-									X												SEMI EMPIRICAL APPROACH PREDICTING PERF LOSSES AND PITCH MOM DUE TO JET INTERFERENCE EFFECTS

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
2.1 (CONT)	81	64	DJ/L+P	E/A	H	M	WT						X														STATIC PRESS DISTRIB ON WALL AROUND A CIRC JET EXHAUSTING NORMALLY FROM PLANE WALL INTO AIRSTREAM
	99	[illegible]	DJ	E/A	T	M	WT	X					X														JET LOCATION INTERFERENCE EFFECTS ON LONG AERO CHAR OF A JET VTOL MODEL
	100	[illegible]	DJ	R/A	T	–	–																	X	X		REORGANIZATION OF THRUST MANAGEMENT CONTROLS FOR VECTORED-THRUST V/STOL VEHICLES DISCUSSED
	112	63	DJ	E	H	M	WT	X							X												SINGLE- AND DOUBLE-JET MODELS. GROUND EFFECTS ON PERFORMANCE
	180	[illegible]	DJ	E/A/PR	H	P	F/SIM												X					X	X		X-14A. UTILITY OF DIRECT SIDE-FORCE MANEUVERING DEVICE FOR VTOL AIRCRAFT
	195	65	DJ	D/PR	H/T/C	PM	F										X										P-1127 (KESTREL). LOG TECHNIQUES, STAB. IN HOVER AND ACCELERATING TRANSITION, ROUGH GRD OPERATION, NIGHT FLYING
	238	62	DJ	E/A	ST/LS	C	ST/WT									X								X			JET DEFLECTOR TESTS AND COMMENTS
	288	64	DJ/L+P	R	S	–	–										X										DORNIER DO-31. JET-LIFT CONCEPT
	289	64	DJ/L+P	A	H	–	–																	X			"MIXED" CONTROL SYSTEM TO HOVER UNSTABILIZED JET-LIFT AIRCRAFT. CONTROL-SYSTEM MOM A FUNCTION OF STICK POS AND RATE OF CHANGE OF STICK POS
	314	63	F/W/ DJ/L+P	R/D	H/T/C	–	–								X									X	X		DESIGN OPTIMIZATION OF V/STOL DIRECT-LIFT TRANSPORT. DESIGN PROBS OF PROPULSION, HANDLING QUALITIES, TRIM IN HOVER AND TRANSITION, GRD EFFECTS
	315	[illegible]	DJ	A	S	SIM	SIM											X	X	X							EFFECT OF VARYING AERO DERIVS FOR 4 FLT COND ON STAB AND CONTROL OF XV-4B
	333	66	DJ	E/A	H/T/C	M	WT	X									X	X	X					X			AERO CHAR OF VTOL AIRPLANE WITH JET EJECTOR FOR AUGMENTING LIFT
	350	[illegible]	F/W/ DJ/L+P	A/D	H	–	–						X														JET LIFT AND/OR LIFT-FAN V/STOL AERO ANALYZED. SIM MODEL OF JET EFFLUX SUPERIMPOSED ON REP OF VEH GEOM. VORTEX LATTICE TECHNIQUE DISCUSSED, APPL TO P-1127. THEO AND TEST COMP
	[illegible]	65	DJ/L+P	R/D	H	–	–								X		X										AERODYNAMICS OF JET VTOL ENGINE INSTALLATIONS. JET INDUCED EFF. EFF OF JET WAKE, GRD, AND INLET LIP SHAPE
	387	[illegible]	DJ/L+P	E/A	T	M	WT	X							X			X	X								AERO CHAR OF A 5-JET VTOL CONFIG. HORIZ-TAIL POSITION EFFECTS. GRD PROXIMITY
	408	[illegible]	DJ	E/A	LS	SIM	SIM												X	X		X			X		FLT INVESTIGATION OF STAB AUGMENTATION SYSTEMS FOR P-1127 JET-LIFT V/STOL AIRCRAFT, WITH VARIABLE-STAB HELICOPTER
	414	64	DJ/L+P	R/D	LS	–	–										X								X		AERODYNAMICS AND FLYING QUALITIES. JET INTERFERENCE. EFF OF MULTIPLE JETS AND WING PLANFORM. INLET EFFECTS. INGESTION CONTROL POWER
	419	66	F/W/ DP/DJ	D	H/T/C	–	–	X							X		X										PROBS OF FAN V/STOL AIRCRAFT
	421	[illegible]	DJ	E/A/PR	H/T/C	E	F											X	X	X	X			X	X		FLT EVALUATION OF P-1127 (XV-6A)
	428	65	DJ/L+P	E	LS	M	WT	X									X	X	X								SEMI SPAN MODEL OF CLOSE-SUPPORT VTOL. INTEGRATED PROPULSION AND/OR LIFTING-SURFACE SYSTEM
	468	66	DJ	R/D	H/T/C	–	–										X										SUMMARY OF XV-4A VTOL RESEARCH. RESULTS OF FLT TEST. DESIGN SYSTEMS. SMALL- AND LARGE-SCALE WT TEST
	484	62	DJ/L+P	E/A	H	M	WT	X										X									MUTUAL INTERFERENCE BETWEEN NOZZLE SYS, W-B COMBINATIONS, AND FREE STREAM. BASIC FUS AND SERIES OF WINGS. JET-INDUCED DOWNLOAD AND PITCH MOM. OUT OF GRD EFF
	520	60	DJ	D/E	S	P	F	X																			BELL X-14
	563	64	DJ	E/A	H/T/C	M	SIM								X			X	X	X				X			DYN STAB AND CONT CHAR. OF A VECTORED-THRUST V/STOL MODEL. FLT SIMULATION

* See table 9B for key to summary

TABLE 9-A (CONTD)*

								AREAS OF INVESTIGATION OR ANALYSIS									STABILITY AND CONTROL										
SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
2.1 (CONT)	569	61	DJ	E/A	H/T	M	WT	X						X													JET INTERFERENCE EFFECTS ON DELTA-WING MODEL
	574	65	JF/L+P	A	H/C	M	WT	X									X										INTEGRATED PROPULSION LIFTING SURFACE SYSTEM. COMPARISONS WITH THEORY
	626	65	DJ	E/A	T	–	–	X										X	X					X			LONG AND LAT-DIR CHAR OF 2 4-JET VECTORED-THRUST-TYPE VTOL MODELS
	653	66	S	R/D	H/T/C	–	–																				V/STOL AERO RESEARCH AT RAE, 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAPS, GRD SIM., WT TEST TECHNIQUES
	661	66	DJ	A	H/T	–	–										X										STAB INVESTIGATION OF VECTORED-THRUST P-1127. EXPRESSIONS DERIVED FOR STAB DERIVS
	667	66	DJ/L+P	R/A	H/LS	–	–	X							X		X										AERO INTERFERENCE EFF DUE TO JET EFFLUX. STATIC INTERFERENCE EFF. FWD-SPEED INTERFERENCE EFF. THEORY FOR JET-EFFLUX INTERFERENCE
2.2	5	66	DJ/L+P	A/D	H/T/C	–	–																				COND NECESSARY FOR GOOD PERFORMANCE AND STAB AND CONTROL CHAR FOR JET V/STOL AIRCRAFT
	59	66	DJ/L+P	T/A	H/T	–	–								X												SEMIEMPIRICAL APPROACH PREDICTING PERF LOSSES AND PITCH MOM DUE TO JET INTERFERENCE EFFECTS
	81	64	DJ/L+P	E/A	H	M	WT						X														STATIC PRESS DISTRIB ON WALL AROUND A CIRC JET EXHAUSTING NORMALLY FROM PLANE WALL INTO AIRSTREAM
	104	65	L+P	A/PR	H/T/C	PM	F																		X		SHORT SC-1. PERFORMANCE, STAB., AND CONTROL, ESPECIALLY IN HOVER AND TRANSITION
	115	60	L+P	D	S	P	F														X			X			SHORT SC-1. DETAILED AIRCRAFT SCHEMATIC
	199	62	L+P	D	H/T	P	F	X							X		X				X			X			SHORT SC-1
	201	62	L+P	D	H/T	P	F	X													X						SHORT SC-1
	288	64	DJ/L+D	R	S	–	–										X										DORNIER DO-31. JET-LIFT CONCEPT
	289•	64	DJ/L+D	A	H	–	–																	X			"MIXED" CONTROL SYSTEM TO HOVER UNSTABILIZED JET-LIFT AIRCRAFT. CONTROL-SYSTEM MOM A FUNCTION OF STICK POS AND RATE OF CHANGE OF STICK POS
	298	63	L+P	E/A/D	H/LS	P	F								X			X	X	X	X			X	X		RESEARCH FLT-TEST RESULTS ON SC-1. FLYING QUALITIES
	299	69	L+P	R	H/LS	–	–								X		X	X	X	X				X	X		SERIES OF TESTS ON SC-1 VARIABLE-STAB VTOL
	314	63	FIW/ DJ/L+P	R/D	H/T/C	–	–								X									X	X		DESIGN OPTIMIZATION OF V/STOL DIRECT-LIFT TRANSPORT. DESIGN PROBS OF PROPULSION, HANDLING QUALITIES, TRIM IN HOVER AND TRANSITION, GRD EFFECTS
	350	69	FIW/ DJ/L+P	A/D	H	–	–						X														JET LIFT AND/OR LIFT FAN V/STOL AERODYNAMICS ANALYZED. SIM MODEL OF JET EFFLUX SUPERIMPOSED ON REPRESENTATION OF VEHICLE GEOM. VORTEX LATTICE TECHNIQUE DISCUSSED, APPLIED TO P-1127. THEORY AND TEST COMPARED
	362	65	DJ/L+P	R/D	H	–	–								X		X										AERODYNAMICS OF JET VTOL ENGINE INSTALLATIONS. JET INDUCED EFF. EFF OF JET WAKE, GRD, AND INLET LIP SHAPE
	372	62	L+P	D	T	P	F														X						SHORT SC-1
	397	66	DJ/L+P	E/A	T	M	WT	X							X			X	X								AERO CHAR OF A JET VTOL CONFIG. HORIZ-TAIL POSITION EFFECTS. GRD PROXIMITY
	414	64	DJ/L+P	R/D	LS	–	–										X								X		AERODYNAMICS AND FLYING QUALITIES. JET INTERFERENCE. EFF OF MULTIPLE JETS AND WING PLANFORM. INLET EFFECTS. INGESTION. CONTROL POWER
	427	54	L+P	A/E	LS	M	WT	X					X		X												SEMISPAN MODEL. INTEGRATED PROPULSION-LIFTING-SURFACE SYSTEM

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
2.2 (CONT)	428	65	DJ/L+P	E	LS	M	WT	X									X	X	X								SEMISPAN MODEL OF CLOSE-SUPPORT VTOL. INTEGRATED PROPULSION AND/OR LIFTING SURFACE SYSTEM
	464	62	DJ/L+P	E/A	H	M	WT	X										X									MUTUAL INTERFERENCE BETWEEN NOZZLE SYS, W-B COMBINATIONS, AND FREE STREAM. BASIC FUS PLUS SERIES OF WINGS. JET-INDUCED DOWN LOAD AND PITCH MOMENT OUT OF GRD EFF
	577	66	L+P	A	H	–	–																	X			PROPULSION SYS AND/OR CONTROL SYS INTERFACE FOR HOVER CONTROL CONCEPTS, USING LIFT PLUS LIFT-CRUISE PROPULSION
	585	68	L+P	E/A	H/T/C	M	WT	X							X			X	X								XV-4B. POWERED INTERFERENCE EFFECTS IN AND OUT OF GRD IN LANGLEY LOW-SPEED TUNNEL. BASIC DATA IN CRUISE IN LANGLEY HIGH-SPEED TUNNEL
	610	68	L+P	E/A	T	M	WT	X											X					X			ROLL STAB OF SHORT SC-1
	625	64	L+P	E/A	LS	M	WT	X							X			X									INTERFERENCE EFF BETWEEN LIFTING JETS, FREE-STREAM VELOCITY, AND MODEL SURFACES AT LOW FWD SPEEDS. EFF ON LONG. AERO CHAR. VARIOUS JET CONFIG AND WING HEIGHTS. GRD EFF.
	653	66	S	R/D	H/T/C	–	–																				V/STOL AERO RESEARCH AT RAE, 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAPS, GRD SIM, W-T TEST TECHNIQUES
	659	69	L+P	E/A	T/C	M	WT								X			X	X					X			LONG. AND LAT-DIR CHAR OF JET-LIFT MODEL. GRD EFF. CONTROL EFFECTIVENESS. EFF OF POWER VARIATIONS OF LIFT JETS
	667	68	DJ/L+P	R/A	H/LS	–	–	X							X		X										AERO INTERFERENCE EFF DUE TO JET EFFLUX. STATIC INTERFERENCE EFF. FWD-SPEED INTERFERENCE EFF. THEORY FOR JET-EFFLUX INTERFERENCE
	671	63	L+P	E/A	H/LS	M	WT								X												SHORT SC-1. THRUST LOSS AS FUNCTION OF WING HT ABOVE GRD FOR JET-LIFT SCHEMES. THRUST LOSS REDUCTION
2.3	222	63	TS/DSS	PR	S	2P	F	X							X			X	X	X	X		X				X-13 AND VZ-3
	284	58	TS	R/D	H	–	–										X										STAB AND CONTROL CHAR OF VERTICAL-ALTITUDE VTOL AIRCRAFT
	386	57	TS	E/A	H/T	PM	F/WT										X		X	X	X						X-13, WING POSITION AND VERTICAL-TAIL POSITION VARIED
	543	60	TS	E/A	LS	PM	WT												X	X							X-13
	554	58	TS	E/A	H/T	PM	WT										X						X				X-13
	556	61	TS	E/A	H/T	PM	F										X	X	X		X		X				X-13
2.4	420	59	TE	E/A	LS	M	WT	X										X	X								WINGLESS JET VTOL TRANSPORT MODEL
2.5	159	69	BLC	E/D	LS	M	WT																				LIFT AUGMENTATION BY SPANWISE BLOWING OVER A LIFTING SURFACE
	422	60	BLC	E/A/T	LS	M	WT	X					X					X	X					X			SIMILAR TO F104. LE AND FLAP BLOWING
	473	69	JF	E/A	LS/C	M	WT	X										X	X								STOL AIRCRAFT EQUIPPED WITH EXTERNAL-FLOW JET FLAP
	597	62	BLC/JF	T/E/A	LS	M	WT	X				X	X														INCR OF LIFT BY BLOWING BLC. JET MOMENTUM REQ TO PREVENT SEP. SURVEY ON SYSTEMATIC MEAS.
	653	66	S	R/D	H/T/C	–	–																				V/STOL AERO RESEARCH AT RAE, 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAP, GRD SIM, W-T TEST TECHNIQUES
3.1	24	65	FIW	E/PR/A	H	SIM	SIM														X	X					XV-5A FLT SIM STUDY OF HOVERING UNDER GUSTY COND. OPTIMIZATION OF STAB AUGMENTATION GAINS
	26	65	FIW	E	H/T/C	M	WT	X									X	X	X					X			XV-4A. FULL SCALE. CONTROL EFFECTIVENESS IN ALL 3 MODES

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
3.1 (CONT)	29	60	FIW	E/A	S	M	ST								X												INVESTIGATION OF THRUST LOSS
	34	66	FIW	E/PR/A	H/T/C	P	F																				XV-5A FAN-IN-WING V/STOL AIRCRAFT
	35	66	FIW	E/PR/A	H/T/C	P	F																				XV-5A FAN-IN-WING V/STOL AIRCRAFT
	36	66	FIW	E/PR/A	H/T/C	P	F																				APPENDIX OF PLOTTED GRAPHS PERTAINING TO VOLS I AND II OF G.E. REPT 166
	41	62	FIW	E/A	ST	M	ST	X																			
	43	63	FIW	E/A	–	M	WT/ST	X				X			X			X	X								LARGE-SCALE TEST DATA
	52	60	FIW	E/D/A	H/T	M	WT	X					X		X												VERTOL
	56	64	FIW	E/T/A	C	M	WT											X	X	X							DYN STAB CHAR OF XV-5A BASED ON THEOR AND EMPIRICAL EST OF DYN AND STATIC DERIVS FROM WT TESTS, CONVENTIONAL FLT.
	57	64	FIW	E/A/T	H/T/C	M	WT										X										XV-5A. EST STATIC STAB AND CONTROL
	60	63	FIF/FIW	D	LS	–	–																				TIP-TURBINE-DRIVEN LIFT-FAN SYS. FIF STATIC PERF, WT EVALUATION, GRD-EFF EVALUATION. FIW STATIC PERF, WT EVALUATION, WT RESEARCH
	87	61	FIW	E/A	H/T	M	ST/WT	X					X		X		X										WT TESTS OF VERTODYNE RESEARCH AIRCRAFT. FAN-THRUST VARIATION. GRD EFF WING SURFACE PRESSURES
	88	60	FIW	E/A	ST/C	M	ST/WT	X					X														VERTODYNE. STATIC AND FWD-SPEED TESTS. WING SURFACE PRESSURES, FORCES AND MOM
	102	66	FIW	E/A	T/LS	M	WT											X		X							STATIC AND DYN LONG. STAB OF VTOL AIRCRAFT
	117	63	FIW	R/D/A	H/T/C	–	–															X			X	X	XV-5A SIMULATION PROGRAM. DESIGN PROBS SOLVED BY SIMULATION
	159	60	DP/FIW	E/A/T	T	M	WT	X			X		X														DUCTED FAN AS LIFTING DEVICE IN FWD FLT
	196	66	FIW	D	T	–	–																				TECHNIQUE AND COMPUTATION FOR POTENTIAL-FLOW SOLUTION OF 3-DIM V/STOL AIRCRAFT. TRANSITIONAL SIM STUDY
	204	67	FIW	E/D/A	LS	M	WT	X																			INFLUENCE OF FAN EFFLUX FLOW ON LIFT AND PITCH MOMENT OF FUS, WING, AND TAILPLANE
	228	63	FIF/FIW	E/A	H/T/C	M	WT	X									X			X				X			LARGE-SCALE CONFIGURATION TESTED AND ANALYZED. GEN STATIC AND DYN STAB AND CONT. STRIKE AIRCRAFT AND ASSAULT TRANSPORT ANALYZED.
	234	62	FIW	E/A	H	M	ST		X						X												GRD EFF ON FIW CONFIG
	239	62	FIW	E/A	ST	M	ST	X							X												WING SIZE VARIED
	265	67	FIW	E/A	LS	M	WT	X									X	X	X					X			EFF OF LIFT-FAN AND CRUISE-FAN VARIABLES ON AERO CHAR
	260	58	FIW	E/A	T	C	WT	X																			
	270	66	FIW	T	LS	–	–										X	X									CALCULATION OF AERO COEFF OF FIW AIRFOIL
	276	63	FIW	E	LS	M	WT								X			X									AERO CHAR OF DIRECT-LIFT FANS IN WING PANELS. EFF OF FAN OPERATION, THRUST CONTROL BY FAN EFFLUX ON LONG CHAR. DOWNWASH AT TAIL

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Slipstream Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
3.1 (CONT)	277	67	FIW/FIF	D	T	–	–	X							X		X										COMPREHENSIVE EXPER RESEARCH PROGRAM TO DEFINE AERO CHAR OF LIFT-FAN V/STOL AIRCRAFT
	278	63	FIW/FIF	A/E	T	M	WT	X										X									PERFORMANCE ESTIMATION METHODS GIVEN
	280	57	FIW	E	H/LS	M	ST/WT					X	X		X												INITIAL INVESTIGATION OF FIW CONCEPT
	281	59	FIW	E/A	ST/T	C	WT	X	X	X			X		X												PROPELLER ALSO TESTED SEPARATELY
	283	67	FIW	T	H/T/C	–	–										X										DIGITAL COMPUTER PROGRAM TO STUDY AERO CHAR. FLOW CHARTS. INPUT DATA FORMATS
	302	63	FIW	R/D	S	–	–	X									X	X									SURVEY OF TECHNOLOGICAL STATE-OF-THE-ART FOR FIW CONCEPT
	303	63	FIW	T/A/D/E	H/T	M	WT	X																			MANY PERF DESIGN GRAPHS
	314	63	FIW/ DJ/L+P	R/D	H/T/C	–	–								X									X	X		DESIGN OPTIMIZATION OF V/STOL DIRECT-LIFT TRANSPORT. DESIGN PROBS OF PROPULSION, HANDLING QUALITIES, TRIM IN HOVER AND TRANSITION, GRD EFFECTS
	328	66	FIW	E	H/T/C	M	WT	X							X			X	X	X		X		X			STAB AND CONT CHAR IN HOVERING AND TRANSITION ON FIW MODEL
	332	64	FIW	E/A	H/T	M	WT	X							X			X	X					X			LARGE-SCALE INVESTIGATION OF FIW CONCEPT. GEN AERO CHAR IN AND OUT OF GRD EFF
	334	67	FIW	E/A	LS			X										X	X								AERO CHAR OF V/STOL TRANSPORT. EFF OF ENGINE PLACEMENT. 6 WING FANS AND 2 LIFT-CRUISE ENGINES IN FUS. FAN FLOW-FIELD INTERFERENCE
	344	65	FIW	A	T	–	SIM													X							ANALOG SIMULATION OF XV-5A DYN STAB CHAR
	360	69	FIW/ DJ/F+P	A/D	H	–	–						X														JET LIFT AND/OR LIFT-FAN V/STOL AERODYANAMICS ANALYZED. SIM MODEL OF JET EFFLUX SUPERIMPOSED ON REPRESENTATION OF VEHICLE GEOM-VORTEX LATTICE TECHNIQUE DISCUSSED, APPLIED TO P-1127 THEORY AND TEST COMPARED
	371	67	FIW	E/PR/A	H/T/C	PM	F								X		X								X		FLIGHT EVALUATION OF HANDLING QUALITIES OF XV-5A
	401	64	FIW	T/A	T	–	–		X								X										THREE-DIMENSIONAL ANALYSIS OF FIW LIFT
	408	61	FIW	T	LS	–	–																				LIFTING-SURFACE THEORY
	415	66	FIW	E/A	LS	M	WT										X										EXPLORATORY TESTS OF FAN-POWERED V/STOL CONFIG, EFFICIENTLY PRODUCING LARGE-LIFT FORCES AT LOW SPEEDS
	419	68	FIW/ DP/DJ	D	H/T/C	–	–	X							X		X										PROBS OF FAN V/STOL AIRCRAFT
	434	65	FIW	A	–	–	–																				METHOD FOR STUDYING EFF ON AERO CHAR OF WINGS IN VICINITY OF LIFTING PROPULSION DEVICES, STAB AND CONT, GRD EFF, AND W-T CORRECTIONS
	439	69	DP/FIW	A/E	AX/N-AX	C	WT	X	X		X																
	459	62	FIW	T	LS	–	–		X									X									TWO-DIM TREATMENT OF DECR IN LIFT AT LOW FWD SPEEDS. COMPARED WITH 2-DIM TEST DATA
	484	65	FIW/FIF	R/D	S	–	–																				LIFT-FAN CONCEPT
	525	67	FIW	T	H/T	–	–										X										INCOMPRESSIBLE POTENTIAL-FLOW THEORY FOR DETERMINING AERO CHAR. THEORY AND APPLICATION
	560	69	FIW	A/T	S	–	–																				ANALYSIS OF AXISYMMETRIC FLOW IN LIFT FAN IN STATIC OPERATION BASED ON DOUGLAS INCOMPRESSIBLE POTENTIAL-FLOW COMPUTER PROGRAM

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Stability and Control: Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
3.1 (CONT)	613	67	FIW	A	H/T/C	–	–	X					X											X			PRELIM "IN-DEPTH" DESIGN OF ADVANCED LIFT-FAN PROPULSION SYSTEM
	616	62	FIW	E/A	H	M	WT	X							X												GRD EFF ON PERF OF LIFTING FAN
	619	63	FIW	D	T	P	WT	X																			SHAFT-DRIVEN FAN IN WING (VANGUARD)
	633	58	FIW	A/D	H/T	–	–	X																			
	634	59	FIW	E/A/T	H/T	C	WT	X	X			X															
	635	59	FIW	E/A/T	H/T	C	WT	X	X			X	X														INCLUDES WATER VISUALIZATION
	653	66	S	R/D	H/T/C	–	–																				BASIC RESEARCH ON V/STOL AERODYNAMICS AT RAE, 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAPS, GRD SIM, W-T TEST TECHNIQUES
3.2	42	61	FIF	E/A	H/T	M	WT	X																			
	58	61	FIF	E/A	H/T	M	WT	X					X					X									LONG CHAR OF LARGE-SCALE MODEL. FAN SUPPORTED FLT FROM 0 TO 100 KNOTS. STATIC PRESS. DISTRIB. DOWN WASH AT HORIZ TAIL
	60	63	FIF/FIW	D	LS	–	–																				TIP-TURBINE-DRIVEN LIFT-FAN SYS. FIF STATIC PERF, WT EVALUATION, GRD EFF EVALUATION, FIW STATIC PERF, WT EVALUATION, WT RESEARCH
	146	65	FIF	E/A	LS	M	WT	X					X				X	X						X			EFF OF SCALE AND WT WALLS ON AERO CHAR. POWER ON AND POWER OFF PITCH. MOM, NORMAL FORCE, AND AXIAL FORCE. PRESSURE DATA
	163	63	FIF	E/A	LS	M	WT	X					X		X			X									AERO CHAR IN GRD EFF. DOWNWASH AT HORIZ TAIL PLUS AREA INDICATED
	228	63	FIW/FIF	E/A	H/T/C	M	WT	X									X			X				X			LARGE-SCALE CONFIGS TESTED AND ANALYZED. GEN STATIC AND DYN STAB. AND CONT. STRIKE AIRCRAFT AND ASSAULT TRANSPORT ANALYZED
	277	67	FIW/FIF	D	T	–	–	X							X		X										COMPREHENSIVE EXPER RESEARCH PROGRAM TO DEFINE AERO CHAR OF LIFT FAN V/STOL AIRCRAFT
	278	63	FIW/FIF	A/E	T	M	WT	X																			PITCH-MOM ESTIMATION METHOD GIVEN
	330	61	FIF	D/E	H/T	M	F										X										SUPERSONIC FIGHTER DESIGN. CONFID REPT. NO PLOTS
	370	65	FIF	E	LS/T	M	WT	X										X									
	386	60	FIF	E/A	T	M	WT	X																			
	484	66	FIW/FIF	R/D	S	–	–																				LIFT-FAN CONCEPT
	493	62	FIF	E/D	LS	M	WT								X												PROPULSION, PERF, AND GRD EFF
	612	63	FIF	E/A	LS	M	WT	X																			INTERFERENCE LOADS DUE TO INTERACTION BETWEEN MAINSTREAM AND EFFLUX. EFF ON LIFT AND PITCH MOMENT
	653	66	S	R/D	H/T/C	–	–																				BASIC RESEARCH ON V/STOL AERODYNAMICS AT RAE, 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAPS, GRD SIM, WT TEST TECHNIQUES
4.1	70	41	–	E/A	AX/LS	C	WT		X	X																	LOW-SPEED, HIGH-THRUST PROPELLERS, DUAL ROTATION
	71	42	–	E/A	AX	C	WT			X																	SINGLE AND DUAL-TRACTOR PROPELLERS, WIDE BLADES

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
4.1 (CONT)	106	69	FP	T	T	–	–	X		X								X	X								METHOD FOR CALCULATING FORCE, MOM, AND POWER COEFFS OF PROPELLERS IN OBLIQUE FLOW
	119	57	–	T/A	ST/AX	–	–			X																	V/STOL PROPELLER SELECTION
	120	59	–	T/A	ST	–	–			X																	PROPELLER STATIC THRUST
	126	52	–	T/A	N-AX	–	–	X		X																	PROPELLER IN YAW (PITCH)
	150	66	FP	E/A	H/T	C	ST			X								X						X			MONOCYCLIC PROPELLER PITCH FOR LONG. CONTROL
	154	64	–	T	LS	–	–	X		X							X										FORCE AND MOM DERIVS DUE TO FREE PROPELLER INCLINED TO FREE STREAM
	166	65	TP	T	H/T/C	–	–	X		X								X	X								GEN FORCE AND MOM EQ DEVELOPED FOR MOD TO HIGH ANGLES OF INCIDENCE
	171	66	S	T	C/ST	–	–																				RESEARCH ON PROP FLOW FIELD ASSOCIATED WITH TYPICAL V/STOL OPERATIONS. CRUISE FLT AND STATIC OPERATION
	173	65	FP	T	ST	–	–			X																	GEN THEORY FOR PERF CALCULATIONS OF VTOL PROPELLERS OPERATING IN STATIC COND
	220	44	–	E/A	ST	C	ST			X																	THRUST AND TORQUE, SINGLE- AND DUAL-TRACTOR PROPELLERS
	236	56	–	D/A	LS	–	–	X		X																	AERO ASPECTS OF VTOL PROPELLERS
	267	56	FP/DF	T/A	LS	–	–			X	X																PERF DIAGRAMS
	306	68	–	T	0-90°	–	–			X																	SIMPLE METHOD TO PREDICT PROP FORCES AND PITCH MOM
	373	67	TP	T	H/T	–	–	X		X																	APPROACH TO DETERMINE FORCES AND MOM ON PROPS AT HIGH ANGLES OF ATTACK
	423	54	–	E/A	0-180°	C	WT	X		X																	4-BLADED PROPELLER
	437	63	TP	E/A	H/T/C	M	ST			X														X			EFFECTIVENESS OF MONOCYCLING VARYING BLADE ANGLE FOR LONG CONTROL. BASIC AERO CHAR OF SAME PROP IN A FLAPPING AND RIGID CONFIG
	476	61	S	T/A/R	LS	–	–																				APPLICATION OF SMALL-PROP DATA
	489	48	–	E/A	ST	C	ST			X																	4 DIFFERENT 2-BLADED PROPS TESTED
	490	48	FP/DP	E/A	ST	C	ST	X		X	X																
	512	45	–	T/A	N-AX	–	–	X		X																	"PROPELLERS IN YAW" (RIBNER)
	545	58	S	T/A	AX/N-AX	–	–	X		X																	GENERALIZED PROP PERF
	646	66	FP	E/A	LS	M	WT	X		X								X	X								FORCES AND MOM ACTING ON PROP CENTER WERE TESTED FOR WIDE RANGE OF ADVANCE RATIO, PROPELLER ATTITUDE, AND BLADE PITCH SETTINGS
	647	61	–	E/A/T	N-AX	M				X																	WATER-TUNNEL PROP AXIS NORMAL TO FLOW, PHOTOS
	675	60	–	E/A	0-85°	C	WT	X		X																	3 PROPS. TESTED. EXTENSIVE POWER DATA

* See table 9B for key to summary

TABLE 9A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	Comments
4.1 (CONT)	676	63	–	E/A	LS	C	WT	X		X																	TWO VTOL PROPS IN DESCENT
4.2	19	60	DP	E/A	S	C	WT/ST	X			X																PERF CHARTS. WATER TESTS ALSO
	72	68	DP	R/A	–	–	–	X			X		X				X										SUMMARY OF TEST RESULTS OF EXTENSIVE RESEARCH PROGRAM ON SHROUDED PROPS
	73	67	DP	E/A	H/T/C	M	WT/ST	X			X		X				X										EXTENSIVE SHROUDED-PROP RESEARCH PROGRAM
	95	62	DP	T/A/E	S	C	WT/ST	X			X		X														
	169	60	DP/FIW	E/A/T	T	M	WT	X			X		X														THE DUCTED FAN AS A LIFTING DEVICE IN FWD FLT
	218	60	DP	T	–	–	–				X																NOMOGRAM ANALYSIS
	219	56	DP	E/A	ST/N-AX	C	WT	X	X		X		X														RING-WING AND SEVERAL DUCTED PROPS IN NONAXIAL FLOW
	237	64	DP	T	LS/ST	–	–				X		X														THEORY FOR STEADY AERO LOADING ON DUCTED PROP IN STATIC AND LOW-SPEED FLT SHROUD THRUST AND SURFACE PRESS
	246	58	DP	E/A	S	C	ST/WT	X			X																DATA FORM = 0 TO 0.6, MAX ANGLE OF ATTACK = 6°
	248	67	DP	E/A	N-AX	M	WT	X			X																α_D = -10° TO 110°
	266	55	DP	T	C	–	–				X																COMPRESSIBILITY EFFECTS
	267	56	FP/DP	T/A	AX	–	–			X	X																PERF DIAGRAM
	271	65	DP	E/A	H/T/C	M	WT	X			X		X														POWERED-DUCT MODEL OF X-22A VTOL AIRCRAFT. FORCES AND MOM ON COMPLETE UNIT AND SHROUD ALONE. SHROUD INTERNAL AND EXTERNAL PRESS DISTRIB
	285	59	DP	E/A	S	C	WT	X			X																DUCTED-PROP DESIGN METHOD (UNIV OF WICHITA)
	286	58	DP	E/A	ST/N-AX	C	ST/WT				X		X														SEVERAL REPTS. FAMILY OF DUCTED PROPS (UNIV OF WICHITA)
	292	66	DP	E/T/A	C	M	WT				X		X														COMPARISON OF THEOR PREDICTIONS OF DUCT-PRESS DISTRIB IN FWD FLT AND TEST RESULTS FOR X-22A DUCTED-PROP UNIT
	306	58	DP	E/A	ST	C	ST	X			X																STATIC THRUST IMPROVEMENT METHOD
	307	64	DP	E/A	H/T	M	WT	X			X																RELATED THRUST PROFILES TESTED TO DETERMINE EFF OF GEOM VARIABLES AND THRUST COEFF ON LIFT AND PITCH. MOM.
	346	64	DP	E/T	LS	M	WT	X			X		X														LARGE-SCALE DUCTED PROPS USED TO EVAL THEOR METHODS. THRUST, NORMAL FORCE, PITCH MOM., DUCT PRESS.
	347	63	DP	T	H/T/C	–	–	X			X						X			X							THEOR METHOD TO PREDICT FORCES, MOM, STAB DERIVS (STATIC AND DYN) OF ISOLATED DUCTED PROP AT ALL α's
	348	64	DP	A/T	AX/T/C	–	–	X			X							X	X	X							FORCE AND MOM COEFF AND DYN PITCH DERIVS PREDICTED BY POTENTIAL FLOW ANALYSIS
	349	64	DP	A/T	H/T/C	–	–	X			X						X	X		X							THEOR STAB DERIVS
	353	44	DP	E/A/T	ST/AX	C	ST/WT	X			X																

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	Comments
								AREAS OF INVESTIGATION OR ANALYSIS									STABILITY AND CONTROL										
4.2 (CONT)	394	64	DP	E/A	C	M	WT				X																SHORT-CHORD LOW-SOLIDITY DUCTED PROPS IN CRUISE COND PERF DATA IN PITCH
	438	67	DP	E/A	AX/N-AX	C	WT	X			X																X-22A COMPONENT
	439	59	DP/FIW	E/A	AX/N-AX	C	WT	X	X		X																
	442	66	DP	E/A	H/C	M	ST/WT	X																			FORCE AND MOM DATA FOR 3 DUCTED-PROP CONFIG (SAME DUCT). STATIC AND FWD-SPEED COND
	444	65	DP	E/A	H/LS	M	ST/WT				X		X														PERF, DUCT PRESS DISTRIB, AND PROP INFLOW DATA FOR TRACTOR AND PUSHER PROPELLERS
	463	60	DP	T	AX	–	–																				3-DIM THEORY. EFF OF BLADE NO., CIRCULATION PROFILE AND STRENGTH, PROP ADV RATIO, TIP CLEARANCE
	467	60	DP	E/A	0-90°	C	WT	X	X		X																DUCT (WITH AND WITHOUT PROP)
	488	60	DP	E/A	ST/N-AX	C	WT				X				X			X									STAB AND CONT INVESTIGATION, STATIC-TYPE SHROUD
	486	57	DP	T/A	AX	–	–				X																RING WING WITH CENTER BODY AND PROP
	490	46	FR/DP	E/A	ST	C	ST	X		X	X		X														
	527	59	DP	T/A/D	S	–	–	X			X																REVIEW AND BIBLIOGRAPHY ON DUCTED PROPS THROUGH 1959
	534	44	DP	A	AX	–	–				X																
	547	61	DP/S	T/D/E	S	P	F				X																APPENDIX PRESENTS PERF DATA ON 20 VTOL'S, 6 JEEPS
	556	60	DP	E/A	T	M	WT	X			X							X									JEEP-TYPE VEHICLE
	594	60	DP	T	H/LS	–	–																				PROBS OF DUCTED FAN AND ITS APPLICATION. THEOR RESULTS FOR THRUST, MOM., AND MOM OF MOMENTUM
	595	60	DP	R/A	H/T/C	M	ST/WT																				REVIEW AND ANALYSIS OF EXPER RESULTS. STATIC, AXIAL AND NONAXIAL
	596	61	DP	T	AX	–	–	X			X																
	599	66	DP	E	H	C	ST						X														FLOW PATTERN AND PRESS. DISTRIB ABOUT THE SHROUD, REARWARD MOTION AND FWD MOTION
	631	66	DP	A																							DUCTED-PROP TEST PROGRAM – DATA ANALYSIS
	636	59	DP	E/A	–	M	WT				X																BLADE TIP EFFECTS
4.3	6	63	HL	E/A	–	M	WT	X	X			X		X													ROTATING-CYLINDER FLAP
•	63	57	TW	T/E/A	T	M	WT	X	X																		WING ALONE IN PROP SLIPSTREAM, "DESTALLING" EFFECTS ANALYZED
	122	60	RF	T/A	LS	–	–	X	X																		ROTATING FLAP AS HIGH-LIFT DEVICE
	123	57	RF	T/E/A	LS	M	WT	X	X																		APPENDIX I AND II (THEORY AND POWER REQ) (SEE REF 122)

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Directional Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
4.3 (CONT)	180	56	BLC	E/A/T/R	LS	C	WT	X	X			X	X	X													BLOWING OVER NOSE OF TE FLAPS, POWER REQ
	205	59	JF	E/A	LS	C	WT	X	X																		FULL-SPAN AND HALF-SPAN BLOWING, AR=8.3
	225	60	–	T/A/E	–	C	WT/ST		X																		WING IN SLIPSTREAM STUDY
	319	56	BLC	T/E	LS	C	WT	X	X			X															BLOWING TYPE BLC
	337	58	HL	A/E	LS	C	ST	X	X																		VISUAL DATA INCLUDED, "ON THE NATURE OF STALL"
	511	58	HL	T	LS	–	–		X																		LIFT AND INDUCED DRAG WITH LARGE DOWNWASH ANGLES
	514	59	–	T	–	–	–		X																		WING IN SLIPSTREAMS
	516	55	BLC/HL	R/T/E/A	LS	C	WT	X	X			X															BLOWING, SUCTION, SLOTTED, PLAIN FLAP, HIGH-LIFT DEVICES
	562	58	DSS/BLC	E/A	ST	C	ST	X	X					X	X												WING IN PROP SLIPSTREAM
	620	61	DSS/TW	E/A	LS	C	WT		X			X		X													PROP TO WING CHORD RELATIONSHIP
	621	59	S	T	LS	–	–		X																		THEORY OF WING-PROPULSION SYSTEMS
	622	60	–	T/A	–	–	–		X																		SLIPSTREAM SHEAR ON AIRFOIL CHAR
	628	57	JF	E/A	LS	C	WT	X	X						X			X									ϵ AND $d\epsilon/d\alpha$ FOR VARIOUS TAIL LOCATIONS, η_t
4.4	198	57	DP	E/A	LS	M	WT	X	X																		LIFT, DRAG, AND PITCH MOM OF FAMILY OF ANNULAR AIRFOILS. EST LIFT-CURVE SLOPES AND INDUCED DRAG COMPARED WITH TEST
	287*	59	–	E/A	N-AX	C	WT	X	X																		RING WING WITH CENTERBODY
	488	63	–	T/A	N-AX	–	–		X																		
	513	47	–	T	N-AX	–	–		X																		
	642	66	DP	A/R/D	LS	–	–																				SPECIAL PROBS DUE TO ANNULAR-WING CONCEPT, FROM POINT OF VIEW OF FLOW MECHANICS
4.5	3	63	JF	E/A	LS	M	WT	X	X						X		X										EFF OF GRD PROXIMITY ON DELTA WING WITH AND WITHOUT JET BLOWING AT TE
	4	61	JF	E/A	LS	M	WT/ST	X																			THRUST, FLOW VISUALIZATION, DOWNWASH MEAS, JET TRAVERSING. COMPARISON WITH THEORY
	75	60	JF	T	LS	–	–	X																			EMPIRICAL RELATIONS FOR LIFT AND DRAG OF UNSWEPT 3-DIM JET-FLAPPED WINGS
	92	66	JF	E/A	LS	M	SIM	X							X												JET-FLAP MODEL WITH MOVING BELT RIG FOR GRD SIMULATION
	93	67	JF	E/A	LS	M	WT	X					X		X			X	X								BASIC AERO CHAR, INCLUDING GRD EFF
	97	67	JF	T/A	LS	–	–																				PROPOSED JET-WING FOR V/STOL AIRCRAFT. THRUST AUGMENTATION CONCEPTS ASSESSED, TEST APPARATUS AND RESULTS DESCRIBED

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
4.5 (CONT)	116	67	JF	D	LS	–	–																				JET AUGMENTOR WING PRINCIPLE DISCUSSED
	146	69	JF	D	LS	–	–	X	X								X										COMMENTS ON AERODYNAMICS OF PROPULSIVE-WING CONCEPT. LIFT, SPAN EFFICIENCY, a.c., DRAG DIVERGENCE
	147	66	JF	E/A	LS	M	WT								X			X	X								SEMISPAN JET-AUGMENTED-FLAP MODEL, WITH AND WITHOUT GRD BOARD
	172	62	JF	T	LS	–	–	X																			THEOR SOLUTION FOR PITCH MOM OF 2-DIM JET-FLAPPED WING
	181	61	JF	E/A	LS	M	WT	X																			AERO FORCES AND MOM ON JET-FLAPPED WING IN PRESENCE OF PROP SLIPSTREAM AND FREE STREAM
	182	61	JF	E/A	LS	M	WT	X									X										LARGE-SCALE EXTERNAL-FLOW JET-AUGMENTED-FLAP MODEL
	193	59	JF	E	H	C	ST	X	X					X													FLATTENED TAILPIPE EXHAUSTED OVERFLAP
	294	57	JF	E/A	LS	M	WT					X	X		X												GRD EFF ON HIGH LIFT COEFFS
	321	69	JF	D/A	LS	M	WT	X									X	X	X	X	X			X	X		DESIGN STUDY OF AUGMENTOR-WING JET STOL RESEARCH AIRCRAFT. ENGINE SURVEY CONFIG DEVELOPMENT, PERF COMPARISONS, CONFIG SELECTION, SYS, AERODYNAMICS
	322	67	JF	T	LS	–	–	X																			ASYMPTOTIC THEORY OF HIGH-ASPECT-RATIO JET FLAP. LIFT, INDUCED DRAG, AND PITCH-MOM COEFFS. COMPARISON WITH EARLIER THEORIES
	325	68	JF	E/A	LS	M	WT	X				X						X									LOW-SPEED CIRCULATION-CONTROLLED AIRFOIL. LIFT, DRAG, AND PITCH MOM AS FUNCTIONS OF BLOWING MOMENTUM COEFF. TWO-DIM.
	335	67	JF	E/A	LS	M	WT	X										X	X								MODEL WITH EXTERNAL JET-AUGMENTED FLAP
	339	64	JF	T/A	LS	–	–	X																			THRUST HYPOTHESIS AND ITS VERIFICATION. APPLICATION OF JET-FLAP PRINCIPLE TO STOL AIRCRAFT
	340	59	JF	A/D	LS	–	–										X										JET-FLAP APPLICATION FOR STOL
	341	63	JF	T	LS	–	–		X			X					X										CHAR OF JET-FLAPPED WINGS AT ANGLES OF ATTACK
	342	64	JF	T/D	–	–	–																	X			CHAR OF JET-FLAPPED WING EVALUATED FOR STOL APPLICATION
	378	67	–	T	LS	–	–								X												LINEAR-THEORY SOLUTION FOR JET FLAP IN GRD EFF
	379	67	JF	T/A	LS	–	–								X												LINEAR THEORY FOR JET FLAP IN GRD EFF. GEN LINEAR CASE OF AN ARBITRARY AIRFOIL AND JET COEFF
	381	58	JF	E/D	LS	M	WT																				PRELIM INVESTIGATION OF JET FLAPS IN 7' X 10' LOW-SPEED TUNNEL
	390	57	JF	A/D	LS	–	–								X		X	X									HIST OF JET-AUGMENTATION PRINCIPLE. INTEGRATION OF PROPULSION AND LIFTING SYSTEMS. PREDICTING AERO CHAR OF WINGS WITH JET-AUG FLAPS. GRD EFF AND DOWNWASH FIELD BEHIND WING. LONGTRIM, S AND C
	391	56	JF	E/A	LS	M	WT																				EFF OF ASPECT RATIO AND END PLATES ON AERO CHAR OF WING WITH JET FLAP. CHART FOR EST JET-CIRCULATION LIFT
	427	65	JF	A	LS	M	WT	X					X		X												DATA ANALYSIS OF SEMISPAN VTOL MODEL. INTEGRATED PROPULSION-LIFTING SURF. FLOW ANGULARITY MEAS AT TAIL
	433	66	JF	T	LS	–	–								X												FLOW PATTERN OF THIN JET-FLAPPED 2-DIM WING IN GRD EFF
	435	69	JF	T	LS	–	–																				ANALYSIS OF A JET SHEET AS AN ALTERNATIVE TO A RIGID DIFFUSER FOR MOMENTUM PROPULSION

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
4.5 (CONT)	473	69	JF	E/A	LS/C	M	WT	X										X	X								STOL AIRCRAFT EQUIPPED WITH EXTERNAL-FLOW JET FLAP
	487	62	JF	T/A/R	LS	–	–	X																			SEMIEMPIRICAL METHOD FOR DETERMINING JET-FLAP PERF. COMPARISON WITH TEST DATA
	524	61	JF	T	LS	–	–																				EVALUATION OF DOWNWASH BEHIND JET-FLAPPED WING
	559	57	JF	T/A	LS	–	–	X				X	X														THEOR SOLUTION FOR 2-DIM JET-FLAPPED WING. COMPARISON WITH EXPERIMENT
	560	61	JF	T/A	LS	–	–	X				X	X														THEOR SOLUTION FOR 2-DIM JET-FLAPPED WING
	566	60	DSS/JF	E	H/LS	C	WT	X	X	X			X		X												WING-PROPELLER CONFIG. JET FLAP PLUS DEFLECTED SLIPSTREAM
	573	57	JF	E/A	LS	M	WT	X																			POWERED BLOWING-TYPE CIRCULATION CONTROL
	574	65	L+P/JF	A	H/C	M	WT	X									X										ANALYSIS OF SELECTED DATA. INTEGRATED PROPULSION-LIFTING-SURFACE SYSTEM. COMPARISON WITH THEORY
	581	60	JF	E	LS	M	WT	X							X			X	X								EFF OF WING JET THRUST ON AERO CHAR
	590	62	JF	T	LS	–	–											X		X							LONG STAB, CONTROL, AND RESPONSE CHAR OF JET-FLAP AIRCRAFT
	597	62	BLC/JF	T/E/A	LS	M	WT	X				X	X														INCR OF LIFT BY BLOWING BLC. JET MOMENTUM REQ TO PREVENT SEP. SURVEY ON SYSTEMATIC MEAS
	617	61	JF	E	LS	M	WT/SIM		X				X		X												FREE-FLT INVESTIGATION TO EVALUATE GRD EFF ON JET-FLAPPED WING
	628	57	JF	E/A	LS	C	WT	X	X						X			X									FLOW-FIELD CHAR AND GRD INFLUENCE ON MODEL WITH JET AUGMENTED FLAPS. DOWNWASH AND DOWNWASH GRADIENTS
	646	67	JF	D	LS	–	–	X									X	X						X			PROGRESS REPT THROUGH LATE 1967 ON AUGMENTOR-WING RESEARCH
	650	61	JF	T	LS	–	–	X							X		X										AERODYNAMICS OF JET FLAPS
	653	66	S	R/D	H/T/C	–	–																				BASIC RESEARCH ON V/STOL AERODYNAMICS AT RAE, 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAPS, GRD SIM, W-T TEST TECHNIQUES
	664	62	JF	T/A	LS	–	–								X												A FORMULA DERIVED BY CONFORMAL TRANSFORMATION FOR LIFT INDUCED BY 90-DEGREE JET FLAP IN GRD EFF. COMPARISON WITH OTHER THEORY AND EXPERIMENT
	672	64	JF	A	LS	–	–																				THEOR TREATMENT OF 2-DIM INCOMPRESSIBLE JET. EFF OF JET ENTRAINMENT ON LOSS OF THRUST FORCE
	677	60	JF	T	LS	–	–																				THEOR METHOD FOR THRUST DEVELOPED BY JET FLAP
5.1	22	64	FIW	T/A	H/T/C	M	WT											X	X					X			EST OF XV-5A AERO CHAR.
	47	68	S	R/D/PR/A	S	–	–										X	X	X	X	X			X	X	X	AIRWORTHINESS STANDARDS FROM RECOMMENDATIONS OF AEROSPACE INDUSTRIES ASSN. FAA DRAFT DISCUSSED
	128	60	TW/DSS	T/A	H/T/C	–	–										X										METHODS PREDICTING AERO STAB DERIVS OF PROP-DRIVEN TILT-WING V/STOL AIRCRAFT
	200	69	S	R/A/D	S	–	–											X	X	X	X			X	X	X	PROBS IN EST STAB AND CONT CHAR OF V/STOL AIRCRAFT. REQ ANALYTICAL STUDIES. MATH MODELS DISCUSSED
	208	62	–	E/A	H/T	P	F																	X	X	X	EFF OF LOW-SPEED-CONTROL CROSS COUPLING. HELICOPTER TEST BED

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed	Control Systems	Handling Qualities Criteria	COMMENTS
5.1 (CONT)	215	67	TW/DSS	T/E/A	LS	M	WT	X										X									EFF OF PROP SLIPSTREAM ON WING PERF. VARIATION IN SLIPSTREAM VELOCITY.
	284	58	DSS	E/A	H	C	ST		X	X							X										WING PLUS PROPELLER. PROP-POSITION EFF
	273	61	–	T	LS	–	–										X										GEN NOMOGRAPHIC SOLUTION FOR INDUCED VELOCITIES AND WAKE SKEW
	293	66	DSS	A	LS	–	–																				EQS AND CHARTS FOR LIFT AND LONG FORCE COEFFS OF WINGS IMMERSED IN PROP SLIPSTREAMS. SAMPLE CALC
	345	67	–	R/D	H/T/C	–	–								X		X										AERO PROBS IN V/STOL. CHANGES IN FORCES AND MOM DURING TRANSITION AND IN STOL WITH GRD INTERFERENCE
	361	60	DSS	E/A	S	M	WT	X							X			X									PROP EFF, LE SLAT, TAIL FAN OPERATION
	430	66	TW/DSS	A	S	SIM	SIM										X	X	X	X	X	X					REVIEW OF V/STOL FLT SIM AT CANADAIR THROUGH FLT TESTING THE CL-84
	468	60	DP	E/A	ST/N-AX	C	WT											X									STAB AND CONT INVESTIGATION. STATIC-TYPE SHROUD
	473	69	JF	E/A	LS/C	M	WT	X										X	X								STOL AIRCRAFT EQUIPPED WITH EXTERNAL-FLOW JET FLAP
	523	67	–	A	H/T/C	–	–										X			X							RESEARCH AIRPLANE DESIGN STUDY. STAB AND CONT SUMMARIES. FLT DYN ANALYSIS
	651	52	–	E/A	LS	M	WT	X										X									PROP THRUST, TAIL LOCATION VARIED, q_H/q_∞, $d\epsilon/d\alpha$
	565	61	S	O/E	T	M/C	WT										X	X									JET INTERFERENCE EFF. SEVERAL CONFIGS
	585	66	L+P	E/A	H/T/C	M	WT	X							X			X	X								XV-4B. POWERED INTERFERENCE EFFECTS IN AND OUT OF GRD IN LANGLEY LOW-SPEED TUNNEL. BASIC DATA IN CRUISE IN LANGLEY HIGH-SPEED TUNNEL
	630	63	–	A/D	H/LS	–	–										X				X		X				STAB DUE TO GYROSCOPIC FORCES
	643	64	–	R/D	H/T	–	–										X							X	X	X	QUALITATIVE DISCUSSION OF STAB AND CONT PROBS OF VTOL AIRCRAFT
	661	68	DJ	A	H/T	–	–										X										STAB OF VECTORED-THRUST P-1127. EXPRESSIONS FOR STAB DERIVS
5.2	31	62	TW	E/A	LS	M	F											X	X	X							4 PROPS., FREE-AIR TESTS
	47	66	S	R/D/PR/A	S	–	–										X	X	X	X	X			X	X	X	AIRWORTHINESS STANDARDS FROM RECOMMENDATIONS OF AEROSPACE INDUSTRIES ASSN. FAA DRAFT DISCUSSED
	56	64	DP	A/T	C/T	–	–													X							XV-5A. ANALYSIS OF CONVENTIONAL FLT CHAR. NATURAL DAMPING CONTRIB TO FLT IN LIFT-FAN MODE
	65	51	TS	E/A	H	M	F													X				X			LOCKHEED "POGO" (XFV-1)
	66	51	TS	E/A	H	M	F													X				X			LOCKHEED "POGO" (XFV-1)
	101	68	TW	A	T	–	–											X		X							FACTORS INFLUENCING DYN LONG STAB OF A TILT-WING V/STOL AIRCRAFT
	103	66	TW	E/A	H/T/C	M	WT	X		X								X		X							STATIC AND DYN LONG STAB DERIVS
	106	58	DSS	T/A/E	H/T	M	WT	X												X							ALSO STATIC STAB (VZ-3)

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.2 (CONT)	124	68	S	R/A	H/T	–	–													X				X	X	X	DYN AND CONT REQUIREMENTS FOR VTOL, BASED ON HANDLING-QUALITY EXPERIMENTS LONG HOVER AND TRANSITION
	125	68	–	R/A	H	–	–												X	X							LAT HOVER-MODE DYNAMICS, SATISFACTORY AND UNACCEPTABLE
	128	60	TW/DSS	T/A	H/T/C	–	–										X										METHODS PREDICTING AERO STAB DERIVS OF PROP-DRIVEN TILT-WING V/STOL AIRCRAFT
	130	68	TW	A	H/T	M	WT											X		X							EXPER VALUES OF LONG STAB DERIVS OF 3 TILT-WING AIRCRAFT VARIED TO ANALYZE CHARACTERISTIC ROOTS AND TRANSIENT RESPONSE
	133	65	–	T	LS	–	–													X							DYN RESPONSE OF VTOL AIRCRAFT WITH VARYING FLT VELOCITY
	135	69	DP/TW	A	LS	–	–	X									X	X		X							ASPECTS OF LONG. DYN STAB CHAR OF PROP-DRIVEN V/STOL AIRCRAFT ANALYZED
	136	67	TW/DSS	E/A	T	M	T											X		X							XC-142A MODEL LONG DYNAMICS AT HIGH WING INCIDENCE
	137	66	–	D	LS	–	–											X	X	X							DESCRIPTION OF PRINCETON DYNAMIC MODEL TRACK (VTOL MODEL TESTING)
	139	61	TW/H	E/A	T	M/E	T/F											X		X							PRINCETON FORWARD FLIGHT FACILITY, VZ-2 AND HELICOPTER
	140	61	S	T/A	H/LS	–	–													X							ANALYSIS OF LONG EQS OF MOTION
	162	61	DSS	D	H/T/C	M/PM/ SIM	W/F/ SIM													X							DISCUSSION OF COORDINATED METHODS USED TO PERFECT DYN BEHAVIOR OF BREGUET 940
	167	63	–	A	T	–	–											X		X							LINEAR TIME-VARYING APPROXIMATION TO DYNAMICS OF LOW-SPEED FLYING MACHINES. APPLICATION TO LONG DYNAMICS OF VTOL AIRCRAFT DURING TRANSITION
	170	62	–	T/A	H/T	–	–											X		X	X	X					RESPONSE DESIRED OF V/STOL AIRCRAFT
	200	69	S	R/A/D	S	–	–											X	X	X	X			X	X	X	PROBS IN EST STAB AND CONT CHAR OF V/STOL AIRCRAFT, REQ ANALYTICAL STUDIES MATH MODELS DISCUSSED
	202	60	L+P	A/T	H/T	P	F											X	X	X	X		X	X	X	X	SHORT SC-1
	256	66	–	T	H	–	–													X							THEORY OF DYN STAB. OF VTOL AIRCRAFT, CHAR. OF DISTURBED MOTION IN HOVER, CONTROLLED TRANSITIONAL FLT DISCUSSED
	259	68	DP	A	T	–	–				X									X							SIMPLIFIED ANALYTICAL APPROACH FOR EVALUATING DYN STAB CHAR OF VTOL CONFIG
	262	61	TW	T/A	T	–	–											X		X							EQS OF MOTION FOR UNCONVENTIONAL FLT CHAR
	301	60	–	T/A/D	H/T	–	–													X							
	315	68	DJ	A	S	SIM	SIM											X	X	X							XV-4B, EFF ON STAB AND CONT OF VARYING AERO DERIVS, 4 FLT COND
	323	66	–	T	H/T	–	–													X							DEVEL OF EQS OF MOTION FOR ANALYZING VTOL DYNAMICS DURING HOVER AND TRANSITION
	324	68	DP	A	T	–	–											X	X	X							X-22A DYNAMICS IN TRANSITION, EQS OF MOTION FOR IDENTIFYING FLT-TEST PARAMETERS
	344	65	F/W	A	T	–	SIM													X							ANALOG SIM OF XV-5A DYN STAB CHAR
	360	68	TW		LS	M	WT													X					X		DYN STAB TESTS, EFF OF STAB DERIVS ON DYN STAB

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
								AREAS OF INVESTIGATION OR ANALYSIS									STABILITY AND CONTROL										
5.2 (CONT)	388	56	TW	E/A	H/T	M	F											X	X	X							4-PROP VTOL
	389	56	TW	E/A	T	M	F													X							4-CASCADE WINGS, 4 PROPS.
	412	63	–	A	–	–	–													X							ANALYSES FOR SIM AND DEVEL OF EQS OF MOTION. EQS OF MOTION FOR X-19, XV-5A, AND P-1127
	416	54	DSS	E/A	H	M	F								X					X							
	417	64	TW/DJ/FIW	R/D	H/LS	–	–											X	X	X	X			X	X		DYN TESTS OF FREE-FLT MODELS OF 3 V/STOL CONCEPTS. DYN STAB AND CONT PROBS.
	451	62	TW	E/A	H/T	M	F											X		X							4-PROP TILT-WING WITH FLAPS
	489	61	DP	E/A	H/T	M	F											X	X	X	X						4-DUCT VEHICLE
	470	61	DP	E/A	H/T	M	F													X	X						2-DUCT VEHICLE
	471	64	–	A/R	LS	–	–													X							DISCUSSION AND RESULTS OF 3 MODEL TEST TECHNIQUES USED BY NASA FOR DYN STAB TESTS
	491	64	–	R/A/D	LS	–	–											X		X							EFF OF TYP NONLINEARITIES IN LIFT AND PITCH-MOM CURVES ON LONG MOTION. APPLIC TO V/STOL AIRCRAFT
	495	68	DP	E/A	H	M	WT	X			X							X	X	X							MODEL SIMILAR TO X-22A. LONG AND LAT TRANSIENT RESPONSE USING DYN MODEL. COMPARISON OF LIFT, DRAG, AND PITCH-MOM OF ISOLATED DUCT
	496	68	DP	E/A	T	M	WT											X		X							MODEL SIMILAR TO X-22A. LONG TRANSIENT RESPONSE USING DYN MODEL. TIME HISTORIES OF MODEL MOTION IN VARIOUS LONG DEGREES OF FREEDOM
	498	69	TW	E/A	T	M	T	X											X	X							XC-142A MODEL TESTED IN 3 DEGREES OF LAT-DIR FREEDOM IN MIDTRANSITION FLT COND. CONTROL EFFECTIVENESS. CONTROL MIXING REQUIREMENTS
	499	61	TW	E/A	T	M	T/F	X										X		X							PRINCETON FORWARD FLIGHT FACILITY (VZ-2 MODEL)
	504	69	–	A	T	–	–											X		X							ASYMPTOTIC APPROX USING MULTIPLE TIME SCALES FOR LONG. DYN OF VTOL VEHICLES
	522	67	–	A	H/T/C	–	–										X			X							RESEARCH AIRPLANE DESIGN STUDY. STAB AND CONT SUMMARIES. FLT DYN ANALYSIS
	531	64	TW/DSS	E/A	T	M	SIM									X		X	X	X							DYN LAT STAB AND CONT CHAR OF THE VZ-2. SIM FLT-TEST EVALUATION. TRANSITION RANGE WHERE WING STALLING OCCURS
	543	60	TS	E/A	LS	PM	WT												X	X							X-13
	553	64	DJ	E/A	H/T/C	M	SIM								X			X	X	X				X			DYN STAB AND CONT CHAR OF A VECTORED-THRUST V/STOL MODEL. FLT SIMULATION
	578	64	TW/DSS	E/A	T	SIM	SIM												X	X		X					PROB AREAS IN SIM OF LAT-DIR DYN BEHAVIOR OF STOL AIRCRAFT. EQ OF MOTION. TURBULENCE EFFECTS
	593	68	–	T/A	T	–	–								X			X	X	X							DEVEL OF DYN MODEL FOR ANALYZING V/STOL TRANSPORTS IN LOW-ALT TURBULENCE IN TRANSITION. FACTORS AFFECTING RESPONSE TO TURBULENCE
	600	60	TW	E/A	T	PM	WT	X										X	X	X							VZ-2
	601	60	TW	E/A	S	PM	F								X			X	X	X				X			X-18
	602	58	TW	E/A	S	PM	F													X							VZ-2

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
6.2 (CONT)	604	55	DSS	E/A	H	M	F	X												X							4-ENGINE TRANSPORT CONFIG, EXTENSIBLE VANES
	607	57	DSS	E/A	T	M	F	X										X	X	X							4-ENGINE TRANSPORT CONFIG, EXTENSIBLE VANES
	606	61	DSS	T/A	T	–	–													X							6 EQS OF MOTION DEVELOPED AND EXAMINED
	662	62	TW	T/A/E	S	P/M	F/WT											X		X							STAB DERIVS (VZ-2)
	663	63	DP	A/T/E	T/C	P/C	F/WT												X	X							LAT STAB DERIVS (VZ-4)
	664	63	DP	A/T/E	T/C	P/C	F/WT											X		X							LONG STAB DERIVS (VZ-4)
	665	66	–	T/A	H	–	–			X	X									X							TECHNIQUE FOR ASSESSING EFF OF CONFIG GEOM, SIZE, AND MASS ON DYNAMICS OF HOVERING VEHICLES. EQ OF MOTION, THEORY COMPARED WITH TEST DATA ON DUCTED PROPS AND FREE PROPS
6.3	2	61	–	A	H/T	–	–													X		X				X	
	7	60	–	E/A	H/T	S	S																		X	X	HELICOPTER, AIRPLANE, V/STOL COMPARISON
	8	63	S	E/A	H/T	S/SIM	S/SIM											X	X			X			X	X	SEVERAL AIRCRAFT, UNPUBLISHED
	39	62	–	D	H/T	–	–																			X	AGARD RECOMMENDATIONS AS OF 1962
	47	66	S	R/D/PR/A	S	–	–										X	X	X	X	X			X	X'	X	AIRWORTHINESS STANDARDS FROM RECOMMENDATIONS OF AEROSPACE INDUSTRIES ASSN, FAA DRAFT DISCUSSED
	79	62	–	D	H/T	–	–																			X	AGARD RECOMMENDATIONS
	86	63	TW	E/D/PR	H/T	SIM	SIM											X	X	X		X		X	X	X	STUDY OF TILT-WING HANDLING QUALITIES, 2° OF FREEDOM
	107	63	DP	E/A	H/T/LS	–	–											X	X	X	X			X	X	X	CONT AND STAB AUGMENTATION REQUIREMENTS, THEOR AND ANALOG-COMPUTER INVESTIGATIONS
	108	63	–	E/A	LS	SIM	SIM															X				X	STUDY TO DETERMINE METHOD OF PRESENTING HANDLING QUALITIES CRITERIA FOR UNSTABLE MODELS
	124	68	S	R/A	H/T	–	–													X				X	X	X	DYN AND CONT REQUIREMENTS FOR VTOL, BASED ON HANDLING-QUALITY EXPERIMENTS. LONG HOVER AND TRANSITION
	132	65	–	D/R	H/T/C	–	–										X	X	X	X				X	X	X	SUGGESTIONS FOR FLYING-QUALITY SPECIFICATIONS FOR VTOL AIRCRAFT
	148	64	–	PR/A	H/LS	SIM	F/SIM												X						X	X	EFF OF WEATHERCOCK STAB ON DIR HANDLING QUALITIES, SYNTHETIC TURBULENCE. VAR-STAB HELICOPTER TESTED
	178	61	–	E/A	H	SIM	SIM													X		X	X			X	PILOTED 1 D.O.F. FLT SIMULATOR, ALTITUDE
	200	69	S	R/A/D	S	–	–											X	X	X	X			X	X	X	PROBS IN EST STAB AND CONT CHAR OF V/STOL AIRCRAFT, REQ ANALYTICAL STUDIES. MATH MODELS DISCUSSED
	207	64	–	E/A	T	SIM	SIM															X					DESCRIPTION OF ANALOG COMPUTER APPROACH TO V/STOL SIMULATION
	213	62	–	E/A	H	SIM	SIM								X					X	X	X		X	X	X	HEIGHT CONTROL, 1 D.O.F. SIMULATOR
	218	64	–	E/A/PR	H	SIM	SIM														X	X		X	X	X	HEIGHT-CONTROL REQ FOR VTOL AIRCRAFT DURING HOVER

* See table 9B for key to summary

TABLE 9-A (CONTD)*

								AREAS OF INVESTIGATION OR ANALYSIS																			
																	STABILITY AND CONTROL										
SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
6.3 (CONT)	217	62	—	E/A	H	SIM/E	SIM/F								X					X	X	X		X	X	X	HEIGHT CONTROL, FIXED-BASE SIMULATOR AND AIRCRAFT FLIGHT CHECKS
	243	69	—	A	H/T/C	—	—																		X	X	PROGRESS IN DEVELOPMENT OF HANDLING QUALITY SPEC FOR MILITARY V/STOL AIRPLANES
	246	63	—	D	H/T	—	—																			X	FAA PROPOSED VTOL FLIGHT REQUIREMENTS
	282	66	—	A	H	—	—																				FACTORS AFFECTING EFFICIENCY OF HOVER CONTROL SYSTEM FOR VTOL CONTROL EFFECTIVENESS. CONTROL CRITERIA
	290	69	S	R/A	C/T/H	SIM	SIM														X	X		X	X	X	NO. AMERICAN ROCKWELL RESEARCH IN V/STOL FLT CONT. VTOL FLT CONTROL DESIGN WITH IFR CAPABILITY. VTOL LDG PROB FROM CONVENTIONAL FLT TO HOVER
	310	66	J/L+F	R/A	H/LS	—	—																		X	X	EFF OF VEHICLE SIZE ON HANDLING QUALITIES OF VTOL AIRCRAFT AT HOVER AND LOW SPEEDS
	318	68	—	A	LS	—	—											X		X					X	X	LONG HANDLING QUALITIES DATA ANALYZED IN TERMS OF PILOT RATING TRENDS ASSOC WITH VARIATIONS IN IMPORTANT PARAMETERS
	351	67	—	R/D	S	—	—																		X	X	DEVEL OF VTOL FLYING-QUALITIES CRITERIA. AREAS FOR FURTHER RESEARCH
	383	63	—	R/D	LS	SIM	SIM														X				X	X	VTOL HANDLING QUALITIES USING FIXED-BASE SIMULATORS. SIM TECHNIQUES. BOUNDARIES OF DAMPING AND CONT SENSITIVITY
	393	60	—	E/A	H/T	SIM	SIM																			X	
	403	62	TW	E/A	H/T/LS	SIM	SIM											X				X			X	X	FLT SIM TO DETERMINE LONG HANDLING QUALITIES AND PILOT TECHNIQUES NORMAL AND EMERGENCY CONDITIONS
	407	64	—	E/PR/A	H/LS	SIM	SIM/F												X	X					X	X	DIHEDRAL EFF ON DIR-HANDLING QUALITIES. AIRBORNE SIMULATOR (VAR STAB HELICOPTER) ANGULAR RATE DAMPING. CONTROL SENSITIVITY
	409	66	—	E/PR/A	H/LS	SIM	SIM											X	X	X	X			X	X	X	FLT RESEARCH TO DETERMINE CONT POWER AND CONT SENSITIVITY REQUIREMENTS DURING VISUAL HOVERING AND LOW-SPEED APPROACH (VARIABLE-STAB HELICOPTERS)
	412	63	—	A	—	—	—													X							V/STOL ANALYSES FOR SIM AND DEVEL OF EQS OF MOTION. EQS OF MOTION FOR X-19, XV-5A, AND P-1127
	505	66	—	E/A	H/T	SIM	SIM											X	X	X		X				X	PARAMETERS IDENTIFIED TO SPECIFY HANDLING-QUALITIES CRITERIA. DERIVS DEFINED
	522	62	DJ	E/A	H	P	F													X	X		X	X	X	X	HOVERING CONT REQUIREMENTS OF VARIABLE STAB AND CONT X-14A
	528	61	—	E/A	H/T	SIM/E	SIM/F											X		X	X	X			X	X	LONG CONT PROBS AT LOW DAMPING
	529	59	H	E/A	H/LS	E	F													X	X	X		X	X	X	DAMPING AND CONT POWER EFF ON HELICOPTER HANDLING QUALITIES
	530	69	—	R/D/A	H/T/C	—	—																		X	X	RESEARCH AND PROGRESS TO 1969 IN DEVEL OF V/STOL FLYING-QUALITIES SPEC. PERTINENT AREAS DISCUSSED
	540	66	—	E/PR/A	H	SIM	F																		X		RESULTS OF FLT TESTS IN HOVERING RIG TO INVESTIGATE HANDLING QUALITIES
	557	66	—	E/A	T	SIM	SIM												X	X		X				X	DIR HANDLING-QUALITIES CRITERIA FOR INSTRUMENT APPROACH
	583	67	—	R	H/T/C	—	—													X	X	X			X		DYN RESPONSE CRITERIA FOR V/STOL AIRCRAFT SIMULATOR
	587	60	—	A	H/T	—	—																			X	
	588	60	—	A	H/T	—	—													X	X				X	X	

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	Comments
6.3 (CONT)	623	69	--	PR/A	H/LS	SIM	SIM											X	X	X	X	X		X	X	X	CRITERIA FOR VTOL DYN RESPONSE IN HOVER AND LOW-SPEED FLT LONG., LAT., HEIGHT, AND DIR HANDLING QUALITIES REQUIREMENTS
	643	64	–	R/D	H/T	–	–										X							X	X	X	QUALITATIVE DISCUSSION OF STAB AND CONT PROBS OF VTOL AIRCRAFT
6.4	7	60	–	E/A	H/T	S	S																		X	X	HELICOPTER, AIRPLANE, V/STOL COMPARISON
	8	63	S	E/A	H/T	S/SIM	S/SIM											X	X			X			X	X	SEVERAL AIRCRAFT, UNPUBLISHED
	9	65	DSS/ DSS+BLC	R/A	LS	–	–										X		X					X	X		LIFT PERF, LIMITATIONS IN LOW-SPEED OPERATION, AND HANDLING QUALITIES PROBS OF STOL AIRCRAFT
	40	64	–	R/D	H/T/C	–	–																		X		FLYING QUALITIES FOR MIL V/STOL VEHICLES RECOMMENDED BY AGARD FLT MECH PANEL
	47	66	S	R/D/PR/A	S	–	–										X	X	X	X	X			X	X	X	AIRWORTHINESS STANDARDS FROM RECOMMENDATIONS OF AEROSPACE INDUSTRIES ASSN, FAA DRAFT DISCUSSED
	64	59	TP	E/A	S	–	–																		X		FLYING QUALITIES REPT FOR KAMAN K-16B
	84	64	DSS	A	LS	SIM	SIM											X		X		X		X	X		OTTER AIRCRAFT, SHORT-FIELD LDG CHAR OF STOL AIRCRAFT FROM PERF STUDIES, MANEUVER DYN ANALYSES AND FLT SIM
	85	66	–	PR/E/A	H/T	SIM	SIM																		X		EFF OF SOME DERIVS, TURBULENCE, AND CONT POWER ON VTOL HANDLING QUALITIES
	86	63	TW	E/D/PR	H/T	SIM	SIM											X	X	X		X		X	X	X	TILT-WING HANDLING QUALITIES, 2° OF FREEDOM
	90	63	–	E/PR	H	M	F														X			X	X	X	CRITICAL DEMANDS ON VTOL ATTITUDE IN HOVER. APPLICATION OF MANEUVERING CRITERIA IN VAR STAB AIRCRAFT
	101	68	TW	A	T	–	-											X		X							FACTORS INFLUENCING DYN LONG STAB OF TILT-WING V/STOL AIRCRAFT
	104	66	L+P	A/PR	H/T/C	PM	F																		X		SHORT SC-1, PERF, STAB., AND CONT, ESPECIALLY IN HOVER AND TRANSITION
	117	63	F/W	R/D/A	H/T/C	–	–															X			X	X	XV-5A SIMULATION PROGRAM. DESIGN PROBS SOLVED BY SIMULATION
	124	68	S	R/A	H/T	–	–													X				X	X	X	DYN AND CONT REQUIREMENTS FOR VTOL, BASED ON HANDLING-QUALITY EXPERIMENTS. LONG HOVER AND TRANSITION
	141	64	DSS	A	C	–	–										X	X	X	X					X	X	BREGUET 941, LOW-SPEED FLYING QUALITIES COMPARED WITH AGARD REQUIREMENTS FOR V/STOL
	148	64	–	PR/A	H/LS	SIM	F/SIM												X						X	X	EFF OF WEATHERCOCK STAB ON DIR HANDLING QUALITIES. SYNTHETIC TURBULENCE. VAR-STAB HELICOPTER TESTED
	151	60	DSS	D	LS/C	P	F	X																	X		BREGUET 941 AND 942
	161	63																	X						X		LAT-DIR HANDLING QUAL OF V/STOL AIRPLANES
	166	61	S	PR	T	P	F																		X		SEVERAL PROTOTYPES
	180	69	DJ	E/A/PR	H	P	F/SIM												X					X	X		X-14A UTILITY OF DIRECT SIDE-FORCE MANEUVERING DEVICE FOR VTOL AIRCRAFT
	200	69	S	R/A/D	S	–	–											X	X	X	X			X	X	X	PROBS IN EST STAB AND CONT CHAR OF V/STOL AIRCRAFT REQ ANALYTICAL STUDIES. MATH MODELS DISCUSSED
	202	60	L+P	A/T/E	H/T	P	F											X	X	X	X		X	X	X	X	SHORT SC-1

* See table 9C for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulators	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.4 (CONT)	203	69	–	A/D/PR	H	SIM	SIM										X					X			X		6°-OF-FREEDOM MOTION SIMULATOR EVALUATED ON ITS ABILITY TO SIMULATE VTOL VISUAL HOVER IC
	208	62	–	E/A	H/T	E	F															X			X		LOW-SPEED CONTROL CROSS COUPLING. HELICOPTER SIMULATOR
	209	64	–	PR/A	LS/H	E	F																	X	X		EFF OF CHANGES IN STATIC DIR STAB ON HANDLING QUALITIES AND ON DIR SENSITIVITY AND DAMPING
	210	61	–	E/A	H/T	SIM	SIM																X		X		GYROSCOPIC CROSS COUPLING, PITCH-ROLL
	211	61	–	E/A	H/T	SIM	SIM																X		X		GYROSCOPIC CROSS COUPLING, PITCH-YAW
	213	62	–	E/A	H	SIM	SIM								X					X	X	X		X	X	X	HEIGHT CONTROL, 1 D.O.F. SIMULATOR
	217	62	–	E/A	H	SIM/E	SIM/F								X					X	X	X		X	X	X	HEIGHT CONTROL, FIXED-BASE SIMULATOR AND AIRCRAFT FLIGHT CHECKS
	221	58	–	D	H/T	–	–														X			X	X		HANDLING QUALITIES, PILOTING TECHNIQUES, AND HUMAN FACTORS OF VTOL
	233	66	–	T/E/PR	LS	SIM	SIM											X	X	X	X	X		X	X		VTOL CONT AND RESPONSE REQUIREMENTS USING VAR-STAB HELICOPTER AS SIMULATOR. C_{n_β} VARIED. CONTROL SENSITIVITY AND CONT POWER REQUIREMENTS. SIMULATED TURBULENCE
	241	66	–	E/A	H	SIM	SIM															X		X	X		6°-OF-FREEDOM MOTION SIMULATOR USED TO INVESTIGATE CONT-SYS REQUIREMENTS. EMPHASIS ON HOVERING. SIMULATOR CHAR
	242	66	–	E/A	H/T	SIM	SIM															X		X	X		6°-OF-FREEDOM MOTION SIMULATOR. LOW-SPEED CONT SYS CONCEPTS RELATING TO HANDLING QUALITIES AND CONT POWER REQUIREMENTS
	243	69	–	A	H/T/C	–	–																		X	X	PROGRESS IN DEVEL OF HANDLING-QUALITY SPEC FOR MIL V/STOL AIRPLANES
	265	60	–	D/A	–	SIM	SIM															X					REVIEW STUDY ON SIMULATORS
	266	62	S	E/A	T	SIM	SIM											X							X	X	3 CONFIGS, DP, TR, AND TW WITH FLAPS
	269	64	–	T/A	LS	–	–													X				X	X		EVALUATION OF LAT-CONT EQS FOR APPLICATION TO STOL AIRCRAFT
	282	66	–	A	H	–	–																				FACTORS AFFECTING EFFICIENCY OF HOVER CONTROL SYS FOR VTOL. CONTROL EFFECTIVENESS. CONTROL CRITERIA
	290	69	S	R/A	H/T/C	SIM	SIM														X	X		X	X	X	NO. AMERICAN ROCKWELL RESEARCH IN V/STOL FLT COND. VTOL FLT-CONT DESIGN WITH IFR CAPABILITY. VTOL LDG PROB FROM CONVENTIONAL FLT TO HOVER
	291	65	DSS/BLC	E/PR/A	LS	PM	F/SIM											X	X	X		X		X	X		HANDLING QUALITIES OF A STOL SEAPLANE
	298	63	L+P	E/A/D	H/LS	P	F								X			X	X	X	X			X	X		RESEARCH FLT-TEST RESULTS ON SC-1. FLYING QUALITIES
	299	60	L+P	R	H/LS	–	–								X		X	X	X	X				X	X		SERIES OF TESTS ON SC-1 VARIABLE-STAB VTOL
	300	61	HL	D/R/A	LS	E	F											X	X						X		FLIGHT EXAMINATION OF STOL APPROACH
	304	59	DSS	E/A	S	P/SIM	WT/SIM	X							X			X	X					X	X		VZ-3 PROTOTYPE WT AND SIMULATOR STUDY
	309	65	DJ/L+P	R/A	H/LS	–	–																		X		EFF OF SIZE ON VTOL AIRCRAFT HOVER AND LOW-SPEED HANDLING QUALITIES
	316	63	DP	E/A/PR	T/LS	P	F											X	X					X	X		RESULTS OF COMBINATIONS OF AIRCRAFT ATTITUDE, AIRSPEED, AND ANGLE OF ATTACK IN SIMULATED GRD-CONTROLLED LDG APPROACHES

* See table 9B for key to summary

TABLE 9-A (CONTD)*

								AREAS OF INVESTIGATION OR ANALYSIS																			
																	STABILITY AND CONTROL										
SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.4 (CONT)	318	68	–	A	LS	–	–											X		X					X	X	LONG HANDLING-QUALITIES DATA ANALYZED IN TERMS OF PILOT RATING TRENDS ASSOCIATED WITH VARIATIONS IN IMPORTANT PARAMETERS
	326	68	DJ		T	SIM	SIM															X		X			SIM OF PRINCIPLES OF CONTROLLING SMALL JET VTOL AIRCRAFT
	336	61	DP	T	H/LS	–	–											X	X	X				X	X		HOVERING IN STILL AIR AND GUST COND, GLIDE APPROACHES AT LOW SPEED. DAMPING AND SENSITIVITY
	351	67	–	R/D	S	–	–																		X	X	DEVEL OF VTOL FLYING-QUALITIES CRITERIA, AREAS FOR FURTHER RESEARCH
	369	68	TW		LS	M	WT													X					X		DYN STAB TESTS. EFF OF STAB DERIVS ON DYN STAB
	371	67	FIW	E/PR/A	H/T/C	PM	F								X		X								X		FLT EVALUATION OF HANDLING QUALITIES OF XV-6A
	376	63	S	D	H/T	P	F																		X	X	FRENCH V/STOLS (BREGUET 941, BALZAC)
	383	63	–	R/D	LS	SIM	SIM														X				X	X	VTOL HANDLING QUALITIES USING FIXED-BASE SIMULATORS. SIM TECHNIQUES. BOUNDARIES OF DAMPING AND CONT SENSITIVITY
	384	68	L+P	E/A	T/LS	E	–																	X	X	X	HANDLING QUALITIES OF VTOL AIRCRAFT, CONT MODES COMPARED IN TERMS OF PILOT ACCEPTANCE AND CONT POWER REQ
	385	66	TW	R	H/T/C	–	–											X	X			X			X	X	SUMMARY OF TEST PROGRAM ON CL-84 V/STOL PROTOTYPE AND 2 TYPES OF SIMULATORS TO ASSESS QUALITATIVELY HANDLING QUALITIES
	402	63	TW	R/A	H/T	–	–											X						X	X		LONG FLT CONT. FLOW SEPARATION. PITCH MOM. CONT SYS
	403	63	TW	E/A	H/T/LS	SIM	SIM											X				X			X	X	FLT SIM TO DETERMINE LONG HANDLING QUALITIES AND PILOTING TECHNIQUES, NORMAL AND EMERGENCY CONDITION
	407	64	–	E/PR/A	H/LS	SIM	SIM/F												X	X					X	X	DIHEDRAL EFF ON DIR HANDLING QUALITIES. AIRBORNE SIMULATOR (VAR-STAB HELICOPTER). ANGULAR RATE DAMPING CONTROL SENSITIVITY
	408	68	DJ	E/A	LS	SIM	SIM												X	X		X			X		FLT INVESTIGATION OF STAB AUGMENTATION SYS FOR P-1127 JET-LIFT V/STOL AIRCRAFT, WITH VAR-STAB HELICOPTER
	409	66	–	E/PR/A	H/LS	SIM	SIM											X	X	X	X			X	X	X	FLT RESEARCH TO DETERMINE CONT POWER AND CONT SENSITIVITY REQUIREMENTS DURING VISUAL HOVER AND LOW-SPEED APPROACH (VAR-STAB HELICOPTERS)
	410	63	–	A/D/E/PR	H/T/N–AX	SIM	SIM											X							X		HOVER, TRANSITION, AND STEEP APPROACHES. CONT CROSS-COUPLING EFF
	411	66	TW	E/A/PR	H/T/C	SIM	SIM										X					X			X	X	CANADAIR CL-84 SIMULATED BY AIRBORNE SIMULATOR
	414	64	DJ/L+P	R/D	LS	–	–										X								X		AERODYNAMICS AND FLYING QUALITIES. JET INTERFERENCE. EFF OF MULTIPLE JETS AND WING PLANFORM. INLET EFF, INGESTION CONT POWER
	417	64	TW/ FIW/DJ	R/D	H/LS	–	–											X	X	X	X			X	X		DYN TESTS OF FREE-FLT MODELS OF 3 V/STOL CONCEPTS, DYN STAB AND CONT PROBS
	421	68	DJ	E/A/PR	H/T/C	E	F											X	X	X	X			X	X		FLT EVALUATION OF P-1127 (XV-6A)
	429	69	DP	R/PR/A	H/T	SIM	SIM										X					X			X		3 TYPES OF GRD-BASED SIMULATORS OF THE X-22A EVALUATED AND COMPARED WITH ACTUAL FLIGHT
	431	68	–	R/A	H/LS	–	–															X			X		
	432	63	TW/DSS	E/A	T	M	WT	X										X							X		VZ-2. WING STALLING PHENOMENA STUDIED. LIFT AND DRAG CORRELATED WITH FLT-TEST RESULTS. FLYING QUALITIES PROBS CORRELATED WITH WING STALL. TUFT STUDY
	440	63	–	R/A	H/T/C	–	–																		X		PILOTING TASKS DEFINED. HANDLING QUALITIES OF VTOL AND CONVENTIONAL AIRCRAFT CONTRASTED

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulators	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.4 (CONT)	462	57	–	T/A	T	–	–										X			X					X		
	474	62	–	E/A	H	SIM	SIM														X	X		X	X	X	INSTRUMENT FLT SIMULATOR STUDY, HOVER CONTROL POWERS
	482	62	TW	E/A	S	P	F	X							X			X	X	X				X	X		SUMMARY OF FLT-TEST RESULTS (VZ-2)
	483	65	–	E/P/A	H/LS	SIM	SIM											X	X	X				X	X		FLT SIMULATOR STUDY OF ATTITUDE CONT REQUIREMENTS FOR JET VTOL AIRCRAFT
	500	64	DSS	E/A	LS	P	F											X	X	X				X	X		BREGUET 941, RESULTS OF FLT TEST OF PERF, HANDLING QUALITIES, AND OPERATIONAL CHAR
	501	57	–	E/PR/A	LS	SIM/PM	SIM/F												X						X		DIR AUGMENTATION FOR SATISFACTORY HANDLING QUALITIES OF STOL AT LOW APPROACH SPEEDS
	502	63	BLC/DSS	E/A/PR	LS	P	F											X	X	X				X	X		MODIFIED C-130, STOL PERF: BLC FLAP, AILERONS, ELEVATOR, RUDDER
	503	63	BLC/HL	E/A/PR	LS	SIM	SIM												X	X		X			X		LAT-DIR HANDLING QUALITIES OF THE C-130
	505	66	–	E/A	H/T	SIM	SIM											X	X	X		X				X	PARAMETERS IDENTIFIED TO SPECIFY HANDLING-QUALITIES CRITERIA, DERIVS DEFINED
	506	61	S	PR	S	P	F								X										X		SEVERAL VTOL AIRCRAFT
	522	62	DJ	E/A	H	P	F													X	X		X	X	X	X	HOVERING CONTROL REQUIREMENT OF VAR STAB AND CONTROL X-14A
	528	[illegible]	–	E/A	H/T	SIM/E	SIM/F											X		X	X	X			X	X	LONG CONT PROB AT LOW DAMPING
	529	59	H	E/A	H/LS	E	F													X	X	X		X	X	X	DAMPING AND CONT POWER EFF ON HELICOPTER HANDLING QUALITIES
	530	[illegible]	–	R/D/A	H/T/C		–																		X	X	RESEARCH AND PROGRESS TO 1969 IN DEVEL OF V/STOL FLYING-QUALITIES SPEC, PERTINENT AREAS DISCUSSED
	535	[illegible]	S	D/A	S	S	F																				BELL XV-3, VERTOL VZ-2PH, DOAK VZ-4DA, MCDONNELL XV-1, HANDLING QUALITIES, DEFICIENCIES AND RECOMMENDED CORRECTIONS
	536	66	–	R/A/D	H/T/C	–	–										X								X		VTOL FLYING QUALITIES AND VAR-STAB AIRCRAFT IN FLYING QUALITIES RESEARCH
	539	[illegible]	–	A	H	SIM	SIM											X	X	X	X	X		X	X	X	AUTO PILOT IN HOVERING CONT, CONT SYS NONLINEARITIES, SIMULATOR TEST, METHOD FOR ANALYZING STAB AND CONT CHAR OF AUTOPILOT
	540	66	–	E/PR/A	F	SIM	F																		X		FLT TESTS IN HOVERING RIG TO INVESTIGATE HANDLING QUALITIES
	541	[illegible]	–	E/PR/A	F	SIM	F											X				X		X	X		VAR-STAB HELICOPTER USED TO DETERMINE EFF OF PARAMETERS ON LONG HANDLING QUALITIES
	548	67	–	R/D	H/T	SIM	SIM															X			X		SIMULATORS AND THEIR CAPABILITY FOR V/STOL VISUAL FLT SIM
	549	68	–	A	H/T	–	–															X			X		STATISITICAL MODELS FOR GUST ENVIRONMENT TO DETERMINE GUST RESPONSE CHAR
	558	59	S	R/A	S	–	–											X	X	X	X			X	X		V/STOL FLYING-QUALITIES CHAR, STATE OF THE ART TO 1960
	575	65	DP/TW+DSS	A	H/T	–	–																		X		USE OF PILOT TRANSFER-FUNCTION MODEL AND OTHER ANALYTICAL TECHNIQUES

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
6.4 (CONT)	584	67	–	A	H	–	–	X											X	X					X		EFF OF GUST VEL DISTRIBUTIONS ON LAT-DIR RESPONSE OF HOVERING VTOL AIRCRAFT
	606	61	TW	E/A	H/T	PM	F											X		X					X		RIGID VS FLAPPING-PROP BLADES ON VZ-2 MODEL
	614	62	DSS	E/A	T	P	F								X			X						X	X		LONG TRIM CHAR (VZ-3)
	723	[illegible]	–	PR/A	H/LS	SIM	SIM											X	X	X	X	X		X	X	X	CRITERIA FOR VTOL DYN RESPONSE IN HOVER AND LOW-SPEED FLT. LONG, LAT, HEIGHT, AND DIR HANDLING-QUALITIES REQUIREMENTS
	[illegible]	[illegible]		[illegible]	H/T	–	–										X							X	X	X	QUALITATIVE DISCUSSION OF STAB AND CONT PROBS OF VTOL AIRCRAFT
	656	64	–	D/A	H/T/C	–	–													X					X	X	PROB AREAS IN DESIGN OF VTOL RELATED TO HANDLING QUALITIES AND NEEDED RESEARCH
	[illegible]	[illegible]	–	A	H/T/C	–	–											X	X	X				X	X		VTOL APPROX TRANSFER FUNCTIONS AND CLOSED-LOOP HANDLING QUALITIES. SAMPLE CALCULATIONS
	679	60	TP	E/A	T	–	–													X					X		FLYING-QUALITIES REPT FOR KAMAN K-16B. DYN STAB IN TRANSITIONAL FLT
6.5	3	63	JF	E/A	LS	M	WT	X	X						X		X										EFF OF GRD PROXIMITY ON A DELTA WING WITH AND WITHOUT JET BLOWING AT TE
	29	59	FIW	E/A	ST	M	S								X												
	92	66	JF	E/A	LS	M	SIM	X							X												JET-FLAP MODEL WITH MOVING-BELT RIG FOR GRD SIM
	93	67	JF	E/A	LS	M	WT	X					X		X			X	X								BASIC AERO CHAR OF JET-FLAP AIRCRAFT INCLUDING GRD EFF
	110	66	–	E/A	H	M	WT								X		X										INVESTIGATION OF VTOL GRD-PROXIMITY PROBS. EFF OF GRD ON AERO CHAR
	111	62	S	R	H	–	–						X		X												VTOL AIRCRAFT IN GRD PROXIMITY. GRD EROSION, RECIRCULATION, AND PRESS DISTRIB ON AIRCRAFT
	112	63	DJ	E	H	M	WT	X							X												SINGLE- AND DOUBLE-JET MODELS. GRD EFF ON PERF
	113	62	–	E/A	H/T	M	WT								X												INVESTIGATION OF V/STOL MODEL TESTING FOR GRD EFF
	114	63	DJ/L+P	E/A	LS/H	M	WT								X												RECIRCULATION PROB OF JET-LIFT AIRCRAFT FLYING OR HOVERING IN WIND IN GRD PROXIMITY
	143	60	–	E/A	ST	M	ST	X							X												MULTIPLE LIFTING JETS
	147	65	JF	E/A	LS	M	WT								X			X	X								SEMISPAN JET-AUGMENTED-FLAP MODEL, WITH AND WITHOUT GRD BOARD
	153	63	FIF	E/A	LS	M	WT	X					X		X			X									AERO CHAR IN GRD EFF. DOWNWASH AT HORIZ TAIL PLUS AREA INDICATED
	168	66	TW/DSS	E/A	LS	M	WT	X							X		X										AERO CHAR OF LARGE-SCALE MODEL OF 4-PROP TILT-WING CONFIG.GRD EFF
	214	66	DJ/L+f	E/T/A	H	M	ST						X		X												LIFT LOSS DUE TO SUCTION PRESS INDUCED BY ENTRAINMENT OF VERTICAL EFFLUX FROM LIFTING JETS. HOVERING IN AND OUT OF GRD
	223	67	DP	E/A	H/T/C	M	WT								X			X						X			LONG. AERO CHAR IN GRD EFF.3 GRD HEIGHTS. VTOL AND STOL OPERATION
	230	67	TW/DSS	E/A	LS	M	WT	X							X			X	X					X			LONG, LAT, AND CONT CHAR OF 4-PROP TILT-WING MODEL IN GRD EFF. RECIRCULATION EFF. MOVING-BELT GRD PLANE. THOROUGH REPT

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.5 (CONT)	231	67	TW	E/A	T	M	WT	X							X		X	X									GRD EFF ON TILT-WING AIRPLANE
	234	62	FIW	E/A	H	M	ST		X						X												GRD EFF ON FAN-IN-WING CONFIG
	239	62	FIW	E/A	ST	M	ST	X							X												WING SIZE VARIED
	247	61	TW	E/A	H/T	M	WT	X							X			X	X								A0-1 CONVERSION TO 4-PROP TILT-WING AIRCRAFT (MOHAWK). AERO CHAR INCLUDING GRD EFF
	251	61	DSS/BLC	E/A	S	M	WT	X							X			X	X								6-PROP VTOL MODEL
	252	66	TW	E/A	H	M	ST	X					X		X				X					X			GRD EFF ON PLAIN, SINGLE-SLOTTED, AND DOUBLE-SLOTTED FULL-SPAN FLAPS USED FOR YAW CONTROL
	272	62	S	T/A/R	LS	–	–								X												LINEARIZED THEORY OF WIND-TUNNEL JET-BOUNDARY CORRECTIONS AND GRD EFF INTERFERENCE FACTORS AS A FUNCTION OF WAKE DEFLECTION
	294	57	JF	E/A	LS	M	WT					X	X		X												GRD EFF ON HIGH-LIFT COEFF OF A JET-FLAP AIRFOIL
	296	60	TW/DSS	E/A	ST	M	ST	X					X		X												
	314	63	FIW/ DJ/L+P	R/O	H/T/C	–	–								X									X	X		DESIGN OPTIMIZATION OF V/STOL DIRECT-LIFT TRANSPORT. DESIGN PROBS OF PROPULSION, HANDLING QUALITIES, TRIM IN HOVER AND TRANSITION, GRD EFF
	332	64	FIW	E/A	H/T	M	WT	X							X			X	X					X			LARGE-SCALE INVESTIGATION OF FIW CONCEPT. GEN AERO CHAR IN AND OUT OF GRD EFF
	357	56	DSS	E/A	ST	C	ST	X	X	X				X	X												EFF OF GRD PROXIMITY AND PROP POSITION ON EFFECTIVENESS OF TURNING THE PROP SLIPSTREAM
	360	61	DSS	E/A	S	M	WT	X							X				X								LAT STAB AND CONT CHAR INCLUDING EFF OF GRD PROXIMITY ON A 4-PROP DSS AIRCRAFT
	361	60	DSS	E/A	S	M	WT	X							X			X									LONG AERO CHAR INCLUDING EFF OF GRD PROXIMITY ON A 4-PROP DSS AIRCRAFT
	368	60	TW	E/A	T	M	WT								X			X									LONG AERODYNAMICS OF 3 PROP-DRIVEN VTOL AIRCRAFT. GRD EFF
	371	67	FIW	E/PR/A	H/T/C	PM	F								X		X								X		FLT EVALUATION OF XV-5A HANDLING QUALITIES
	374	68	L+P	E/A	H/LS	PM	ST	X							X												EXHAUST GAS INGESTION CHAR AND INDUCED AERODYNAMICS FOR VTOL FIGHTER MODEL IN GRD PROXIMITY. STATIC TEST OF FULL-SCALE AIRCRAFT
	375	67	L+P	E/A	H	M	S								X												PARAMETRIC DATA ON GAS INGESTION AND JET EFF IN JET-POWERED VTOL VEHICLES IN GRD PROXIMITY
	378	67	[illegible]	T	LS	–	–								X												LINEAR-THEORY SOLUTION FOR JET FLAPS IN GRD EFF
	379	67	JF	T/A	LS	–	–								X												LINEAR THEORY FOR JET FLAP IN GRD EFF. GEN LINEAR CASE OF AN ARBITRARY AIRFOIL AND JET COEFF
	392	64	DF/ FIW/FIF	E/A	H/LS	M	WT/ST								X												FLOW UNDER NORMALLY IMPINGING JET INVESTIGATED. PROPERTIES OF FLOW NEAR GRD. ROTORS AND DUCTED FANS
	427	65	JF	A	LS	M	WT	X					X		X												DATA ANALYSIS OF SEMISPAN VTOL MODEL. INTEGRATED PROPULSION-LIFTING SURF. FLOW ANGULARITY MEAS AT TAIL
	433	66	JF	T	LS	–	–								X												THEOR CONSIDERATIONS OF FLOW PATTERN OF THIN JET-FLAPPED 2-DIM WING IN GRD EFF
	434	65	FIW	A	–	–	–																				METHOD FOR STUDYING EFF ON AERO CHAR OF WINGS OF LIFTING-PROPULSION DEVICES. STAB AND CONT, GRD EFF, AND W-T CORRECTIONS

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.5 (CONT.)	446	57	TW	E/A	ST	M	ST	X							X												4-PROP CONFIGURATION
	447	57	TW/DJ	E/A	H	M	WT	X							X												QUANTITATIVE MEASURE OF GRD EFF ON 2 JET VTOL AIRCRAFT
	448	60	TW+E DJ	E/A	H	M	ST	X							X												INCLUDES TUFT STUDIES
	456	62	TW	E/A	H	M	ST								X												SLIPSTREAM FLOW AROUND VZ-2, X-18, AND ARB CONFIG
	492	64	TF	E	H	M	WT								X												FULL-SCALE, HALF-MODEL SIMULATION OF A DUAL TANDEM DUCTED-PROP AIRCRAFT. DOWNWASH ALLEVIATION
	494	68	TW/DSS	E/A	T	M	T/WT	X							X												XC-142A MODEL. GRD EFF ON LONG FORCES AND PITCH MOM
	532	59	S	E/A	S	S	F								X												GRD INTERFERENCE STUDY
	538	68	DJ/L+P	R	H/LS	–	–								X												TABULAR SURVEY OF 132 REPORTS ON GRD EFF ON JET LIFT V/STOL AIRCRAFT. REGION OF DEFLECTED JET DESCRIBED
	546	69	DJ/L+P	E/A	H	M	ST	X							X												JET-INDUCED LIFT EFF ON VTOL AIRCRAFT. JET DECAY PROFILES NOZZLE LAT SPACING. 5 JET ARRANGEMENTS
	550	69	DJ/L+P	E/T/A	H/LS	M	WT/ST								X												THEOR AND TEST DATA FOR CIRCULAR, SUBSONIC JETS. AERO EFF SINGLE AND MULTIPLE JETS IN AND OUT OF GRD. INFLUENCE OF EXTERNAL FLOWS
	561	63	DF	E/A	H	M	WT	X							X			X	X								TRENDS IN LIFT, PITCH MOM, AND ROLLING MOM DUE TO GRD EFF
	563	53	DJ	E	H	M	ST						X		X												GRD EFF ON SIMPLE JET EXHAUSTING BENEATH A FLAT SURFACE
	566	60	DSS/JF	E/A	ST/LS	M	WT	X	X	X			X		X					X							AERO CHAR OF A COMBINATION OF JET-FLAP AND DEFLECTED-SLIPSTREAM CONFIG
	585	68	L+F	E/A	H/T/C	M	WT	X							X			X	X								XV-4B. POWERED INTERFERENCE EFF IN AND OUT OF GRD IN LANGLEY LOW-SPEED TUNNEL BASIC DATA IN CRUISE IN LANGLEY HIGH-SPEED TUNNEL
	593	68	–	T/A	T	–	–								X			X	X	X							DEVEL OF DYN MODEL FOR ANALYZING V/STOL TRANSPORTS IN LOW-ALT TURBULENCE IN TRANSITION. FACTORS AFFECTING RESPONSE TO TURBULENCE
	616	62	F-W	E/A	H	M	WT	X							X												GRD EFF ON PERF OF LIFTING FAN
	617	61	JF	E	LS	M	WT SIM		X				X		X												FREE-FLT INVESTIGATION TO EVALUATE GRD EFF ON JET-FLAPPED WING
	624	66	DJ/L+P	E/A	LS	M	WT	X							X		X	X						X	X		EFF OF GRD AND JET FREE-STREAM INTERFERENCE ON LONG CHAR
	625	64	L+P	E/A	LS	M	WT	X							X			X									INTERFERENCE EFF BETWEEN LIFTING JETS, FREE-STREAM VELOCITY, AND MODEL SURFACES AT LOW FWD SPEEDS. EFF ON LONG AERO CHAR. VARIOUS JET CONFIG AND WING HEIGHTS GRD EFF
	628	57	JF	E/A	LS	C	WT	X	X						X			X									FLOW-FIELD CHAR AND GRD INFLUENCE ON MODEL WITH JET-AUGMENTED FLAPS. DOWNWASH AND DOWNWASH GRADIENTS
	629	57	–	E/A	ST	C	ST								X												GRD EFF ON CIRCULAR AND ANNULAR NOZZLES
	632	69	TW	R/D	H/T/C	–	–								X		X										TECH AND OPERATIONAL LESSONS FROM XC-142 PROGRAM. W-T and FLT-TEST RESULTS COMPARED. PROP PITCH MOM AT HIGH INFLOW ANGLES
	653	66	S	R/D	H/T/C	–	–																				V/STOL AERO RESEARCH AT RAE. 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAPS, GRD SIM, W-T TEST TECHNIQUES
	654	62	JF	T/A	LS	–	–								X												A FORMULA DERIVED BY CONFORMAL TRANSFORMATION FOR LIFT INDUCED BY 90° JET FLAP IN GRD EFF. COMPARISON WITH OTHER THEORY AND EXPERIMENT

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two Dimensional Data	Pressure Data	Max Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.5 (CONT)	669	69	L+P	E/A	T/C	M	WT								X			X	X					X			LONG AND LAT-DIR CHAR OF JET-LIFT MODEL GRD EFF. CONTROL EFFECTIVENESS. EFF OF POWER VARIATION OF LIFT JETS
	671	63	L+P	E/A	H/LS	M	WT								X												SHORT SC-1. THRUST LOSS AS FUNCTION OF WING HEIGHT ABOVE GRD FOR JET-LIFT SCHEMES. THRUST LOSS REDUCTION
	678	64	L+P	E/A	H	M	ST								X		X										INLET TEMPERATURE RISE IN GRD EFF AND ITS EFF ON LIFT
5.6	175	58	–	T/A	S	–	–														X		X				
	210	61	–	E/A	H/T	SIM	SIM																X		X		GYROSCOPIC CROSS COUPLING, PITCH-ROLL
	211	61	–	E/A	H/T	SIM	SIM																X		X		GYROSCOPIC CROSS COUPLING, PITCH-YAW
	222	63	TS/DSS	PR	S	P	F	X							X			X		X	X		X				X-13 AND VZ-3
	554	58	TS	E/A	H/T	PM	WT										X						X				X-13
	630	63	–	A/D	H/LS	–	–										X				X		X				STAB DUE TO GYROSCOPIC FORCES
5.7	16	63	TW	A/E	H/T	–	–											X	X	X	X		X	X	X		MECHANICAL GYROSCOPIC STABILIZER APPLIED TO TILT-WING VTOL AIRCRAFT. DESIGN CRITERIA. PERF. DESIGN FEATURES
	18	61	–	DS	H/T	–	–											X			X						FEASIBILITY STUDY
	24	66	FIW	E/PR/A	H	SIM	SIM														X	X					XV-5A FLT SIMULATOR STUDY OF HOVERING IN GUSTY COND. OPTIMIZATION OF STAB AUGMENTATION GAINS
	53	61	–	D	N/T	–	–														X						V/STOL CONT SYS DESIGN
	67	65	DP	D	H/T/C	–	–											X	X	X	X	X		X	X		DESCRIPTION OF X-22A VAR STAB SYS
	178	60	–	A	H	–	–														X						
	177	62	–	A/D	H	SIM/P	–														X						
	201	62	L+P	D	H/T	P	F	X													X			X			SHORT SC-1 CONTROL SYS
	202	60	L+P	A/T/E	H/T	P	F											X	X	X	X		X	X	X	X	SHORT SC-1
	285	60	S	A/E/PR	S	SIM	SIM														X	X					FACTORS AFFECTING PILOTED-FLT SIM. USE OF SIMULATORS TO STUDY FLT TECHNIQUES
	289	64	DJ/L+P	A	H	–	–																	X			"MIXED" CONT SYS TO HOVER UNSTABILIZED JET-LIFT AIRCRAFT. CONTROL SYS MOM A FUNCTION OF STICK POS AND RATE OF CHANGE OF STICK POS
	372	62	L+P	D	T	P	F														X						SHORT SC-1 "LIFT COMPENSATION"
	621	65	DJ	E/PR	H/LS	E	F												X					X			HOVERING VTOL AIRCRAFT (X-14A) WITH VARIATION IN CONT POWER AND STICK TRAVEL
	576	62	–	A	H/T	–	–														X						
	530	63	–	A/D	H/LS	–	–										X				X		X				STAB DUE TO GYROSCOPIC FORCES

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	AREAS OF INVESTIGATION OR ANALYSIS									STABILITY AND CONTROL									COMMENTS
								Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities Criteria	
5.8	10	62	–	D	LS	P	F	X									X	X					X			SKYLARK (SINGLE-ENGINE LIGHT AIRCRAFT)
	18	63	TW	A/E	H/T	–	–										X	X	X	X		X	X	X		MECHANICAL GYROSCOPIC STABILIZER APPLIED TO TILT-WING VTOL AIRCRAFT. DESIGN CRITERIA, PERF, DESIGN FEATURES
	21	63	–	D	H/T	SIM	SIM													X.			X			MECHANICAL V/STOL CONT SYS
	47	68	S	R/D/PR/A	S	–	–									X	X	X	X	X			X	X	X	AIRWORTHINESS STANDARDS FROM RECOMMENDATIONS OF AEROSPACE INDUSTRIES ASSN., FAA DRAFT DISCUSSED
	48	59	DP	T/E	H	C	ST	X			X															THRUST CONTROL BY RUDDERS AT DUCT OUTLETS
	84	64	DGS	A	LS	SIM	SIM										X		X		X		X	X		OTTER AIRCRAFT. SHORT-FIELD LDG CHAR OF STOL AIRCRAFT FROM PERF STUDIES, MANEUVER DYN ANALYSES, AND FLT SIM
	90	63	–	E/PR	H	M	F													X			X	X	X	CRITICAL DEMANDS ON VTOL ATTITUDE. APPLICATION OF MANEUVERING CRITERIA USING VAR-STAB AIRCRAFT
	98	64	–	R/A	LS	–	–																X			VTOL CONT CRITERIA. DATA FROM INDUSTRY AND NASA CORRELATED. COMPARISON WITH CRITERIA FROM HELICOPTER MIL SPEC, AGARD 408, AND MIL-F-8785
	124	68	S	R/A	H/T	–	–												X				X	X	X	DYN AND CONT REQUIREMENTS FOR VTOL, BASED ON HANDLING-QUALITY EXPERIMENTS. LONG HOVER AND TRANSITION
	127	59	S	D/A	H/T	P	F										X	X					X	X		SEVERAL TEST-BED AIRCRAFT
	142	63	S	A	H	–	–																X	X	X	HANDLING QUALITIES, EST OF CONT POWER, AND CONT THRUST REQ. CONTROL-SYS DESIGN CRITERIA
	150	66	FP	E/A	H/T	C	ST		X								X						X			MONOCYCLIC PROP PITCH FOR LONG CONT
	180	69	DJ	E/A/PR	H	P	F/SIM											X					X	X		X-14A. UTILITY OF DIRECT SIDE-FORCE MANEUVERING DEVICE FOR VTOL AIRCRAFT
	202	60	L+P	A/T	H/T	P	F										X	X	X	X		X	X	X	X	SHORT SC-1
	209	64	–	PR/A	LS/H	E	F																X	X		EFF OF STATIC DIR STAB ON HANDLING QUALITIES AND DIR SENSITIVITY AND DAMPING
	212	65	–	PR	H/C	E	F										X	X			X		X	X		SIM OF VTOL CONT REQUIREMENTS USING VAR-STAB HELICOPTER
	227	66	FIW/FIF	R/A	H/T	–	–										X	X	X	X	X		X	X		CLOSED-LOOP DYN RESPONSE OF VTOL AIRPLANE, PILOT, AND AUTOSTABILIZATION SYS SHOWING IMPORTANCE OF LOW-SPEED CONT REQUIREMENTS
	236	62	DJ	E/A	ST/LS	C	ST/WT																X			JET DEFLECTOR TESTS AND COMMENTS
	241	66	–	E/A	H	SIM	SIM														X		X	X		6°-OF-FREEDOM MOTION SIMULATOR FOR STUDYING CONT SYS REQUIREMENTS. SIMULATOR CHAR
	262	66	TW	* E/A	H	M	ST	X				X		X				X					X			GRD EFF ON PLAIN, SINGLE-SLOTTED, AND DOUBLE-SLOTTED FULL-SPAN FLAPS USED FOR YAW CONT
	267	64	S	R/D	H/LS	–	–													X			X			LOW-SPEED CONT SYS REQ FOR VTOL. GUIDANCE, FREQUENCIES, ATTITUDE CONT, GENERATION OF MOMENTS DISCUSSED. STABILIZATION DEVICES. CONT SYS OF GER VJ101 TILT-ENGINE CONFIG DESCRIBED
	288	64	DJ/L+P	A	H	–	–																X			"MIXED" CONT SYS TO HOVER UNSTABILIZED JET-LIFT AIRCRAFT. CONT-SYS MOM A FUNCTION OF STICK POS AND RATE OF CHANGE OF STICK POS.
	290	69	S	R/A	C/T/H	SIM	SIM													X	X		X	X	X	NO. AMER. ROCKWELL RESEARCH IN FLT-CONT AREA. STUDY OF VTOL FLT-CONT DESIGN WITH IFR CAPABILITY. LDG PROB FROM CONVENTIONAL FLT TO HOVER.
	313	59	TW	E/A	T	M										X							X			4-POINT CONTROL

* See table 9B for key to summary

TABLE 9-A (CONTD)*

								AREAS OF INVESTIGATION OR ANALYSIS																			
																	STABILITY AND CONTROL										
SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.8 (CONT)	336	61	DP	T	H/LS	–	–											X	X	X				X	X		HOVERING IN STILL AIR AND GUST COND, GLIDE APPROACHES AT LOW SPEED. DAMPING AND SENSITIVITY
	369	56	DSS	E/A	ST	C	ST	X	X	X								X						X			WING PLUS PROPS, LE SLAT
	382	65	–	A	LS	–	–														X			X			CONT PROBS OF LARGE V/STOL TRANSPORTS. CONT POWER REQ, THEIR INFLUENCE ON HARDWARE DESIGN AND AIRCRAFT WEIGHT
	384	68	L+P	E/A	T/LS	E	–																	X	X	X	VTOL HANDLING QUALITIES. CONT MODES COMPARED IN TERMS OF PILOT ACCEPTANCE AND CONT POWER REQ
	409	68	–	E/PR/A	H/LS	SIM	SIM											X	X	X	X			X	X	X	FLT-RESEARCH PROGRAM TO DETERMINE CONT POWER AND CONT SENSITIVITY REQ DURING VISUAL HOVER AND LOW-SPEED APPROACH (VAR-STAB HELICOPTERS)
	422	60	BLC	E/A/T	LS	M	WT	X					X					X	X					X			LIKE F-104. SEVERAL SPOILERS, 2 AILERON CONFIGS, 3 TAIL HEIGHTS
	481	62	TW	E/A	H/T	P	F																	X			AILERONS FOR YAW CONTROL (VZ-2)
	517	62	HL	D	LS	P	F											X	X					X	X		ULTRA LOW-SPEED CONT SYS
	522	62	DJ	E/A	H	P	E													X	X		X	X	X	X	HOVERING CONT REQUIREMENTS OF VAR STAB AND CONT.
	539	63	–	A	H	SIM	SIM											X	X	X	X	X		X	X	X	AUTOPILOT FOR VTOL HOVER CONT. CONT-SYS NONLINEARITIES. METHOD FOR ANALYZING STAB AND CONT CHAR OF AUTOPILOT
	564	67	–	E/A	LS	M	WT						X						X					X			JET AND FREE-STREAM INTERFERENCE EFF ON ROLL CONT OF V/STOL AIRCRAFT IN TRANSITION
	572	66	DP	E/A	H/T/C	M	WT	X			X						X	X	X					X			LONG AERO AND CONT CHAR OF DUCTED-PROP VTOL MODEL
	577	66	L+P	A	H	–	–																	X			~~PROPULSION SYS AND/OR CONT SYS INTERFACE FOR HOVER CONT CONCEPTS~~. USING LIFT + LIFT CRUISE PROPULSION
	593	68	–	T/A	T	–	–								X			X	X	X							DEVEL OF DYN MODEL FOR ANALYZING V/STOL TRANSPORTS IN A LOW-ALT TURBULENCE IN TRANSITION. FACTORS AFFECTING RESPONSE TO TURBULENCE
	614	62	DSS	E/A	T	P	F								X			X						X	X		LONG TRIM CHAR (VZ-3)
	643	64	–	R/D	H/T	–	–										X							X	X	X	QUALITATIVE DISCUSSION OF STAB AND CONT PROBS OF VTOL AIRCRAFT
	659	69	L+P	E/A	T/C	M	WT								X			X	X					X			LONG AND LAT-DIR CHAR OF JET-LIFT MODEL. GRD EFF CONT EFFECTIVENESS. EFF OF POWER VARIATION OF LIFT JETS
5.9	183	69	TW/DSS	E/A	LS	M	WT									X		X									LONG AERO CHAR,EFF OF PROP-ROTATION DIRECTION
	184	66	TW	E	LS	M	WT	X	X							X	X	X									EFF OF PROP-ROTATION DIRECTION, FLAPS, SLATS, AND FENCES ON AERO AND FLOW CHAR
	185	66	TW	E	LS	M	WT	X	X							X	X	X									EFF OF PROP-ROTATION DIRECTION, FLAPS, SLATS, AND FENCES ON AERO AND FLOW CHAR
	186	67	TW	E	LS	M	WT	X	X							X	X	X									EFF OF PROP-ROTATION DIRECTION, FLAPS, SLATS, AND FENCES ON AERO AND FLOW CHAR
	187	67	TW	E	LS	M	WT	X	X							X	X	X									EFF OF PROP-ROTATION DIRECTION, FLAPS, SLATS, AND FENCES ON AERO AND FLOW CHAR
	188	67	TW	E	LS	M	WT	X	X							X	X	X									EFF OF PROP-ROTATION DIRECTION, FLAPS, SLATS, AND FENCES ON AERO AND FLOW CHAR
	485	43	–	E/A	LS/C	M	F									X			X	X							EFF OF PROP-ROTATION DIRECTION ON LAT STAB CHAR

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.9 (CONT)	819	43	–	E/A	LS/C	PM	WT	X								X		X	X								EFF OF PROP-ROTATION DIRECTION ON STATIC STAB
	831	64	TW/DSS	E/A	T	M	F									X		X	X	X							DYN LAT STAB AND CONT. REMOTE-CONTROL MODEL.EFF OF WING STALLING AND STALL-CONTROL DEVICES
5.10	30	56	FP	R/D/A	LS	–	–		X	X				X													LIFT ON A WING IN PROP SLIPSTREAM
	59	69	DJ/L+P	T/A	H/T	–	–								X												SEMIEMPIRICAL APPROACH TO PREDICTING PERF LOSSES AND PITCH MOM. CAUSED BY JET INTERFERENCE
	61	66	TW/DSS	R/A	T	–	–																				WING STALL DURING TRANSITION, STALL-FREE TRANSITION, EFF OF SLIPSTREAM ON PITCH MOM
	129	63	TW/DSS	T	LS	–	–																				METHOD PREDICTING WING-SLIPSTREAM INTERACTIONS, LIFTING-SURFACE THEORY
	156	66	TW/DSS	T	H/T	–	–								X		X										WING LOADING OF ARBITRARY PLANFORM EQUAL TO OR LESS THAN SPAN OF PROP JET
	171	68	S	T	C/ST	–	–																				RESEARCH ON PROP FLOW FIELD ASSOCIATED WITH TYPICAL V/STOL OPERATIONS
	181	61	JF	E/A	LS	M	WT	X																			AERO FORCES AND MOM ON JET-FLAPPED WING IN PRESENCE OF PROP SLIPSTREAM AND FREE STREAM
	183	69	TW/DSS	E/A	LS	M	WT									X		X									LONG AERO CHAR, EFF OF PROP-ROTATION DIRECTION
	228	64	DSS	A	LS	–	–										X										AERO FORCES ON WING-PROP COMBINATIONS INCL SLIPSTREAM EFF THEORY APPLIED TO 2- AND 4-PROP V/STOL CONFIG
	293	65	DSS	A	LS	–	–																				EQ AND CHARTS FOR LIFT AND LONG - FORCE COEFFS OF WINGS IN PROP SLIPSTREAMS, SAMPLE CALCULATIONS
	311	58	DJ/L+P	E/A	LS	M	WT						X														FLOW IN JETS EJECTED NORMAL TO THE WIND
	382	65	DJ/L+P	R/D	H	–	–								X		X										AERO OF JET VTOL ENGINE INSTALLATIONS, JET INDUCED EFF. EFF OF GRD, JET WAKE, AND INLET LIP SHAPE
	388	66	DJ/L+P	R/D	T	M	WT	X									X										CHAR OF JET-POWERED VTOL FIGHTER CONFIGS. INTERFERENCE EFF DUE TO INTERACTION BETWEEN FREE STREAM AND JET WAKES
	400	69	DJ/L+P	E/A	LS	M	WT																				PATH AND SHAPE OF WAKE FROM A SINGLE JET EXITING AT LARGE ANGLES TO FREE STREAM
	404	65	DSS	E/T/A	LS	M	WT	X									X										AERO CHAR OF PROP-WING-FLAP SYS. EQ FOR EST AERO FORCES. PROP SLIPSTREAM EFF. COMPARISON OF TEST AND THEORY
	457	67	DSS	E/A	H/T	M	WT		X		X																WING WITH DUCTED FANS AND DOUBLE-SLOTTED FLAPS. DUCT POS AND DUCT EXIT CONFIG VARIED. FLAP TURNING EFFECTIVENESS
	477	60	FP	R/D	LS	–	–										X										PROP EFFECTS ON STAB AND CONT OF VTOL AIRCRAFT
	509	58	FP/TW	E/A	LS	–	–																				LIFT-GENERATING CAPABILITIES OF WINGS EXTENDING THROUGH PROP SLIPSTREAMS
	582	37	FP	A	LS	–	–		X	X																	METHOD CALCULATING INCR IN LIFT OF WING DUE TO PROP SLIPSTREAM. COMPARISON WITH TEST
	584	67	–	E/A	LS	M	WT						X						X					X			JET AND FREE-STREAM INTERFERENCE EFF ON ROLL CONTROL OF V/STOL AIRCRAFT IN TRANSITION
	612	63	FIF	E/A	LS	M	WT	X																			INTERFERENCE LOADS DUE TO INTERACTION BETWEEN MAINSTREAM AND EFFLUX EFF ON LIFT AND PITCH MOM.
	620	61	TW/DSS	E/A	LS	C	WT		X			X		X													EFF OF 2-DIM STREAM-SHEAR FLOW ON AIRFOIL MAX LIFT. PROP TO WING CHORD RELATIONSHIP

* See table 9B for key to summary

TABLE 9-A (CONTD)*

								AREAS OF INVESTIGATION OR ANALYSIS									STABILITY AND CONTROL										
SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulation	Gyroscopic Effects	Zero or Low Airspeed Control Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.10 (CONT)	622	60	–	T/A	–	–	–		X			X															2-DIM EFF OF SLIPSTREAM SHEAR ON AIRFOIL CHAR
	624	66	DJ/L+P	E/A	LS	M	WT	X							X		X	X						X	X		EFF OF GRD AND FREE-STREAM INTERFERENCE ON LONG CHAR
	656	62	TW/DSS	E/A	ST	M	ST							X													PROP SLIPSTREAM EFF OF 6-PROP VTOL MODEL AT STATIC THRUST
	660	63	TW/DSS	E/A	T	M	WT	X					X														EFF OF NONUNIFORM FLOW AND SLIPSTREAM – FREE STREAM INTERACTION ON WING AERODYNAMICS
	670	63	TW/DSS	T	H/T/C	–	–				X			X													LIFTING-SURFACE THEORY FOR WINGS EXTENDING THROUGH INCLINED JETS SPANWISE LIFT DISTRIBUTION AND INDUCED DRAG
5.11	1	67	–	E/A	ST/LS	M	ST/LS																				RECIRCULATION EFF OF VERT AND INCLINED JETS ON HORIZ SURF
	59	68	DJ/L+P	T/A	H/T	–	–								X												SEMIEMPIRICAL APPROACH TO PREDICTING PERF LOSSES AND PITCH MOMENTS CAUSED BY JET INTERFERENCE
	62	67	–	R/D	H/T	–	–																				AERO INTERFERENCE EFFECTS OF JET LIFT SYSTEMS
	63	68	L+P/DJ	R/A	H/T	–	–	X							X		X										PROPULSION-SYSTEM – AIRFRAME-INTERFERENCE EFF, LIFT-ENGINE-INLET-FLOW DISTORTION, EXHAUST GAS REINGESTION
	69	68	–	E/D	LS	–	–						X														COANDA EFF AT WIDELY SEPARATED DEFLECTION SURFACES
	81	64	DJ/L+P	E/A	H	M	WT						X														STATIC PRESS DISTRIB ON WALL AROUND A CIRCULAR JET EXHAUSTING NORMALLY FROM A PLANE WALL INTO AN AIRSTREAM
	82	63	DJ	A/T/E	H/LS	M	WT						X		X												FLOW FIELD UNDER A UNIFORM CIRCULAR JET NORMAL TO AND IMPINGING ON GRD. JET-GRD-PLANE INTERACTION
	99	69	DJ	E/A	T	M	WT	X					X														JET LOCATION INTERFERENCE EFF ON LONG AERO CHAR OF JET VTOL MODEL
	114	63	DJ/L+P	E/A	LS/H	M	WT								X												RECIRCULATION PROB OF JET-LIFT AIRCRAFT FLYING OR HOVERING IN WIND IN GRD PROXIMITY
	121	67	–	E/A	ST	M	ST																				RECIRCULATION EFF OF VERT JET DIRECTED DOWNWARD ON HORIZ SURF
	204	67	F/W	E/D/A	LS	M	WT	X																			INFLUENCE OF FAN EFFLUX FLOW ON LIFT AND PITCH MOMENTS OF FUS, WING, AND TAILPLANE
	206	67	–	–	–	–	–																				REVIEW OF JET-EFFLUX STUDIES. ANALYTICAL DESCRIPTION OF FLOW FIELD CREATED BY V/STOL AIRCRAFT
	214	66	DJ/L+P	E/T/A	H	M	ST						X		X												LIFT LOSS DUE TO SUCTION PRESS INDUCED BY ENTRAINMENT OF VERT EFFLUX FROM LIFTING JETS HOVERING IN AND OUT OF GRD
	240	67	F/W/F/F	E/A	LS	M	WT	X																			NACELLE WITH 2 LIFTING FANS IN TANDEM. EFF OF EFFLUX ON LIFT
	201	67	DJ/L+P	E/A	LS	M	WT																				HOT GAS INGESTION, AERO SUCK-DOWN, JET INTERFERENCE IN TRANSITION
	287	66	DJ/L+P	T/A	H/LS	–	–																				FORMULAS FOR APPROX CALC OF FLOW PHENOMENA FOR A TURBULENT JET COLLIDING WITH A FLAT SURF
	350	69	F/W/ DJ/L+P	A/D	H	–	–						X														JET LIFT AND/OR LIFT FAN V/STOL AERODYNAMICS ANALYZED. SIM MODEL OF JET EFFLUX SUPERIMPOSED ON REPRESENTATION OF VEHICLE GEOM. VORTEX LATTICE TECHNIQUE DISCUSSED, APPLIED TO P 1127. THEORY AND TEST COMPARED
	362	65	DJ/L+P	R/D	H	–	–								X		X										AERODYNAMICS OF JET VTOL ENGINE INSTALLATIONS. JET INDUCED EFF. EFF OF GRD, JET WAKE, AND INLET LIP SHAPE
	375	67	L+P	E/A	H	M	S								X												PARAMETRIC DATA ON GAS INGESTION AND JET EFF IN JET-POWERED VTOL VEHICLES IN GRD PROXIMITY

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Reversal Directional Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	COMMENTS
5.11 (CONT)	382	64	DP/ FIW/FIF	E/A	H/LS	M	WT/ST								X												FLOW UNDER NORMALLY IMPINGING JET INVESTIGATED. PROPERTIES OF FLOW NEAR GRD.ROTORS AND DUCTED FANS
	397	68	DJ/L+P	E/A	T	M	WT	X							X			X	X								AERO CHAR OF A 5-JET VTOL CONFIG. HORIZ-TAIL-POSITION EFFECTS. GRD PROXIMITY
	400	68	DJ/L+P	E/A	LS	M	WT																				PATH AND SHAPE OF WAKE FROM A SINGLE JET EXITING AT LARGE ANGLES TO FREE STREAM
	414	64	DJ/L+P	R/D	LS	–	–										X								X		AERODYNAMICS AND FLYING QUALITIES. JET INTERFERENCE. EFF OF MULTIPLE JETS AND WING PLANFORM. INLET EFFECTS. INGESTION.CONTROL POWER
	424	66	DJ/L+P	–	H	M	ST						X														JET INDUCED LIFT LOSSES OF JET-VTOL CONFIGURATIONS
	434	65	FIW	A	–	–	–																				METHOD FOR STUDYING EFF ON AERO CHAR OF WINGS IN VICINITY OF LIFTING PROPULSION DEVICES, STAB AND CONT, GRD EFF, AND W T CORRECTIONS
	464	62	DJ/L+P	E/A	H	M	WT	X										X									MUTUAL INTERFERENCE BETWEEN NOZZLE SYS, W-B COMBINATIONS, AND FREE STREAM. BASIC FUS PLUS SERIES OF WINGS. JET-INDUCED DOWNLOAD AND PITCH MOMENTS. OUT-OF-GRD EFF
	479	64	DJ/ L+P/FIW	E/A	LS	M	WT						X														MEAS OF PRESS ON WING SURF WITH A JET ISSUING NORMALLY FROM THE SURF INTO A MAINSTREAM
	537	67	DJ/L+P	A	H/LS	–	–																				METHOD OF SIMULATING 3-DIM ENTRAINING JET EXHAUSTING INTO LOW-VEL CROSS WIND. EFF OF ENTRAINMENT ON POTENTIAL FLOW FIELD
	544	62	DJ/L+P	T	H/LS	–	–								X												ANALYSIS OF JET – GRD-PLANE INTERACTION. (VERT AXISYMMETRICAL JET)
	546	69	DJ/L+P	E/A	H	M	ST	X							X												JET-INDUCED LIFT EFF ON VTOL AIRCRAFT. JET DECAY PROFILES. NOZZLE LAT SPACING. 5 JET ARRANGEMENTS
	550	69	DJ/L+P	E/T/A	H/LS	M	WT/ST								X												THEOR AND TEST DATA FOR CIRCULAR, SUBSONIC JETS. AERO EFF. SINGLE AND MULTIPLE JETS IN AND OUT OF GRD. INFLUENCE OF EXTERNAL FLOWS
	563	58	DJ	E	H	M	ST						X		X												GRD EFF ON SIMPLE JET EXHAUSTING BENEATH A FLAT SURFACE
	565	61	S	R/D	T	–	–										X	X									JET-INDUCED EFF. DUE TO JET EFFLUX
	569	61	DJ	E/A	H/T	M	WT	X							X												JET-INDUCED INTERFERENCE EFF. INTERACTION OF DEFLECTED JET WITH FREE STREAM AND GRD
	582	67	DJ/L+P	T	H	–	–								X												THEORY FOR OBLIQUE IMPINGEMENT OF STATIC ROUND JET ON GRD. VEL DISTRIB ALONG GRD AND ACROSS JET AXIS. THRUST RATIOS. COMPARISON WITH BENCH TEST
	585	66	L+P	E/A	H/T/C	M	WT	X							X			X	X								XV-4B. POWERED INTERFERENCE EFF IN AND OUT OF GRD IN LANGLEY LOW-SPEED TUNNEL. BASIC DATA IN CRUISE IN LANGLEY HIGH-SPEED TUNNEL
	609	62	FIF	E/A	H	M	WT	X										X									EFF OF FAN IN FUSELAGE ON LONG AERO CHAR
	625	64	L+P	E/A	LS	M	WT	X							X			X									INTERFERENCE EFF BETWEEN LIFTING JETS, FREE-STREAM VEL, AND MODEL SURFACES AT LOW FWD SPEEDS. EFF ON LONG AERO CHAR. VARIOUS JET CONFIGS AND WING HEIGHTS. GRD EFF
	626	65	DJ	E/A	T			X										X	X					X			LONG AND LAT-DIR CHAR OF TWO 4-JET VECTORED-THRUST-TYPE VTOL MODELS
	627	63	DJ/L+P	E/A	LS	M	WT						X														PRESS DISTRIB ON SURF OF FLAT PLATE INDUCED BY A ROUND COLD-AIR JET EXITING NORMAL TO LOW-SPEED FREE STREAM
	648	65	FIW/FIF/ L+P/DJ	R/A	S	–	–	X					X		X												AERO INTERFERENCE EFF THAT ARISE WITH JET AND LIFT-FAN V/STOL SCHEMES
	649	66	FIW/FIF/ L+P/DJ	R/A	H/T	–	–	X							X												AERO FEATURES DUE TO ADVERSE FLOWS INDUCED AROUND THE AIRFRAME
	667	66	DJ/L+P	R/A	H/LS	–	–	X							X		X										AERO INTERFERENCE EFF DUE TO JET EFFLUX. STATIC INTERFERENCE EFF. FWD-SPEED INTERFERENCE EFF. THEORY FOR JET-EFFLUX INTERFERENCE

* See table 9B for key to summary

TABLE 9-A (CONTD)*

SUBJECT INDEX CLASSIFICATION	REFERENCE NUMBER	YEAR OF PUBLICATION	V/STOL CONCEPT	NATURE OF REPORT MATERIAL	FLIGHT REGIME OR AIRFLOW	TEST ARTICLE	AREAS OF INVESTIGATION OR ANALYSIS: TYPE OF TEST	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	STABILITY AND CONTROL: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities Handling Qualities Criteria	COMMENTS
5.11 (CONT)	668	67	DJ/L+P	T	LS	–	–					X														INTERACTION BETWEEN A JET EXHAUSTING NORMALLY FROM A LIFTING SURF INTO A UNIFORM STREAM. COMPARISON WITH TEST
	669	69	–	T/E/A	LS	M	WT					X														POTENTIAL-FLOW MODEL OF A CIRCULAR JET ISSUING NORMALLY FROM AN INFINITE FLAT PLATE INTO A DEFLECTING STREAM. FLOW SURVEY. COMPARISON WITH TEST
5.12	16	64	–	R/D	S	–	–																			SEVERAL REPORTS ON V/STOL MODEL TESTING. WT, PRINCETON DYNAMIC MODEL TRACK, NASA TECHNIQUES
	74	69	TW/DSS	R/A	H/T/C	M/PM	WT/F																			W-T-FLT-TEST PROGRAM TO DETERMINE STATUS OF W-T TEST TECHNIQUES
	137	66	–	D	LS	–	–										X	X	X							DESCRIPTION OF PRINCETON DYNAMIC MODEL TRACK (VTOL MODEL TESTING)
	145	66	F/F	E/A	LS	M	WT	X					X				X	X						X			EFF OF SCALE AND TUNNEL WALLS ON AERO CHAR
	174	62	TW	E/A	T	M	WT	X																		W-T DATA CORRELATION
	250	66	TW/DSS	E/A	T	M	WT	X									X	X						X			TUNNEL-WALL EFF ON DEFLECTED-SLIPSTREAM AND TILT-WING MODELS
	272	62	S	T/A/R	LS	–	–								X											LINEARIZED THEORY OF W-T JET-BOUNDARY CORRECTIONS AND GRD EFF. INTERFERENCE FACTORS AS A FUNCTION OF WAKE DEFLECTION
	274	67	–	D	LS	–	–																			FEATURES TO BE CONSIDERED IN APPLYING WALL-INTERFERENCE CORRECTIONS TO V/STOL DATA
	275	68	–	R/D/T	LS	–	–																			W-T WALL EFF AT EXTREME FORCE COEFFS. EFF OF NONUNIFORM INTERFERENCE GRADIENTS
	279	66	S	R/D	T	M/PM	WT/F										X										CORRELATION OF W-T AND FLT-TEST DATA ON 5 V/STOL AIRCRAFT. W-T WALL CORRECTIONS. SIZING CRITERIA
	366	59	S	D	LS	–	–																			W-T WALL EFFECTS IN V/STOL TESTING FROM EXPERIENCE OF LANGLEY RESEARCH CENTER
	380	69	–	E/A	–	S	WT																			THEOR AND EXPERIMENTAL STUDY TO DEVELOP V/STOL W-T WALLS
	426	61	–	D	H/T/C	–	–																			WIND TUNNEL FOR LOW FWD SPEED, HOVER, AND TRANSITION TESTING
	428	67	–	D	H/T/C	–	–																			LARGE-SCALE, CANADIAN V/STOL TUNNEL
	440	66	DP	E/A	H/T	M	WT																			W-T BOUNDARY EFFECTS RELATED TO V/STOL DATA
	461	65	–	R/D	LS	–	–																			W-T BOUNDARY CORRECTIONS APPLICABLE TO VTOL MODEL TESTING
	471	64	L	A/R	LS	–	–												X							3 MODEL TEST TECHNIQUES USED BY NASA TO INVESTIGATE DYN STAB OF V/STOL MODELS, AND TEST RESULTS
	478	60	TW	R/D	H/T	–	–																			W-T TEST METHODS FOR POWERED V/STOL MODELS. PROP EFF ON STAB AND CONT OF VTOL AIRCRAFT
	582	68	S	D	S	–	–																			LOW-SPEED W-T DESIGN AND TECHNIQUES. SIZE AND TEST SECTION REQ. NEW TUNNELS
	611	68	–	R/T	H/T	–	–								X											TECHNIQUES FOR TESTING LIFTING-JET OR LIFTING-FAN MODELS
	662	64	–	T	LS	–	–								X											METHODS TO EXPEDITE W-T TESTING OF JET AND LIFT-FAN MODELS
	663	66	S	R/D	H/T/C	–	–																			V/STOL AERO RESEARCH AT RAE, 1962-66. JET LIFT, FAN LIFT, BLC, JET FLAPS, GRD SIM, W-T TEST TECHNIQUES

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	S&C: General	S&C: Longitudinal	S&C: Lateral-Directional	S&C: Dynamic	S&C: Stabilization	S&C: Simulations	S&C: Gyroscopic Effects	S&C: Zero or Low Airspeed Control/Systems	S&C: Handling Qualities	S&C: Handling Qualities Criteria	COMMENTS
5.13	14	66	S	R/D	H/T/C	–	–																				AERO PROBS AND REQ FOR V/STOL AIRCRAFT
	17	67	–	R/D	H/T/C	–	–																				SURVEY OF FLT MECHANICS OF VTOL AIRCRAFT, INCL TECHNOLOGY, EFF OF VEHICLE CHAR
	28	67	–	R/A	H/T/C	–	–																				SURVEY PAPERS, THRUST FOR HOVER CONTROL, GRD EFF, JET-INDUCED EFF, REINGESTION
	44	60	S	R/D	S	–	–										X										NASA-AMES RESEARCH THROUGH 1960
	54	68	S	R/A	H/T/C	–	–																				PROMISING V/STOL CONFIGS. LIFT SYS, PROPULSION, AIRFRAME SYS, DYN AND AERO CHAR, CONTROL SYS
	96	57	S	E/A	LS	M	WT		X			X															NATURE OF TURBULENCE IN WAKE OF 2-DIM AIRFOIL
	100	64	–	–	–	SIM	SIM																				METHODS OF MECHANIZING EQ OF MOTION USING ANALOG COMPUTER
	118	67	S	A	LS	–	–							X													METHODS PRODUCING HIGH LIFT, COMPARISON ON BASIS OF MAX LIFT
	263	60	S	A/R/D	H/T/LS	–	–																				EST OF V/STOL CHAR. INTERACTION BETWEEN LIFTING SYS AND PROPULSION WAKES. JET AND PROP SLIPSTREAM INTERACTIONS
	273	61	S	A	LS	–	–																				GEN NOMOGRAPHIC SOLUTION FOR INDUCED VEL AND WAKE SKEW ANGLE
	308	64	DSS/JF	R/D	LS	–	–											X	X					X			BASIC STOL PERF AND LOW-SPEED CONT AND HANDLING DEVEL. de HAVILAND AIRCRAFT CO
	338	61	S	R/A/D	S	–	–										X										SUMMARY OF VTOL STATE OF THE ART THROUGH 1961
	364	61	S	D	H/T/C	–	–																				PRINCIPLES OF V/STOL AERODYNAMICS REGARDING DESIGN FOR GOOD PERF
	508	60	DP/FP	A	LS	–	–																				PREDICTION OF OPTIMUM PERF CHAR
	510	59	S	T/A	LS	–	–																				LIFT-GENERATING SYSTEMS COMPARED. FIXED WING, ACTUATOR DISK, DUCTED PROP, ANNUAL WING. THEORY AND TEST COMPARED
	526	68	FIW/FIF	T	H/T	–	–	X					X														NUMERICAL SOLUTION OF 3-DIM INCOMPRESSIBLE FLOW PROBS, ITS APPLICATION TO V/STOL CONFIGS
	651	61	S	D	S	–	–										X										AERO ASPECTS OF V/STOL SYS. RESEARCH AT RAE THROUGH 1961, ESPECIALLY DIRECT-LIFT JET, PROP LIFT, JET FLAPS, BLC
	667	65	–	A	LS	–	–																				RELATIONSHIPS INVOLVED IN SHORTENING TAKEOFF AND LANDING DIST OF HIGH-SPEED AIRCRAFT
6.0	12	66	S	R/A/T/D	S	–	–	X	X		X			X			X										AERO PROBS OF V/STOL AIRCRAFT
	13	66	S	R/A	S	–	–																				RECOMMENDATIONS FOR V/STOL AERO RESEARCH
	20	66	S	S	H/T/C	S	S				X				X		X					X			X		PAPERS OF VTOL-STOL CONF, 1966
	23	64	S	A/R	S	–	–			X	X				X					X					X	X	RESEARCH AND RECOMMENDATIONS ON V/STOL AERODYNAMICS
	32	60	S	S	S	S	S	X							X		X	X	X	X	X	X		X	X	X	NASA CONF ON V/STOL AIRCRAFT (26 PAPERS)
	37	61	S	BIB	S	–	–																				NASA V/STOL REPT, BIBLIOGRAPHY AND V/STOL TRANSPORT STUDY

* See table 9B for key to summary

TABLE 9-A (CONTD)*

Subject Index Classification	Reference Number	Year of Publication	V/STOL Concept	Nature of Report Material	Flight Regime or Airflow	Test Article	Type of Test	Areas of Investigation or Analysis: Force and Moment	Wing	Free Propeller	Ducted Propeller	Two-Dimensional Data	Pressure Data	Max. Lift or Turning	Ground Effect	Propeller Rotation Direction Effects	Stability and Control: General	Longitudinal	Lateral-Directional	Dynamic	Stabilization	Simulations	Gyroscopic Effects	Zero or Low Airspeed Control/Systems	Handling Qualities	Handling Qualities Criteria	Comments
SC (CONT)	38	59	S	BIB	S	P	F	X									X								X		3 ARTICLES ON V/STOL. NASA BIBLIOGRAPHY. REF 37
	46	60	S	S	S	S	S	X							X		X										AGARD SYMPOSIUM ON V/STOL AIRCRAFT
	50	66	S	R	S	–	–																				DDC VTOL BIBLIOGRAPHY, 1953 – JUNE 1966
	51	68	S	R	S	–	–																				DDC VTOL BIBLIOGRAPHY. EXPERIMENTAL VTOL MODELS, XV-5, XC 142, X-22, ETC., 1953 – JUNE 1968
	54	68	S	R/D	H/T/C	–	–										X							X	X		VTOL STATE OF THE ART, LIFT SYS, PROPULSION, AIRFRAME SYS, DYN AND AERO CHAR, CONT SYS OF PROMISING VTOL CONFIGS
	76	63	S	BIB	S	–	–																				V/STOL LITERATURE SURVEY COVERING 1961-62
	77	61	S	BIB	S	–	–																				AGARD V/STOL BIBLIOGRAPHY THROUGH 1960
	320	60	S	E/A/D	S	M	WT																				LARGE-SCALE, W T STUDIES OF VTOL TYPES. NASA CONF ON V/STOL AIRCRAFT
	343	60	JF	R/BIB	LS	–	–	X																			DETAILED JET FLAP REVIEW, THEORIES, DATA BIBLIOGRAPHY
	352	68	S	BIB	S	–	–																		X		VTOL FLYING-QUALITIES BIBLIOGRAPHY
	405	67	S	T/E/A/D	S	–	–																				CLASSROOM TEXT ON AERODYNAMICS OF V/STOL FLIGHT
	527	59	DP	R/BIB	S	–	–	X			X																REVIEW AND BIBLIOGRAPHY
	533	61	BLC/JF	S	LS	S	S	X							X												AERO ASPECTS OF V/STOL AIRPLANES
	538	68	DJ/L+P	R	H/LS	–	–								X												TABULAR SURVEY OF 132 REPORTS ON GRD EFF OF JET-LIFT V/STOL AIRCRAFT. REGION OF DEFLECTED JET
	586	62	–	BIB/D	LS	–	–																				BIBLIOGRAPHY OF PRINCETON LOW-SPEED WORK

* See table 9B for key to summary

9.1 FREE-PROPELLER CHARACTERISTICS

The methods of this Section are for estimating forces and moments on propellers. The primary purpose of this work is to provide information for analysis of direct propeller effects during the transition flight phase of V/STOL aircraft.

Operation of a propeller in an unsymmetrical flow field results in unsymmetrical loading on the blades as a function of their rotational position, which, in turn, produces forces normal to the thrust axis resulting in pitching and yawing moments. Flow field asymmetries result from either thrust-axis tilt or from flow angles induced by the airplane lifting surfaces. The propellers on V/STOL aircraft will encounter greater asymmetries than those of conventional aircraft because of the greater thrust-axis tilt and greater induced upwash of more effective high-lift devices.

Methods for the prediction of forces and moments on propellers inclined with respect to the free stream are developed by DeYoung in reference 1. DeYoung has generalized existing small-incidence theory (references 2 and 3) using a propeller solidity based on average blade chord. Simple expressions are thus developed for propeller normal (or side) force and some of the principal derivatives. DeYoung develops these expressions by first determining approximate equations of propeller geometry and operating parameters from the theory presented by Ribner in references 2 and 3, and then establishing by statistical means the equation constants and slightly altered functions from computed data of given blade shapes.

DeYoung also derives expressions for the ratio of normal force at high incidence to normal-force derivative at zero incidence, and the ratios of thrust, torque, and power at high incidence to the zero-incidence values.

Reference 5 presents results of a propeller test for three full-scale propellers of different design at nine angles of incidence ranging from 0 to 85 degrees. The operating conditions were selected to simulate the take-off, landing, and transition regimes of V/STOL aircraft. From the data of this reference certain generalizations can be made regarding propeller characteristics likely to be encountered in transition flight. It is shown that the thrust coefficients for given values of blade angle and advance ratio are nearly constant over a large range of thrust-axis angles of attack and that this range decreases with increasing advance ratio. Furthermore, it is shown that, over the same range of thrust-axis angles, the variations of propeller normal force and pitching moment are nearly linear. Using these generalizations it is possible to present approximate methods for the estimation of propeller forces and moments at large angles of inclination from experimental data at small angles of inclination for certain transition programs.

A general notation list is included in this Section for all free-propeller Sections.

The positive direction of forces and moments is shown in figure 9.1-4.

Notation List

A	wing aspect ratio
a_o	blade section lift-curve slope, per rad
B	number of blades

Notation List (continued)

b'	propeller blade chord, ft
$\bar{b}'$	average blade chord, ft
$b'_{.25, .50,}$	blade chord at $\frac{r}{R} = .25, .50, \cdots$, ft
C_N'	normal-force coefficient based on free-stream velocity and propeller disk area, $\frac{N}{q_\infty S_p}$
C_N	normal-force coefficient, $\frac{N}{\rho n^2 D^4} = \frac{\pi J^2}{8} C_N'$
C_T	thrust coefficient, $\frac{T}{\rho n^2 D^4} = \frac{\pi J^2}{8} T_c$
c_r	wing root chord, ft
D	propeller diameter, ft
J	advance ratio, $\frac{V_\infty}{nD}$
J'	modified advance ratio, $J \cos \alpha$
J_{o_T}	advance ratio at zero thrust
J_{o_P}	advance ratio at zero power
N	propeller normal force, lb
n	propeller rotational speed, rps
q_∞	free-stream dynamic pressure, lb/sq ft
R	propeller radius, ft
R_{fus}	maximum fuselage radius forward of propeller plane
r	radial distance to blade element, ft
S_p	propeller disk area, $\frac{\pi}{4} D^2$, sq ft
T	propeller thrust, lb
T_c	thrust coefficient based on free-stream velocity and propeller disk area, $\frac{T}{q_\infty S_p} = \frac{8}{\pi J^2} C_T$
x	longitudinal coordinate measured positive forward from wing leading edge, ft
y	lateral coordinate measured positive to right of plane of symmetry, f
Δ_y	lateral distance from thrust axis of one propeller blade to element of another, ft

V_∞	free-stream velocity, ft/sec
α	wing angle of attack measured from zero lift, deg
α_{in}	inflow angle at propeller disk, deg
β	blade angle at .75R blade station, deg
$\epsilon_{z_{slip}}$	upwash induced by propeller slipstream, positive downward, deg
σ	propeller solidity, ratio of blade element area to annulus area at .75R
σ_e	effective propeller solidity (propeller solidity based on average blade chord)
δ_f	force phase angle, deg

Subscripts

α_{in}	differentiation with respect to inflow angle, α_{in}
$L_{.75}$	left blade position at three-quarters radius point
$R_{.75}$	right blade position at three-quarters radius point
fus	fuselage

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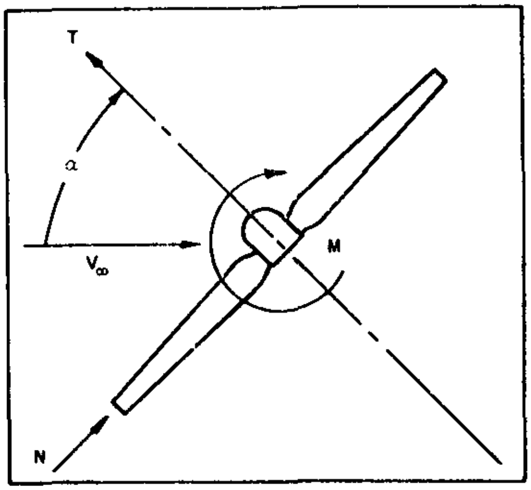

FIGURE 9.1-4 CONVENTIONS USED TO DEFINE POSITIVE SENSE OF FORCES AND MOMENTS

9.1.1 PROPELLER THRUST VARIATION WITH ANGLE OF ATTACK

Two methods are presented in this Section for estimating the thrust of a propeller at high angles of incidence. The first method is that of reference 1 and provides thrust relative to the zero-incidence value. This ratio is approximately proportional to the square of the tangent of the angle of incidence with a constant advance ratio, determined from the velocity normal to the propeller disk. In the theory the thrust is represented by the phase-angle change of the resultant velocity at the blade and takes into account both the angle-of-attack changes and the dynamic-pressure changes. A 90-degree incidence level is formulated from helicopter theory to provide a relatively small correction to the propeller theory. This thrust ratio is dependent on blade angle and advance ratio but, except for a small dependence on solidity, is independent of propeller geometry.

In the absence of complete data on a particular propeller, a second method is given that can be used to approximate the thrust at large incidence angles from experimental data at small incidence angles. This approach is formulated in reference 2, wherein it is demonstrated that certain VTOL transition programs can lie within the region of linear slope of the propeller forces and moments.

The methods presented herein are for an isolated propeller where the thrust-axis angle of attack is the angle between the free-stream velocity and the propeller thrust axis. For airplane installations this angle is often affected by flow induced by the wing, fuselage, and other propellers; however, the results of references 3 and 4 indicate that the major effects of induced flow on propeller thrust occur under conditions that are not likely to be of practical interest (high forward speed at high angles of attack).

DATCOM METHODS

Method 1

The variation of propeller thrust with angle of attack is given relative to the value at zero angle of attack, provided equal advance ratios exist as determined from the velocity normal to the propeller disk. This thrust ratio is given in reference 1 as

$$\frac{C_T\ (\alpha, J')}{C_T\ (0, J')} = 1 + \frac{3\left(\frac{J'}{J_{O_T}}\right)^2}{4\left(1 - \frac{J'}{J_{O_T}}\right)} \sin(\beta + 5) \Bigg[\tan\ (\beta + 5)$$

$$+ \sigma_e \left(1 + \sqrt{1 + \frac{2}{\sigma_e} \tan\ (\beta + 5)}\right)(1 - \cos\alpha)\Bigg] \tan^2\alpha \qquad \text{9.1.1-a}$$

where all parameters are defined in the general notation list of Section 9.1 and the positive direction of forces and angles is shown in figure 9.1-4.

The procedure to be followed in evaluating equation 9.1.1-a is outlined in the following steps.

Step 1. Determine the propeller effective solidity σ_e by

$$\sigma_e = \frac{b'}{b'_{.75}} \sigma = \frac{4B\bar{b}'}{3\pi D} \qquad 9.1.1\text{-b}$$

where

$\bar{b}' = \frac{1}{0.8} \int_{.2}^{1} b' \, dx'$, which may be approximated by

$$\bar{b}' = 0.16 \left(\frac{5}{4} b'_{.25} + 2b'_{.50} \; ' \; 2b'_{.75} + b'_{.95} \right) \qquad 9.1.1\text{-c}$$

$b'_{.25, .50, \ldots}$ are obtained from the propeller blade planform curve at $\frac{r}{R} = 0.25, 0.50, \ldots$

Step 2. The advance ratio at zero-thrust J_{O_T} is obtained from figure 9.1.1-7 as a function of β. This functional relationship is given in reference 1 as

$$J_{O_T} = 2.2 \tan(\beta + 5) \qquad 9.1.1\text{-d}$$

Step 3. Using equation 9.1.1-a obtain $\frac{C_T(\alpha,J')}{C_T(0,J')}$ with the σ_e and J_{O_T} values obtained in Steps 1 and 2. With this result values of the thrust ratio can be computed for a range of angles of attack and modified advance ratios.

Step 4. Determine the propeller thrust coefficient at selected angles of attack and modified advance ratios by

$$C_T(\alpha,J') = \frac{C_T(\alpha,J')}{C_T(0,J')} C_T(0,J')$$

where $C_T(0,J')$ is the propeller thrust coefficient at zero angle of attack, but with the velocity equal to $V_\infty \cos \alpha$. This parameter will normally be a known quantity.

Figures 9.1.1-8a-g and 9.1.1-11a-d present a comparison of experimental data from reference 2 with the Datcom method as computed from equation 9.1.1-a.

Method 2

This method is suggested in reference 2 for estimating propeller thrust at high angles of attack when experimental data at zero angle of attack are available.

The experimental data of reference 2 show that the thrust coefficient for given values of blade angle and advance ratio is practically constant over a wide angle-of-attack range at low advance ratios, and that this range diminishes with increasing advance ratio. Using these observations, it is possible to identify these ranges in VTOL transition programs.

The boundary of this region, presented in figure 9.1.1-13, has been determined on the basis of five-percent thrust-coefficient increases from the zero-angle-of-attack values for two propellers at a constant blade angle, tested in reference 2. The region varies with blade angle. The boundary curve of figure 9.1.1-13 is defined for a 12-degree blade angle, typical for maximum propeller efficiency in very low-speed flight. The characteristics of the two test propellers are presented in table 9.1.1-A.

As a simple rule of thumb, the propeller thrust at high angles of attack may be assumed to equal the value at zero angle of attack if the modified advance ratio falls below the boundary of figure 9.1.1-13.

A 1-g transition program for a hypothetical airplane described in reference 3 is also shown in figure 9.1.1-13. This program is based on the data obtained for propeller 1 of reference 2. The modified advance ratio lies well below the boundary curve. However, for conditions of steep descent or rapidly decelerating transition the boundary could be exceeded.

Sample Problem

Method 1

Given: The three-bladed propeller designated as propeller number 1 of reference 2. The following example is based on four values of the modified advance ratio over a thrust-axis angle-of-attack range from 0 to 85°.

$B = 3$ $D = 12$ ft $\beta = 12^\circ$

r/R	0.25	0.50	0.75	0.95
b', ft	0.89	1.115	1.175	1.18

J'	0.1	0.2	0.4	0.6
$C_T(0,J')$	0.132	0.121	0.083	0.032

Compute:

Step 1. Determine the effective propeller solidity σ_e.

$$\bar{b}' = 0.16\left[\frac{5}{4}b'_{.25} + 2b'_{.50} + 2b'_{.75} + b'_{.95}\right] \quad \text{(equation 9.1.1-c)}$$

$$= 0.16\left[\frac{5}{4}(0.89) + (2)(1.115) + (2)(1.175) + 1.18\right]$$

$$= 0.16\,(6.87) = 1.10$$

$$\sigma_e = \frac{4B\bar{b}'}{3\pi D} = \frac{(4)(3)(1.10)}{(3)(12)\pi} = 0.117 \quad \text{(equation 9.1.1-b)}$$

Step 2. Determine the advance ratio at zero-thrust J_{O_T} from figure 9.1.1-7 at $\beta = 12^\circ$.

$$J_{O_T} = 0.6725$$

Solution:

Determine the ratio of the thrust coefficient at inclination to the thrust coefficient at zero angle of incidence.

$$\frac{C_T(\alpha,J')}{C_T(0,J')} = 1 + \frac{3\left(\frac{J'}{J_{O_T}}\right)^2}{4\left(1 - \frac{J'}{J_{O_T}}\right)} \sin(\beta + 5)\Big[\tan(\beta + 5)$$

$$+ \sigma_e \left(1 + \sqrt{1 + \frac{2}{\sigma_e}\tan(\beta + 5)}\right)(1-\cos\alpha)\Big] \tan^2\alpha$$

(equation 9.1.1-a)

$$= 1 + \frac{3\left(\frac{J'}{0.6725}\right)^2}{4\left(1 - \frac{J'}{0.6725}\right)} \sin(17)\Big[\tan(17)$$

$$+ 0.117\left(1+\sqrt{1+\frac{2}{0.117}\tan(17)}\right)(1-\cos\alpha)\Big] \tan^2\alpha$$

$$= 1 + \frac{6.64\,J'^2}{4 - 5.95J'}(0.2924)\Big[0.3057 + 0.409(1-\cos\alpha)\Big]\tan^2\alpha$$

$$= 1 + \frac{1.939J'^2}{4 - 5.95J'}\Big[0.3057 + 0.409\,(1-\cos\alpha)\Big]\tan^2\alpha$$

Using this result obtain $\frac{C_T(\alpha,J')}{C_T(0,J')}$ as a function of J' and α. This is calculated below for seven angles of attack. Note that at $J' = 0$, $\frac{C_T(\alpha,J')}{C_T(0,J')} = 1.0$; and at

$$J' = J_{O_T}, \quad \frac{C_T(\alpha,J')}{C_T(0,J')} \longrightarrow \infty$$

①	②	③	④	$\left[C_T(\alpha,J')/C_T(0,J')\right] - 1$						
				$\alpha=85°$	79.5°	75°	67.5°	60°	45°	30°
J'	$4-5.95J'$	$1.939J'^2$	③ / ②	88.68 ④	18.63 ④	8.465 ④	3.252 ④	1.531 ④	.4255 ④	.1206 ④
.05	3.7025	.0048	.00130	.1152	.0244	.0111	.0042	.0020	.00056	.00016
.10	3.405	.0194	.00570	.505	.1062	.0482	.0185	.0087	.0024	.00069
.15	3.1075	.0436	.01404	1.245	.2619	.1190	.0456	.0215	.0060	.0017
.20	2.810	.0776	.02760	2.447	.5142	.2336	.0898	.0423	.0117	.0033
.30	2.215	.1745	.07879	6.987	1.468	.6669	.2562	.1206	.0335	.0095
.40	1.620	.3102	.1915	16.983	3.568	1.621	.6228	.2931	.0815	.0231
.50	1.025	.4848	.4729	41.934	8.811	4.003	1.538	.7239	.2012	.0570
.60	0.430	.6980	1.6233	143.95	30.24	13.740	5.279	2.485	.6907	.1958
.65	0.1325	.8192	6.1829	548.30	115.19	52.340	20.107	9.464	2.631	.7457

The calculated values of the thrust ratio are compared with the experimental results from reference 1 in figure 9.1.1-14.

The thrust coefficient at angle of inclination and given advance ratio is then

$$C_T(\alpha,J') = C_T(0,J') \; \frac{C_T(\alpha,J')}{C_T(0,J')}$$

	$C_T(\alpha,J')$			
α	J'=.1	J'=.2	J'=.4	J'=.6
0	0.132	0.121	0.083	0.032
30	0.1321	0.1214	0.0849	0.0383
45	0.1323	0.1224	0.0898	0.0541
60	0.1331	0.1261	0.1073	0.1115
67.5	0.1344	0.1319	0.1347	0.2009
75	0.1384	0.1493	0.2175	0.4717
79.5	0.1462	0.1832	0.3791	0.9997
85	0.1987	0.4171	1.4926	4.6384

The calculated values of the thrust coefficients are compared with the experimental results from reference 1 in figure 9.1.1-15. The results may be converted to thrust in pounds by

$$-T(\alpha,J') = \frac{8}{\pi(J')^2} \, C_T(\alpha,J') \; q_\infty \, S_p$$

REFERENCES

1. DeYoung, J.: Force and Moment Derivatives Due to Propellers of Arbitrary Configuration Inclined with Respect to Free Stream. AIAA Preprint No. 64-169, 1964. (U)

2. Yaggy, P. F., and Rogallo, V. L.: A Wind-Tunnel Investigation of Three Propeller Through an Angle-of-Attack Range From 0° to 85°. NASA TN D-318, 1960. (U)

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TABLE 9.1.1-A
Reference 2

Propeller	No. 1 Curtiss C6345-C500	No. 2 Curtiss C6345-C300
Diameter	12.0 ft	10.0 ft
No. of blades	3	3
Airfoil section	NACA 16 series	NACA 64 series
Blade designation	858-7C4-36	X100188
Activity factor/blade	150	188
Solidity	0.124	0.183

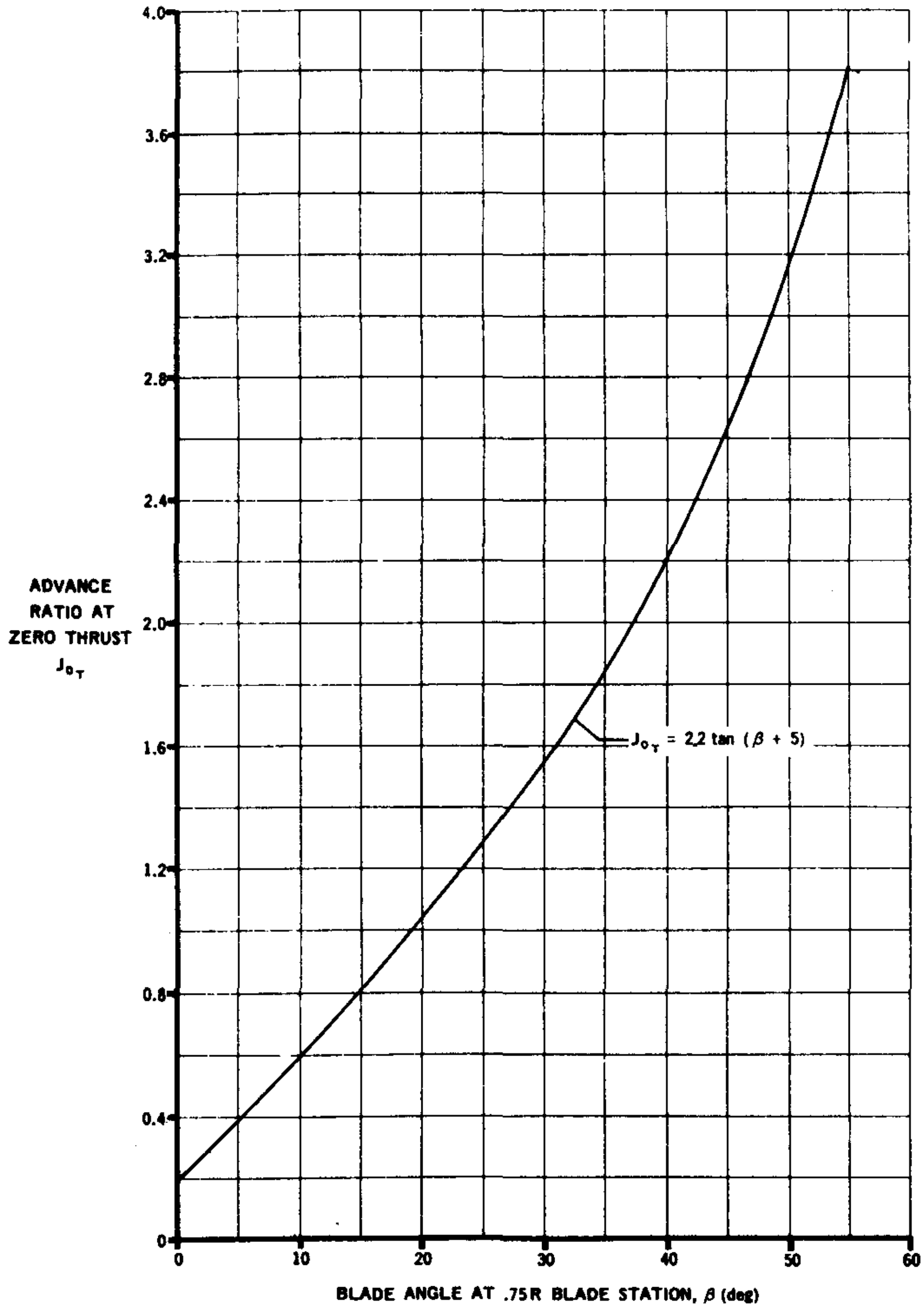
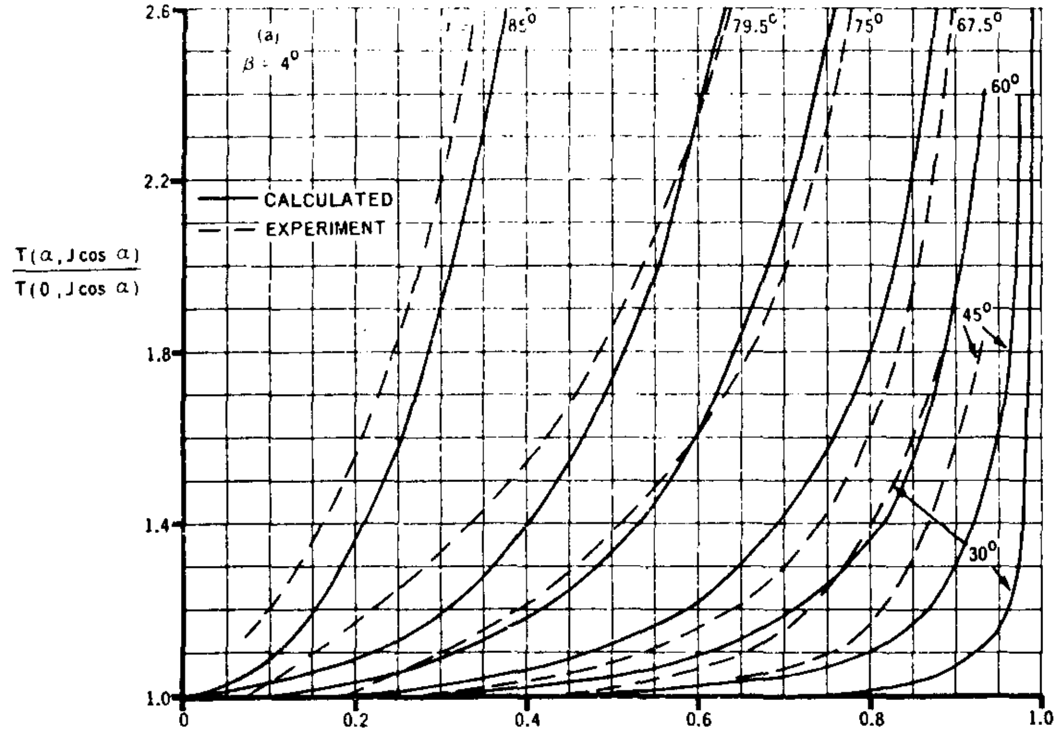


FIGURE 9.1.1-7 ADVANCE RATIO AT ZERO THRUST



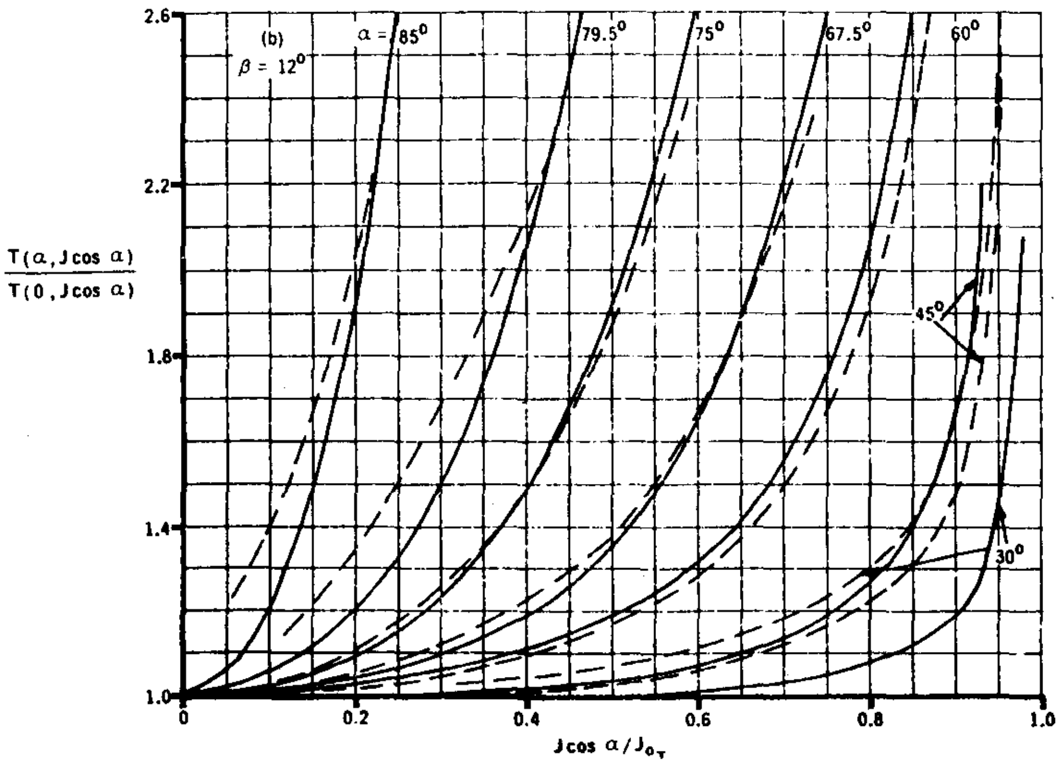
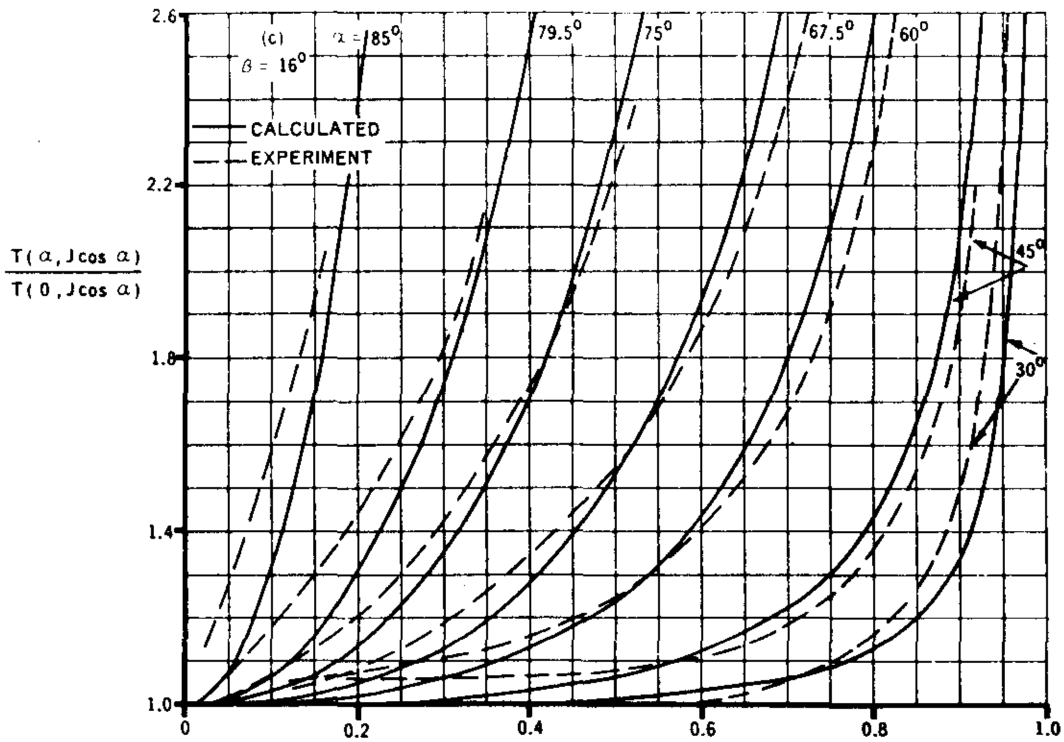


FIGURE 9.1.1-8 COMPARISON OF CALCULATED AND EXPERIMENTAL RATIOS OF THRUST AT PROPELLER THRUST-AXIS ANGLE OF ATTACK TO THRUST AT ZERO THRUST-AXIS ANGLE OF ATTACK FOR PROPELLER 1 OF REFERENCE 2



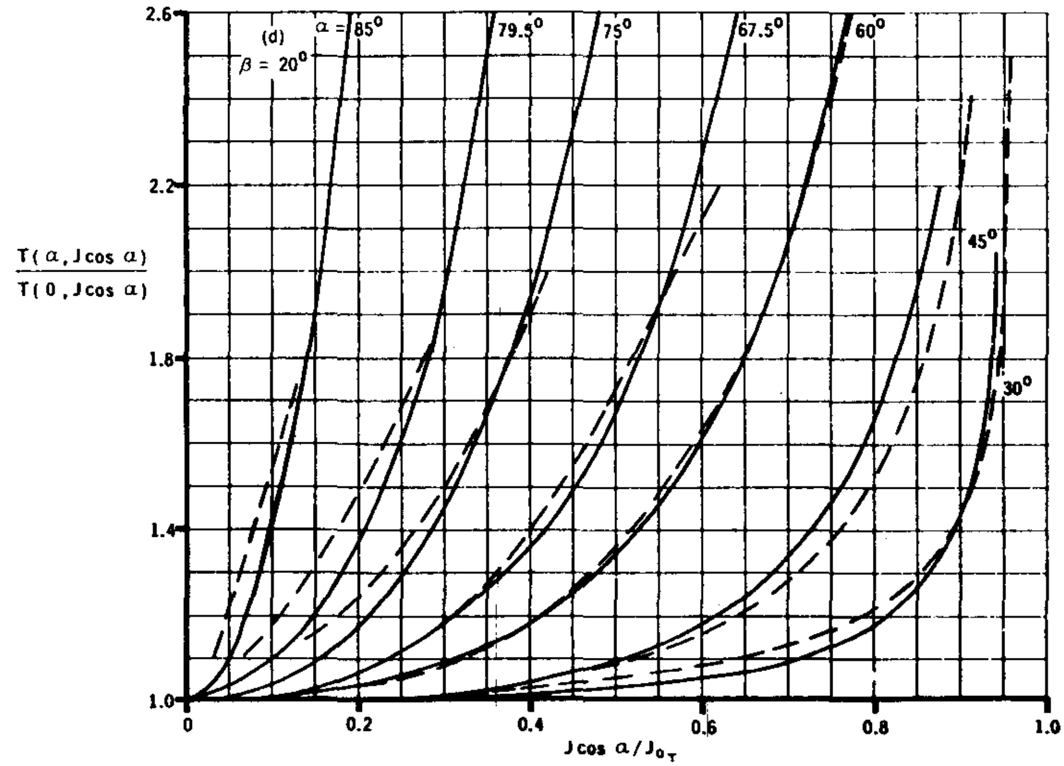


FIGURE 9.1.1-8 (CONTD)

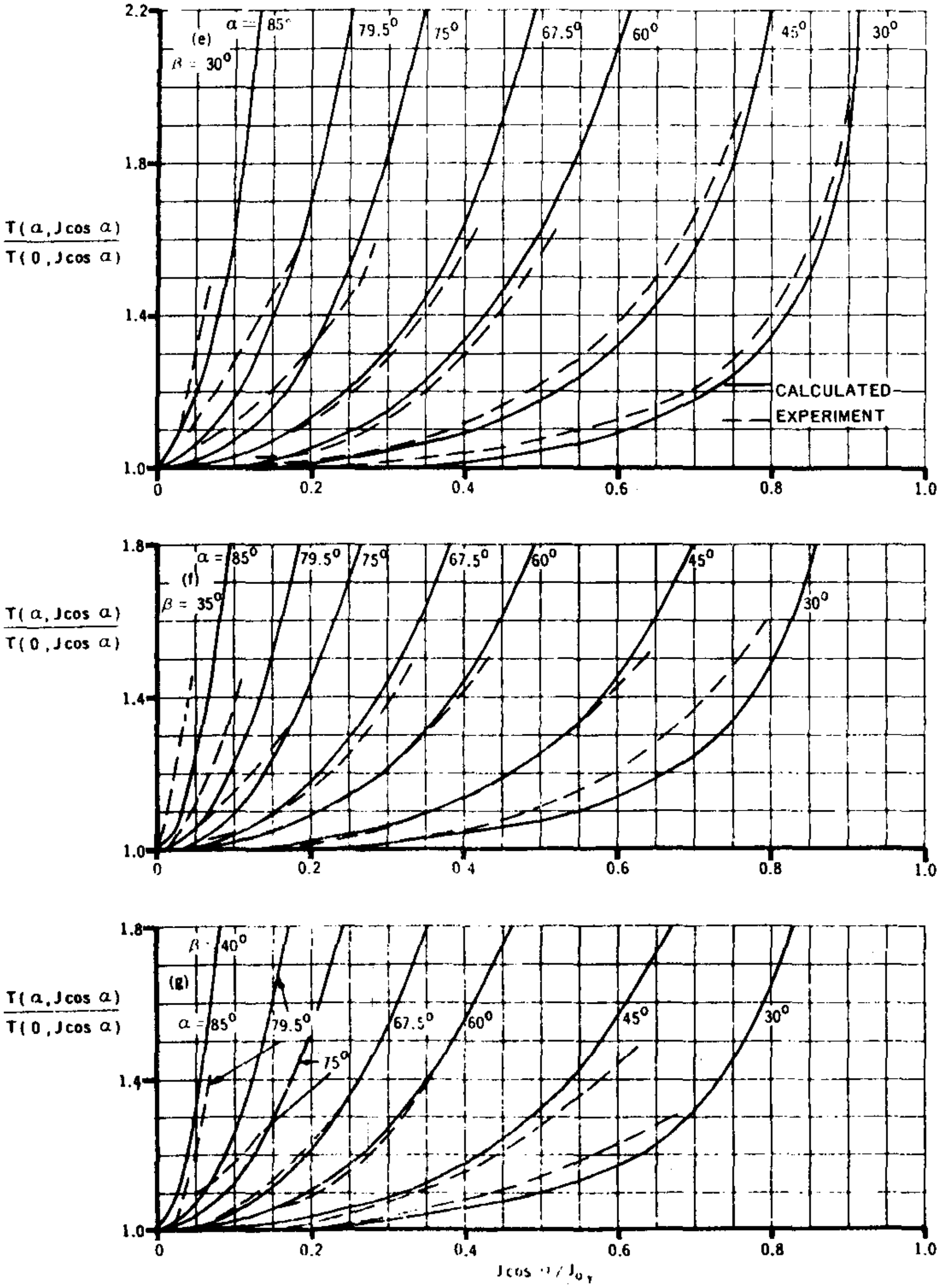


FIGURE 9.1.1-8 (CONT'D)

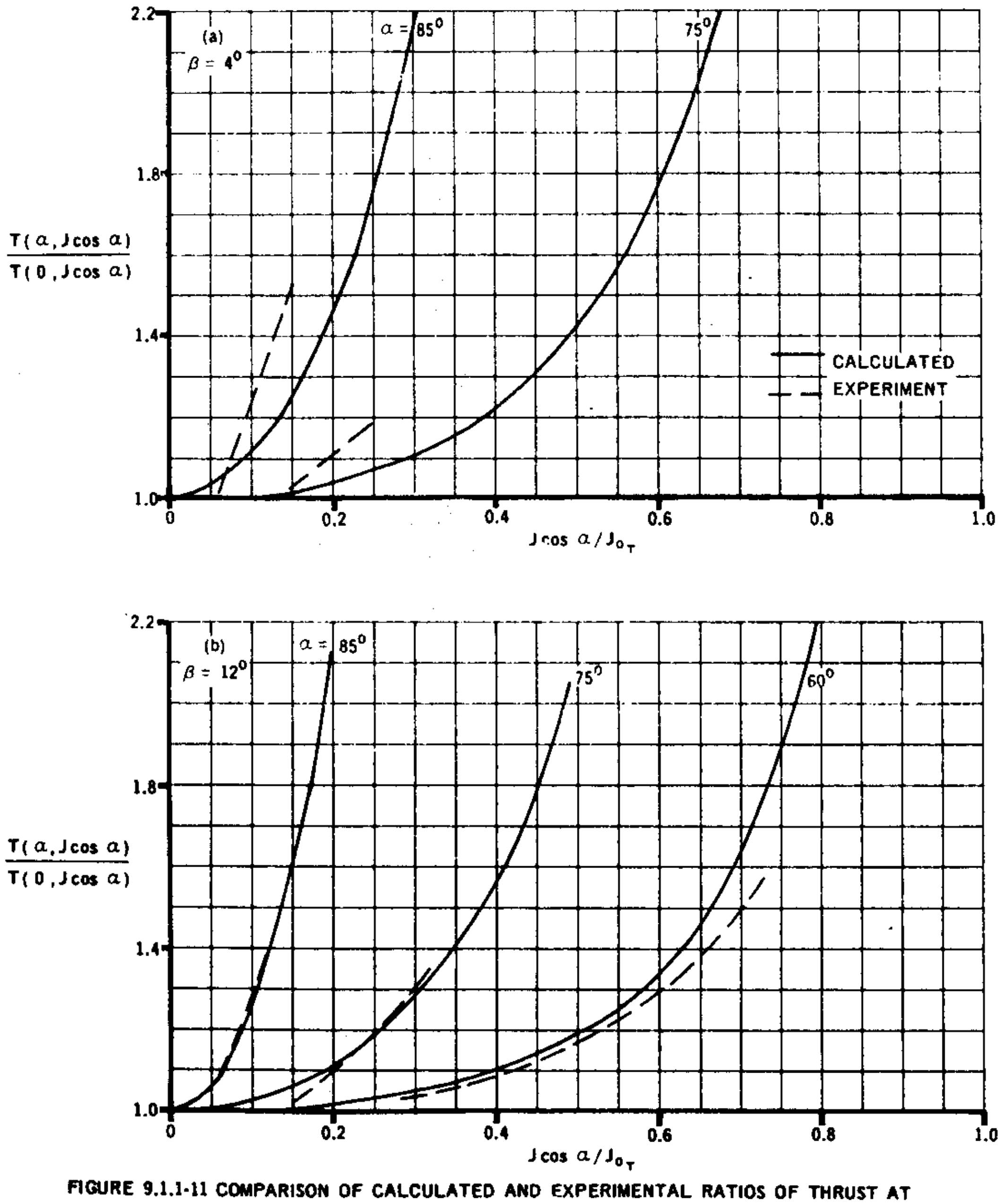


FIGURE 9.1.1-11 COMPARISON OF CALCULATED AND EXPERIMENTAL RATIOS OF THRUST AT PROPELLER THRUST-AXIS ANGLE OF ATTACK TO THRUST AT ZERO THRUST-AXIS ANGLE OF ATTACK FOR PROPELLER 2 OF REFERENCE 2

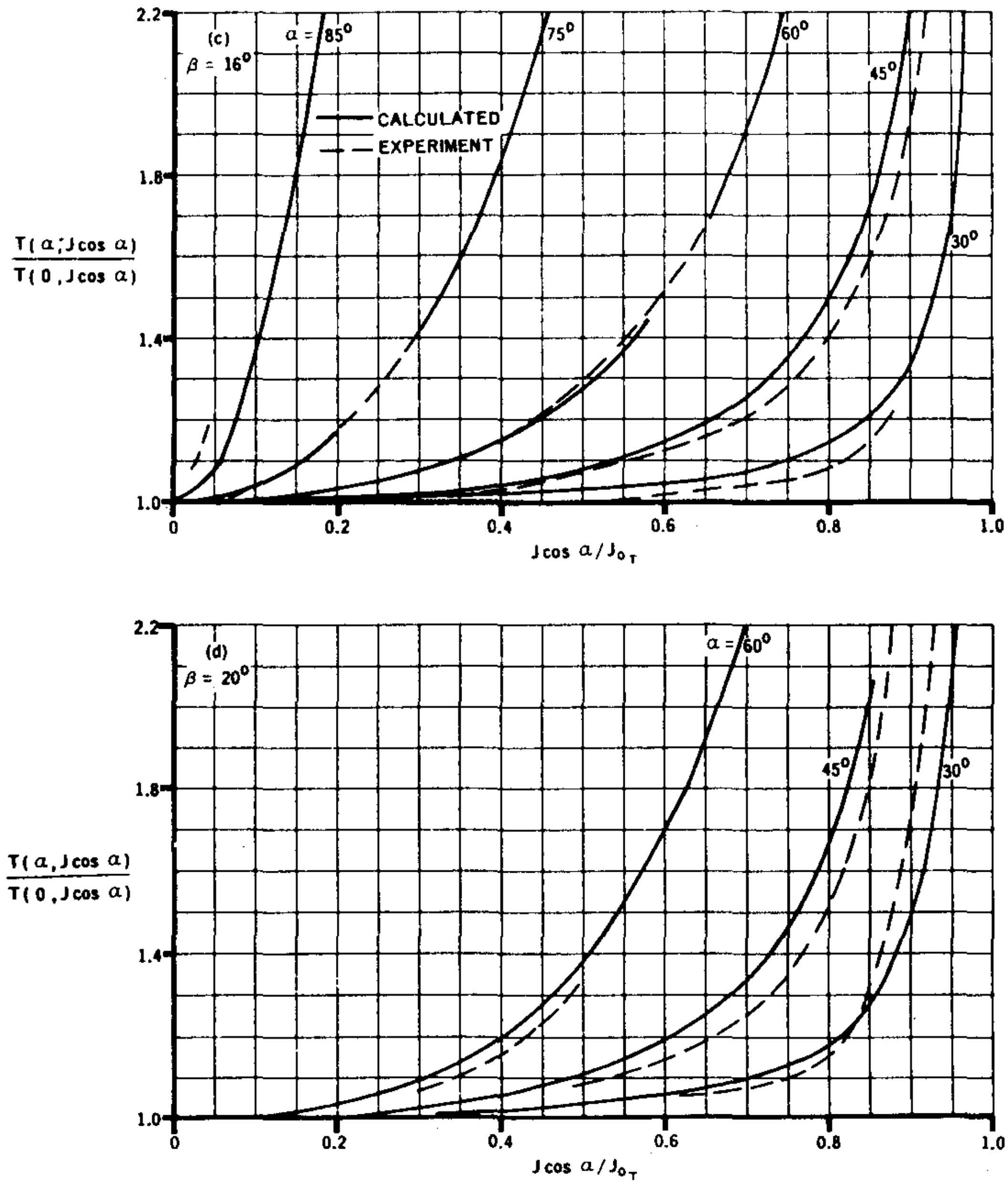


FIGURE 9.1.1-11 (CONTD)

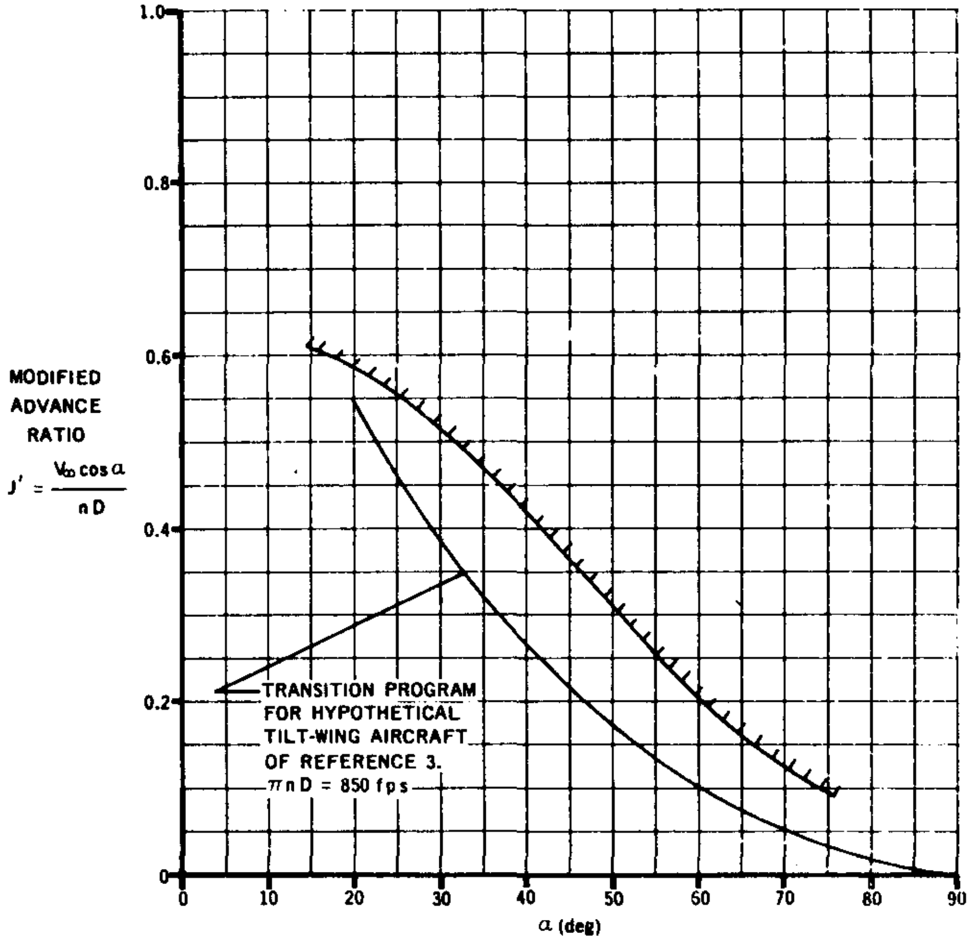


FIGURE 9.1.1-13 BOUNDARY CURVE FOR 5-PERCENT INCREASE OF COEFFICIENT OVER VALUE AT ZERO THRUST-AXIS ANGLE OF ATTACK

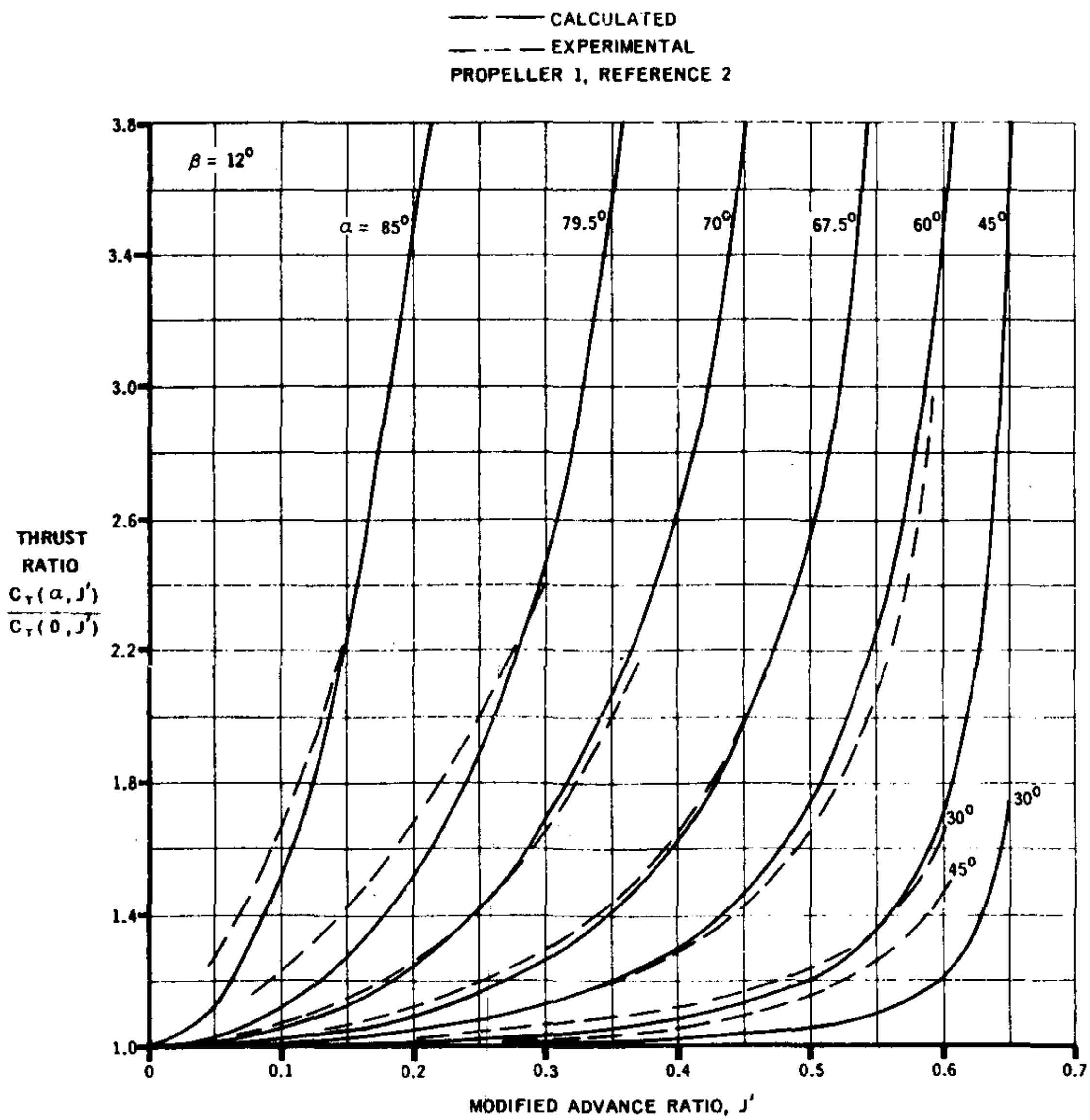


FIGURE 9.1.1-14 DATCOM METHOD 1 SAMPLE PROBLEM RESULTS

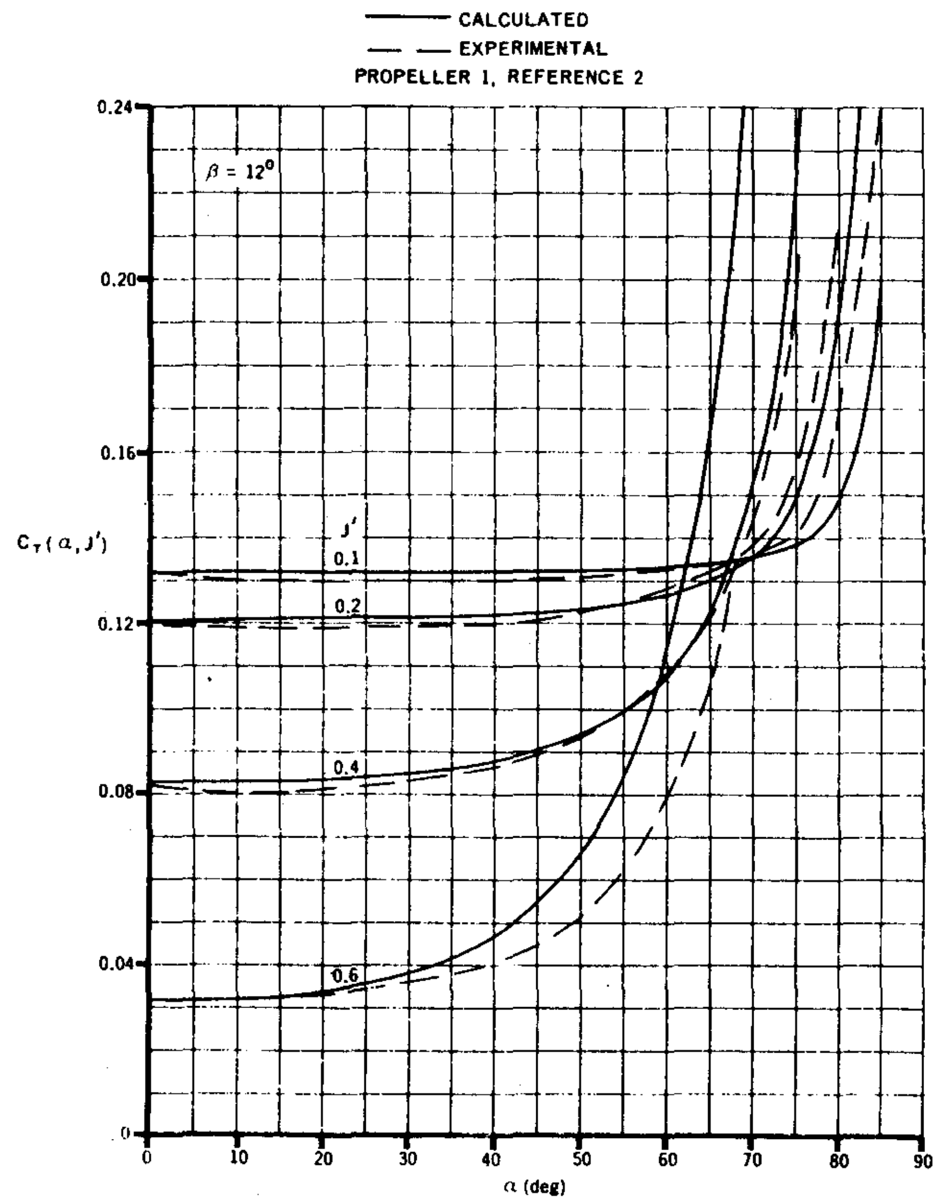


FIGURE 9.1.1-15 DATCOM METHOD 1 SAMPLE PROBLEM RESULTS

9.1.2 PROPELLER PITCHING-MOMENT VARIATION WITH POWER AND ANGLE OF ATTACK

At the present there are no theoretical or semi-empirical methods available in the literature for the prediction of propeller pitching moments at high angles of attack. The method presented herein is empirical and requires experimental data at two moderate angles of attack.

Experimental data indicate that there is an appreciable direct pitching moment on the propeller during operation at angle of attack. This pitching moment may be regarded as being due to the fact that the center of thrust is some distance away from the center of rotation. Figures 9.1.2-3 and 9.1.2-4 show the direct propeller pitching moment expressed as an effective thrust-axis shift for the propeller and the propeller-wing combination of reference 1 and for propeller 1 of reference 2, respectively. These data indicate an increase in propeller pitching moment with increasing angle of attack and a more pronounced shift of the effective thrust axis at the lower thrust coefficients. The data of figure 9.1.2-3 further show that the propeller pitching moment was approximately doubled when the propeller was operated in the presence of the wing because of the upwash induced by the wing.

The Datcom method which follows is based on observations of the large body of test data presented in reference 2.

DATCOM METHOD

This method is suggested in reference 2 for estimating propeller pitching moment at high thrust-axis angles of attack when experimental data are available at two angles of attack, such as zero and 15 degrees.

The experimental data of reference 2 show that the propeller pitching moment for given values of blade angle and advance ratio have nearly a constant slope over wide angle-of-attack ranges at low advance ratio and that the width of these ranges diminishes with increasing advance ratio.

It is not possible to define the limits of the regions of linearity of propeller pitching moments from the experimental data as was done for the propeller thrust in Section 9.1.1. However, in view of the fact that the angle-of-attack ranges of pitching-moment linearity are essentially those over which the thrust is constant, it is assumed that, to a first approximation, the boundary, defined in figure 9.1.1-13, also applies to pitching moments. As noted in Section 9.1.1, this boundary varies with blade angle. It is defined for a blade angle typical of maximum propeller efficiency in very low-speed flight.

As a simple rule of thumb, the propeller pitching moment at high angles of attack may be obtained with accuracy acceptable for preliminary design analysis by a linear extrapolation of experimental data at moderate angles of attack, provided the modified advance ratio falls below the boundary of figure 9.1.1-13 .

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1. Draper, J. W., and Kuhn, R. E.: Investigation of the Aerodynamic Characteristics of a Model Wing-Propeller Combination and of the Wing and Propeller Separately at Angles of Attack Up to 90°. NACA TN 3304, 1954. (U)

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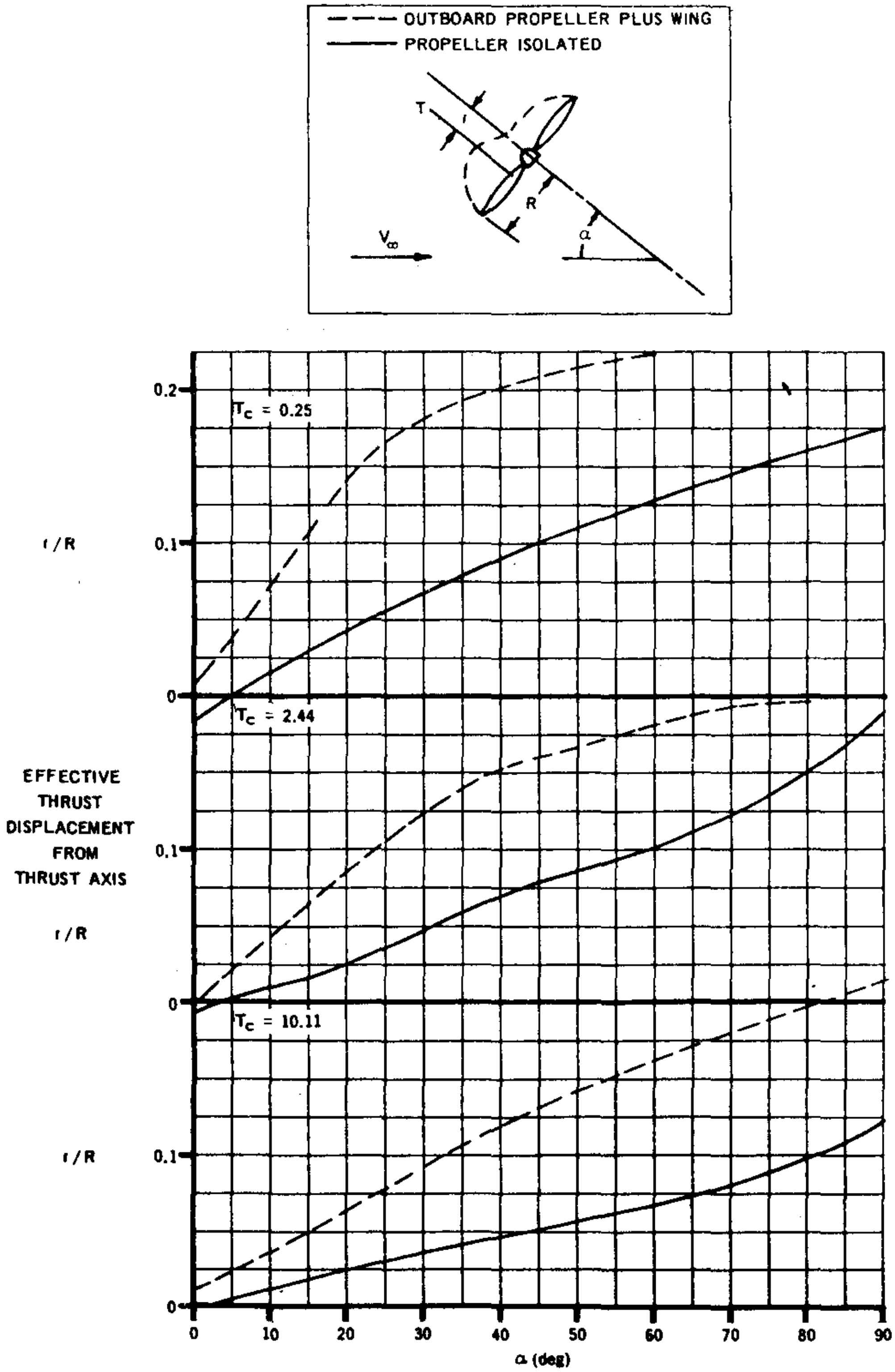
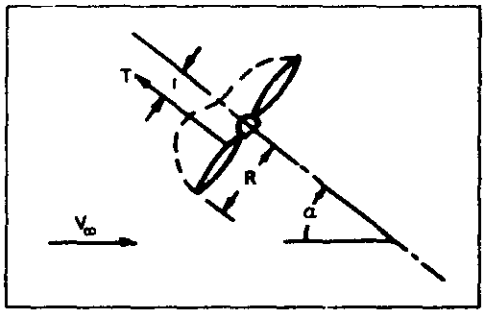


FIGURE 9.1.2-3 EFFECT OF ANGLE OF ATTACK ON EFFECTIVE THRUST DISPLACEMENT FROM THRUST AXIS FOR THE PROPELLER OF REFERENCE 1



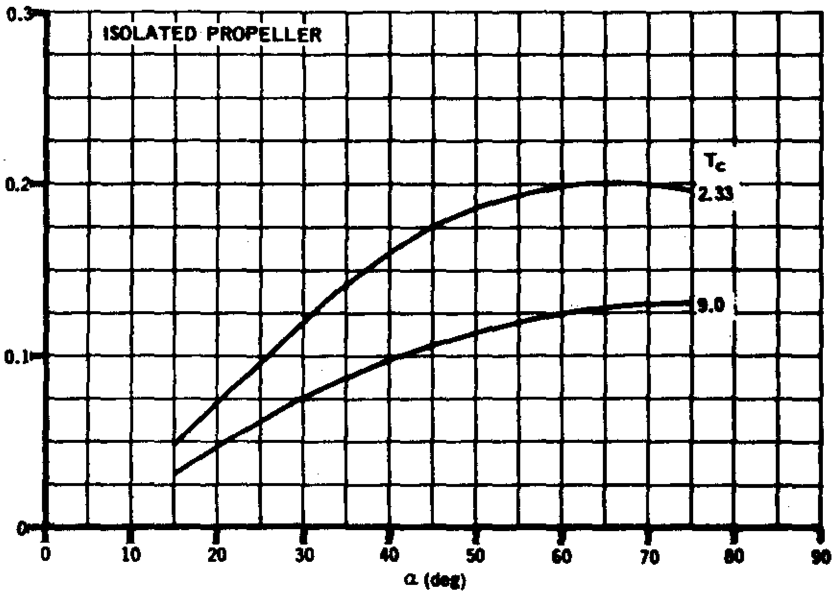


FIGURE 9.1.2-4 EFFECT OF ANGLE OF ATTACK ON EFFECTIVE THRUST DISPLACEMENT FROM THRUST AXIS FOR PROPELLER 1 OF REFERENCE 2

9.1.3 PROPELLER NORMAL-FORCE VARIATION WITH POWER AND ANGLE OF ATTACK

Two methods are presented in this Section for estimating the propeller normal force at high angles of attack .

The first method, developed by DeYoung in reference 1, provides the normal-force coefficient at high angles of attack relative to the linear relation $\left(\frac{dC_N}{d\alpha}\right)_{\alpha=0}$

This ratio is equal to the tangent of the angle of attack, provided equal advance ratios, as determined from the velocity normal to the propeller disk, exist. In theory, the normal force is considered to be proportional to the torque difference due to angle of incidence between the down-going blade and the up-going blade.

The essential part of Datcom method 1 is the estimation of $\left(\frac{dC_N}{d\alpha}\right)_{\alpha=0}$. This involves determining the normal-force derivative with respect to the local angle of attack, the local angle-of-attack gradient, and a correction for phase-angle shift.

DeYoung, in reference 1, has obtained a simple relationship for the normal-force derivative with respect to local angle of attack in the manner described in Section 9.1. A general expression for this derivative as a function of propeller geometry and operating parameters is obtained from the analysis of Ribner in references 2 and 3 and the assumption of a blade section lift-curve slope of $c_{l_\alpha} = 0.95(2\pi)$ per radian. The constants of the resulting expression are evaluated by statistical means from the computed data of the given blade shapes of reference 4.

The normal-force derivative with respect to wing angle of attack is given as the product of the normal-force derivative with respect to the local propeller angle of attack and the local angle-of-attack gradient $\frac{d\alpha_{in}}{d\alpha}$, obtained in reference 1 by an analysis of the upwash due to the wing, fuselage, and other propellers.

Propellers operating at high angles of attack experience appreciable angle-of-attack variation on the blades. Lift increases and decreases in a harmonic fashion. As the angle of attack is increased, circulation increases, and a starting vortex is shed which induces a downwash and changes the buildup of circulation. This unsteady motion causes the lift cycle to be out of phase with the angle-of-attack cycle; consequently, the propeller forces and moments have components in both the lateral and vertical directions. The normal force at incidence is then the product of the normal force computed for zero phase angle and the cosine of the phase angle. In Datcom method 1 the effect of this phase-angle shift is applied to the computed linear relation $\left(\frac{dC_N}{d\alpha}\right)_{\alpha=0}$.

In the theory of reference 1 the propeller phase angle is approximated by an analogous wing unsteady solution, assuming that the propeller forces and blade angle of attack are analogous to those of a wing that is harmonically pitching about its quarter-chord line.

A second method is given which, in the absence of complete data on a particular propeller, can be used to approximate the normal force at large angles of attack from experimental data at small angles of attack. This approach is formulated in reference 5, wherein it is demonstrated that certain VTOL transition programs can lie within the region of linear slope of the propeller forces and moments.

DATCOM METHODS

Method 1

The variation of propeller normal force with angle of attack is given relative to $\left(\frac{dC_N}{d\alpha}\right)_{\alpha=0}$, provided equal advance ratios, as determined from the velocity normal to the propeller disk, exist. This ratio is given in reference 1 as

$$\frac{C_N(\alpha, J')}{C_{N_\alpha}(0, J')} = \tan\alpha \qquad 9.1.3\text{-a}$$

The positive normal-force and angle-of-attack senses are shown in figure 9.1-4, and the required parameters are defined in the general notation list of Section 9.1.

This method is essentially one of determining the denominator values in the form of $C_{N'_\alpha}$ where

$$C_{N'_\alpha} = C_{N'_{\alpha_{in}}} \frac{d\alpha_{in}}{d\alpha} \text{ per rad} \qquad 9.1.3\text{-b}$$

In computing these values the J or thrust in the relation for $C_{N'_{\alpha_{in}}}$ must be taken at J' and velocity at $V_\infty \cos\alpha$.

The derivatives $C_{N'_\alpha}$ and C_{N_α} are related by

$$C_{N_\alpha}(0, J') = \frac{\pi}{8}(J')^2\, C_{N'_\alpha}(0, J') \text{ per rad} \qquad 9.1.3\text{-c}$$

The procedure to be followed in evaluating the normal force is outlined in the following steps.

Step 1. Determine at zero phase angle the propeller normal-force derivative with respect to the local angle of attack at the propeller disk by

$$C_{N'_{\alpha_{in}}} = \frac{4.25\,\sigma_e}{1 + 2\,\sigma_e} \sin(\beta + 8)\left(1 + \frac{3T_c}{8\sqrt{1 + (2/3)T_c}}\right) \text{ per rad} \qquad 9.1.3\text{-d}$$

for single-rotation propellers, and by

$$C_{N'_{\alpha_{in}}} = \frac{3.86\ \sigma_e}{1 + \sigma_e} \sin(\beta + 14)\left(1 + \frac{3T_c}{8\sqrt{1 + (2/3)T_c}}\right) \text{ per rad} \qquad 9.1.3\text{-d}'$$

for counter-rotating propellers;

where σ_e is obtained as outlined in Step 1 of Datcom method 1 of Section 9.1.1 and the thrust values are taken at J', with velocity equal to $V_\infty \cos\alpha$. The thrust values will normally be known.

Step 2. Determine the local angle-of-attack gradient $\frac{d\alpha_{in}}{d\alpha}$ by

$$\frac{d\alpha_{in}}{d\alpha} = \frac{1 + \frac{2A}{9(A+10)}\left(\frac{1}{\frac{x_{L\ .75}}{c_r} + \frac{1}{10}} + \frac{1}{\frac{x_{R\ .75}}{c_r} + \frac{1}{10}}\right) + \frac{1}{2}\left[\left(\frac{R_{fus}}{y_{L\ .75}}\right)^2 + \left(\frac{R_{fus}}{y_{R\ .75}}\right)^2\right]}{1 - \frac{1}{4}\sum_{\substack{\text{other}\\ \text{props}}}\left[\left(\frac{R}{\Delta y_{L\ .75}}\right)^2 + \left(\frac{R}{\Delta y_{R\ .75}}\right)^2\right]\frac{d\epsilon_{z\ slip}}{d\alpha_{in}}} \qquad 9.1.3\text{-e}$$

where the first two terms in the numerator are the average upwash at the propeller .75R station due to the wing, and the third term in the numerator is the average upwash at the propeller .75R station due to the fuselage.

The summation term in the denominator is the average downwash in the propeller slipstream at the propeller .75R station. For propellers operating near each other this downwash must be considered in predicting the local angle-of-attack gradient. This downwash may be neglected if a fuselage separates the propellers or if adjacent propellers are sufficiently far apart so that $\Delta y > 2R$. The slipstream gradient is given by

$$\frac{d\epsilon_{z_{slip}}}{d\alpha_{in}} = \frac{T_c}{4 + \frac{8}{7}T_c} + \frac{\left(C_{N'_{\alpha_{in}}}\right)_{T_c=0}\sqrt{1 + 1.3\,T_c}}{4 + 2T_c} \qquad 9.1.3\text{-f}$$

Step 3. Determine the propeller normal-force derivative with respect to wing angle of attack at zero phase angle using the terms obtained in Steps 1 and 2 and equation 9.1.3-b

$$C_{N'_\alpha} = C_{N'_{\alpha_{in}}}\frac{d\alpha_{in}}{d\alpha} \quad \text{per rad}$$

Step 4. Correct the $C_{N'_\alpha}$ value obtained for zero phase angle (Step 3) for phase-angle shift by

$$C_{N'_\alpha}(\delta) = C_{N'_\alpha}\cos\delta_f \quad \text{per rad} \qquad 9.1.3\text{-g}$$

The phase angle is determined by

$$\delta_f = 0.825 \tan^{-1} \frac{15\ \sigma_e}{B\sqrt{2\ J_{o_P}\ J' - (J')^2}} \qquad 9.1.3\text{-h}$$

where

$$J_{o_P} = J_{o_T} + \frac{16}{\sin(\beta + 5)\cos^4(\beta + 5)}\left(\frac{\sigma_e}{B}\right)^2 \qquad 9.1.3\text{-i}$$

and J_{o_T} is obtained as a function of β from Figure 9.1.1-7.

Step 5. Convert the C_{N_α}' results of Step 4 to C_{N_α} using equation 9.1.3-c.

$$C_{N_\alpha}(0,J') = \frac{\pi}{8}(J')^2\, C_{N_\alpha}'(0,J') \text{ per rad}$$

Step 6. Determine the normal force at selected wing angles of attack and modified advance ratios using

$$C_N(\alpha,J') = C_{N_\alpha}(0,J') \tan\alpha$$

A comparison of normal-force derivative at zero thrust, computed using equations 9.1.3-d and 9.1.3-d', with the theory of reference 4 is presented in Table 9.1.3-A. The percentage difference shown has been taken with respect to the values of reference 4. The comparison includes data with two blade shapes and wide variations of solidity, blade pitch angles, and number of blades. The percentage difference is considered to be within the accuracy of detailed propeller theory.

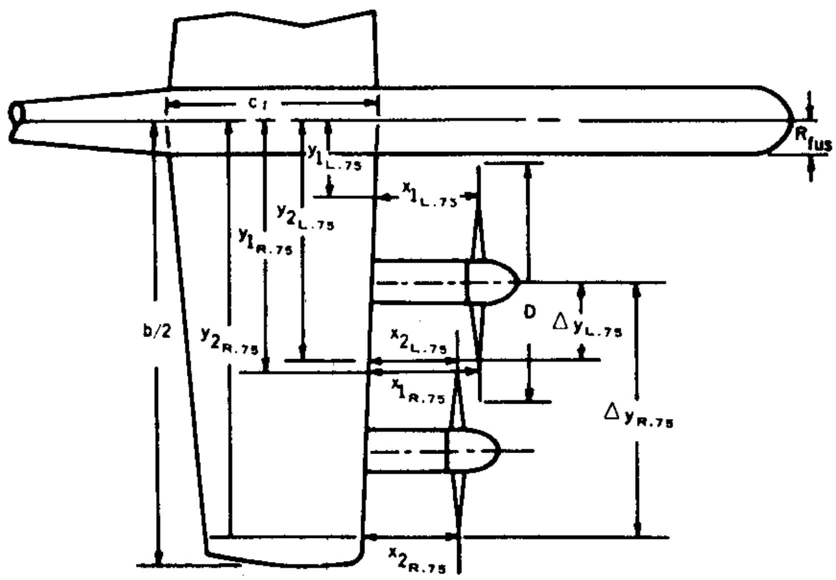
The normal-force ratio given by equation 9.1.3-a is compared with experimental data from reference 5 in figure 9.1.3-14.

Method 2

This method is suggested in reference 5 for estimating the propeller normal force at high angles of attack when experimental data are available at two angles of attack, such as zero and 15 degrees. This is an empirical method based on observations of a large body of test data in reference 5. The method is analogous to the method of Section 9.1.2 for estimating propeller pitching moments and provides acceptable accuracy for preliminary-design analysis. The method merely states that the propeller normal force at high angles of attack may be obtained by linear extrapolation of experimental data, provided the modified advance ratio falls below the boundary of figure 9.1.1-13.

Method 1

Given: The hypothetical four-propeller, tilt-wing airplane of reference 6 with linear dimensions six times those of the model. The propellers are those designated as propeller 1 of reference 5. The following example is computed for four values of the modified advance ratio over an angle-of-attack range from 0 to 80 degrees.



Propeller Characteristics

The propellers are the same as those of the sample problem of Section 9.1.1.

$B = 3$ $D = 12$ ft $\beta = 12^{o}$ $\sigma_e = 0.117$ $J_{OT} = 0.6725$

J'	0.1	0.2	0.4	0.6
T_c (0, J')	33.61	7.703	1.321	0.2267

These T_c (0,J') values have been obtained from the C_T (0,J') values given in the sample problem of Section 9.1.1 by

$$T_c\ (0,J') = \frac{8}{\pi\ (J')^2}\ C_T\ (0,J')$$

Airplane Characteristics

$c_r = 10.0$ ft $A = 4.89$ $R_{fus} = 1.25$ ft

Propeller 1 (Inboard)

$x_{L\ .75} = 5.25$ ft $y_{L\ .75} = 3.25$ ft

$x_{R\ .75} = 5.60$ ft $y_{R\ .75} = 12.25$ ft

Propeller 2 (Outboard)

$x_{L\ .75} = 4.50$ ft $y_{L\ .75} = 11.75$ ft

$x_{R\ .75} = 4.80$ ft $y_{R\ .75} = 20.75$ ft

$\Delta y_{L\ .75} = 4.0$ ft

$\Delta y_{R\ .75} = 13.0$ ft

Compute:

Step 1. Determine the propeller normal-force derivatives at zero phase angle with respect to the local angle of attack at the propeller disk $C_{N'_{\alpha_{in}}}$

$$C_{N'_{\alpha_{in}}} = \frac{4.25\ \sigma_e}{1 + 2\ \sigma_e} \sin(\beta + 8) \left(1 + \frac{3T_c}{8\sqrt{1 + (2/3)T_c}}\right) \text{per rad}$$

(equation 9.1.3-d)

$$= \frac{(4.25)(0.117)}{1 + 2\ (0.117)} \sin(12 + 8) \left(1 + \frac{3T_c}{8\sqrt{1 + (2/3)T_c}}\right)$$

$$= 0.138 + \frac{0.0517T_c}{\sqrt{1 + (2/3)T_c}}$$

TABLE I

1	2	3	4	5	6
J'	T_c	$0.0517T_c$ 0.0517 (2)	$\sqrt{1 + (2/3)\ T_c}$ $\sqrt{1 + (2/3)}$ (2)	$C_{N'_{\alpha_{in}}} - 0.138$ (3)/(4)	$C_{N'_{\alpha_{in}}}$ (1/rad) 0.138 + (5)
0.1	33.61	1.74	4.84	0.3600	0.498
0.2	7.703	0.398	2.48	0.1600	0.298
0.4	1.321	0.0683	1.371	0.0498	0.1878
0.6	0.2267	0.0117	1.072	0.0109	0.1489

Step 2. Determine the local angle-of-attack gradient $d\alpha_{in}/d\alpha$.

For this configuration $\Delta y < 2R$ and the propeller downwash effect on the local angle-of-attack gradient must be considered.

$$\frac{d\alpha_{in}}{d\alpha} = \frac{1 + \frac{2A}{9(A+10)}\left(\frac{1}{\frac{x_{L\ .75}}{c_r} + \frac{1}{10}} + \frac{1}{\frac{x_{R\ .75}}{c_r} + \frac{1}{10}}\right) + \frac{1}{2}\left[\left(\frac{R_{fus}}{y_{L\ .75}}\right)^2 + \left(\frac{R_{fus}}{y_{R\ .75}}\right)^2\right]}{1 - \frac{1}{4}\sum_{prop\ 1}^{prop\ 2}\left[\left(\frac{R}{\Delta y_{L\ .75}}\right)^2 + \left(\frac{R}{\Delta y_{R\ .75}}\right)^2\right]\frac{d\epsilon_{z\ slip}}{d\alpha_{in}}}$$

(equation 9.1.3-e)

Propeller 1 (Inboard)

$$\left(\frac{d\alpha_{in}}{d\alpha}\right)_1 = \frac{1 + \frac{2(4.89)}{9(4.89 + 10)}\left(\frac{1}{\frac{5.25}{10} + \frac{1}{10}} + \frac{1}{\frac{5.60}{10} + \frac{1}{10}}\right) + \frac{1}{2}\left[\left(\frac{1.25}{3.25}\right)^2 + \left(\frac{1.25}{12.25}\right)^2\right]}{1 - \frac{1}{4}\left[\left(\frac{6.0}{4.0}\right)^2 + \left(\frac{6.0}{13.0}\right)^2\right]\frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

$$= \frac{1 + 0.073\left(\frac{1}{0.625} + \frac{1}{0.660}\right) + \frac{1}{2}(0.148 + 0.0104)}{1 - 0.25\ (2.25 + 0.213)\ \frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

$$= \frac{1 + 0.073\ (3.115) + 0.0792}{1 - 0.25\ (2.463)\ \frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

$$= \frac{1.3067}{1 - (0.616)\ \frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

Propeller 2 (Outboard)

$$\left(\frac{d\alpha_{in}}{d\alpha}\right)_2 = \frac{1 + 0.073\left(\frac{1}{\frac{4.50}{10} + \frac{1}{10}} + \frac{1}{\frac{4.80}{10} + \frac{1}{10}}\right) + \frac{1}{2}\left[\left(\frac{1.25}{11.75}\right)^2 + \left(\frac{1.25}{20.75}\right)^2\right]}{1 - (0.616)\ \frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

$$= \frac{1 + 0.073\left(\frac{1}{0.550} + \frac{1}{0.580}\right) + \frac{1}{2}(0.0113 + 0.0036)}{1 - (0.616)\frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

$$= \frac{1 + 0.073\ (3.542) + 0.00745}{1 - (0.616)\frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

$$= \frac{1.266}{1 - (0.616)\frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}}$$

$\left(C_{N_{\alpha'}}{}_{in}\right)_{T_c=0} = 0.138$ (step 1 with T_c=0)

$$\frac{d\epsilon_{z_{slip}}}{d\alpha_{in}} = \frac{T_c}{4 + \frac{8}{7}T_c} + \frac{\left(C_{N'_{\alpha}}{}_{in}\right)_{T_c=0}\sqrt{1 + 1.3\ T_c}}{4 + 2\ T_c} \quad \text{(equation 9.1.3-f)}$$

$$= \frac{T_c}{4 + \frac{8}{7}T_c} + \frac{0.138\sqrt{1 + 1.3\ T_c}}{4 + 2\ T_c}$$

TABLE II

① J'	② T_c	③ $4 + \frac{8}{7}T_c$	④ $\frac{T_c}{③}$	⑤ $\sqrt{1 + 1.3\ T_c}$	⑥ $4 + 2\ T_c$	⑦ $\frac{0.138\ ⑤}{⑥}$	⑧ $d\epsilon_{z_{slip}}/d\alpha_{in}$ ④ + ⑦
0.1	33.61	42.41	0.7925	6.69	71.22	0.0130	0.8055
0.2	7.703	12.80	0.6018	3.32	19.41	0.0236	0.6254
0.4	1.321	5.51	0.2397	1.65	6.642	0.0343	0.2740
0.6	0.2267	4.259	0.0532	1.14	4.453	0.0353	0.0885

Using the $\frac{d\epsilon_{z_{slip}}}{d\alpha_{in}}$ values from Table II calculate $\frac{d\alpha_{in}}{d\alpha}$ for propellers 1 and 2.

TABLE III

① J'	② $\dfrac{d\epsilon_{z_{slip}}}{d\alpha_{in}}$	③ 1 - (0.616) ②	④ $(d\alpha_{in}/d\alpha)_1$ 1.3067/③	⑤ $(d\alpha_{in}/d\alpha)_2$ 1.266/③
0.1	0.8055	0.5038	2.594	2.513
0.2	0.6254	0.6148	2.125	2.059
0.4	0.2740	0.8312	1.572	1.523
0.6	0.0885	0.9455	1.382	1.339

Step 3. Determine the propeller normal-force derivatives at zero phase angle with respect to wing angle of attack $C_{N'_\alpha}$

$$C_{N'_\alpha} = C_{N'_{\alpha_{in}}} \frac{d\alpha_{in}}{d\alpha} \quad \text{per rad} \qquad \text{(equation 9.1.3-b)}$$

TABLE IV

① J'	② $C_{N'_{\alpha_{in}}}$ (1/rad) Col. ⑥, Table I	③ $(C_{N'_\alpha})_1$ (1/rad) Col. ④, Table III x ②	④ $(C_{N'_\alpha})_2$ (1/rad) Col. ⑤, Table III x ②
0.1	0.498	1.292	1.251
0.2	0.298	0.633	0.614
0.4	0.1878	0.295	0.286
0.6	0.1489	0.206	0.199

Step 4. Correct the $C_{N'_\alpha}$ values obtained in step 3 for phase-angle shift.

$$J_{o_P} = J_{o_T} + \frac{16}{\sin(\beta + 5)\cos^4(\beta + 5)}\left(\frac{\sigma_e}{B}\right)^2 \qquad \text{(equation 9.1.3-i)}$$

$$= 0.6725 + \frac{16}{\sin(17)\cos^4(17)}\left(\frac{0.117}{3}\right)^2$$

$$= 0.6725 + \frac{16}{(0.2924)(0.9563)^4}(0.00152)$$

$$= 0.6725 + 0.0995$$

$$= 0.772$$

$$\delta_f = 0.825 \tan^{-1} \frac{15 \quad \sigma_e}{B\sqrt{2 J_{o_p} J' - (J')^2}} \qquad \text{(equation 9.1.3-h)}$$

$$= 0.825 \tan^{-1} \frac{15(0.117)}{3\sqrt{2(0.772)(J') - (J')^2}}$$

$$= 0.825 \tan^{-1} \frac{0.585}{\sqrt{1.544 J' - (J')^2}}$$

TABLE V

① J'	② $(J')^2$ ①^2	③ $1.544 J'$ 1.544 ①	④ $1.544 J' - (J')^2$ ③ - ②	⑤ $\sqrt{④}$	⑥ $\frac{0.585}{⑤}$	⑦ $\tan^{-1}$ ⑥ (deg)	⑧ δ_f (deg) 0.825 ⑦
0.1	0.01	0.1544	0.1444	0.3800	1.539	57.0	47.0
0.2	0.04	0.3088	0.2688	0.5180	1.129	48.5	40.0
0.4	0.16	0.6176	0.4576	0.6760	0.865	40.9	33.7
0.6	0.36	0.9264	0.5664	0.7530	0.777	37.8	31.2

The $C_{N'_\alpha}$ values are corrected for phase-angle shift by

$$C_{N'_\alpha}(\delta) = C_{N'_\alpha} \cos \delta_f \quad \text{per rad} \qquad \text{(equation 9.1.3-g)}$$

TABLE VI

① J'	② $(C_{N'_\alpha})_1$ (1/rad) Col. ③, Table IV	③ $(C_{N'_\alpha})$ (1/rad) Col. ④, Table IV	④ $\cos \delta_f$	⑤ $(C_{N'_\alpha})_1 \cos \delta_f$ ② ④	⑥ $(C_{N'_\alpha})_2 \cos \delta_f$ ③ ④
0.1	1.292	1.251	0.6820	0.881	0.853
0.2	0.633	0.614	0.7660	0.485	0.470
0.4	0.295	0.286	0.8320	0.245	0.238
0.6	0.206	0.199	0.8554	0.176	0.170

Step 5. Convert the $C_{N'_\alpha}$ values obtained in Step 4 to C_{N_α}.

$$C_{N_\alpha}(0, J') = \frac{\pi}{8} (J')^2 C_{N'_\alpha}(0, J') \quad \text{per rad} \qquad \text{(equation 9.1.3-c)}$$

TABLE VII

① J'	② $(J')^2$ ①^2	③ $\pi/8\ (J')^2$ $(\pi/8)$ ②	④ $C_{N_\alpha}(0, J')_1$ (1/rad) ③ x Col. ⑤, Table VI	⑤ $C_{N_\alpha}(0, J')_2$ (1/rad) ③ x Col. ⑥, Table VI
0.1	0.01	0.00393	0.00346	0.00335
0.2	0.04	0.0157	0.00761	0.00738
0.4	0.16	0.0628	0.0154	0.0149
0.6	0.36	0.1414	0.0249	0.0240

Solution:

The variation of propeller normal-force coefficient with angle of attack at the chosen values of J' is tabulated below using

$$C_N(\alpha, J') = C_{N_\alpha}(0, J') \tan\alpha \quad \text{(equation 9.1.3-a)}$$

for both the inboard and outboard propellers.

$C_N(\alpha, J')$

		Propeller 1 (Inboard)				Propeller 2 (Outboard)			
α	$\tan\alpha$	J' = 0.1	0.2	0.4	0.6	J' = 0.1	0.2	0.4	0.6
0	0	0	0	0	0	0	0	0	0
10	0.1763	0.00061	0.00134	0.00272	0.00439	0.00059	0.00130	0.00263	0.00423
20	0.3640	0.00126	0.00277	0.00561	0.00906	0.00122	0.00269	0.00542	0.00874
30	0.5774	0.00200	0.00439	0.00889	0.01438	0.00193	0.00426	0.00860	0.01386
40	0.8391	0.00290	0.00639	0.01292	0.02089	0.00281	0.00619	0.01250	0.02014
50	1.1918	0.00412	0.00907	0.01835	0.0297	0.00399	0.00880	0.0178	0.0286
60	1.7321	0.00599	0.0132	0.0267	0.0431	0.00580	0.0128	0.0258	0.0416
70	2.7475	0.00951	0.0209	0.0423	0.0684	0.00920	0.0203	0.0409	0.0659
80	5.6713	0.0196	0.0432	0.0873	0.1412	0.0190	0.0419	0.0845	0.1361

The calculated values of the normal-force coefficients for both the inboard and outboard propellers are plotted in figure 9.1.3-15.

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TABLE 9.1.3-A
COMPARISON OF NORMAL-FORCE DERIVATIVE AT ZERO THRUST COMPUTED BY DATCOM METHOD 1 WITH THEORY OF REFERENCE 4

Hamilton Standard 3155-6

$\frac{r}{R}$	.25	.50	.75	.95
$\frac{b'}{b'_{.75}}$	0.615	1.03	1.00	0.57

σ , σ_e	β (deg)	$(C_{N'\alpha_{in}})_{T_c=0}$ ref. 4	$(C_{N'\alpha_{in}})_{T_c=0}$ Datcom Method 1	% Diff.
σ = .061	25	.079	.079	0
σ_e = .0527	25	.111	.109	-1.8
2	35	.134	.137	2.2
Blades	45	.158	.160	1.3
	55	.177	.179	1.1
σ = .091	15	.112	.112	0
σ_e = .079	25	.155	.156	0.6
3	35	.194	.196	1.0
Blades	45	.229	.230	0.4
	55	.258	.256	-0.8
σ = .121	15	.142	.144	1.4
σ_e = .1054	25	.198	.200	1.0
4	35	.249	.250	0.4
Blades	45	.295	.293	-0.7
	55	.332	.328	-1.2
σ = .182	15	.192	.197	2.6
σ_e = .158	25	.271	.276	1.8
6	35	.346	.346	0
Blades	45	.413	.406	-1.7
	55	.471	.452	-4.0
Counter-Rotation				
σ = .182	15	.250	.253	1.2
σ_e = .158	25	.332	.329	-0.9
6	35	.393	.392	-0.3
Blades	45	.446	.448	0.4
	55	.490	.490	0

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$\frac{r}{R}$	.25	.50	.75	.95
$\frac{b'}{b'_{.75}}$	1.03	1.03	1.00	0.765

σ , σ_e	β (deg)	$(C_{N'\alpha_{in}})_{T_c=0}$ ref. 4	$(C_{N'\alpha_{in}})_{T_c=0}$ Datcom Method 1	% Diff.
σ = .083	20	.143	.139	-2.8
σ_e = .081	25	.162	.161	-0.6
2	35	.204	.202	-1.0
Blades	45	.235	.236	0.4
	55	.260	.263	1.1
σ = .124	20	.196	.194	-1.0
σ_e = .122	25	.226	.225	-0.4
3	35	.284	.281	-1.0
Blades	45	.333	.330	-0.9
	55	.372	.368	-1.1
σ = .165	20	.243	.244	0.4
σ_e = .162	25	.280	.282	0.7
4	35	.352	.353	0.3
Blades	45	.416	.414	-0.5
	55	.471	.462	-1.9
Counter-Rotation				
σ = .248	15	.363	.364	0.4
σ_e = .244	25	.478	.473	-1.0
6	35	.567	.566	-0.2
Blades	45	.634	.642	1.3
	55	.689	.699	1.4

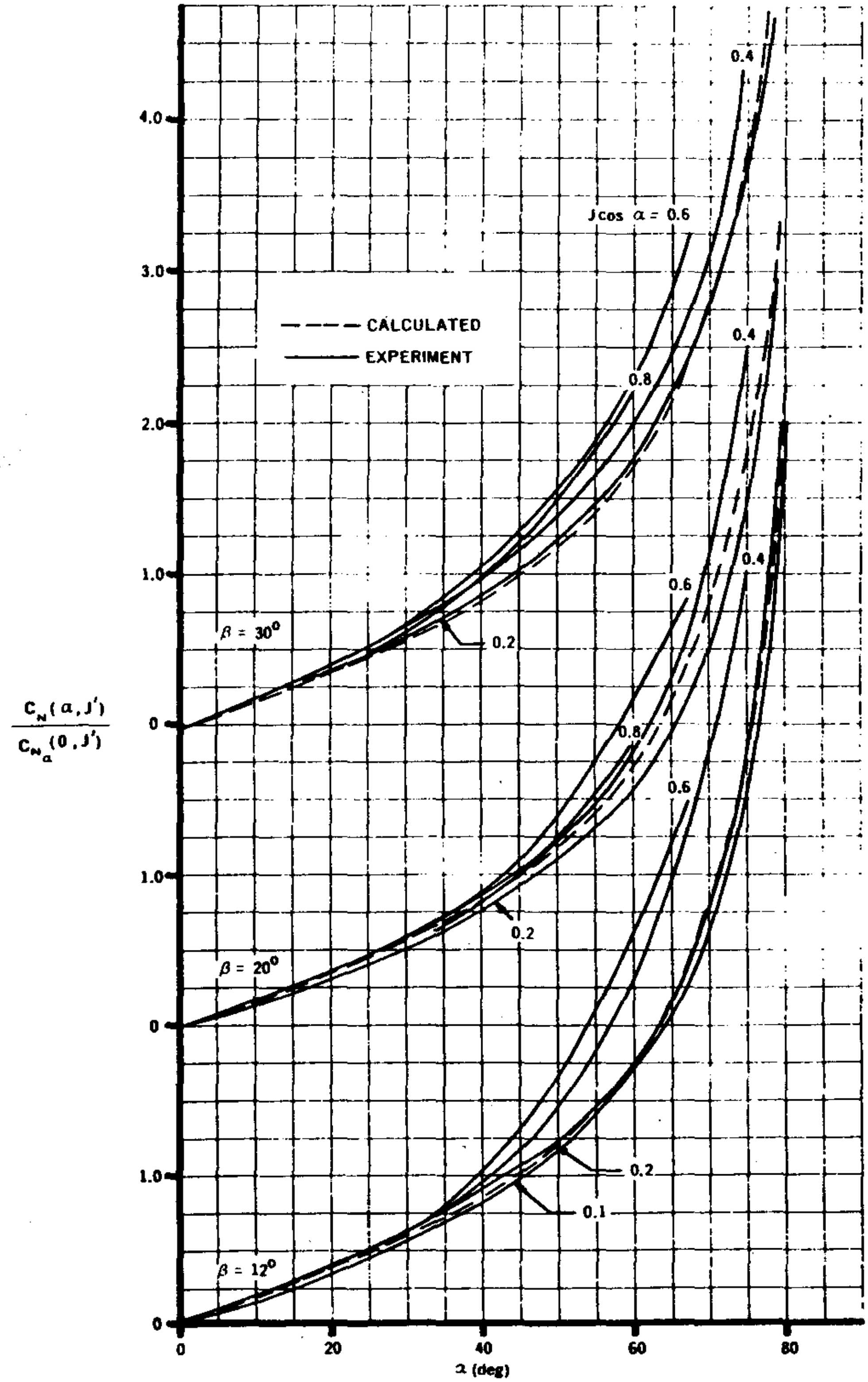

FIGURE 9.1.3-14 COMPARISON OF CALCULATED AND EXPERIMENTAL NORMAL-FORCE RATIO WITH PROPELLER THRUST-AXIS ANGLE OF ATTACK FOR PROPELLER 1 OF REFERENCE 5

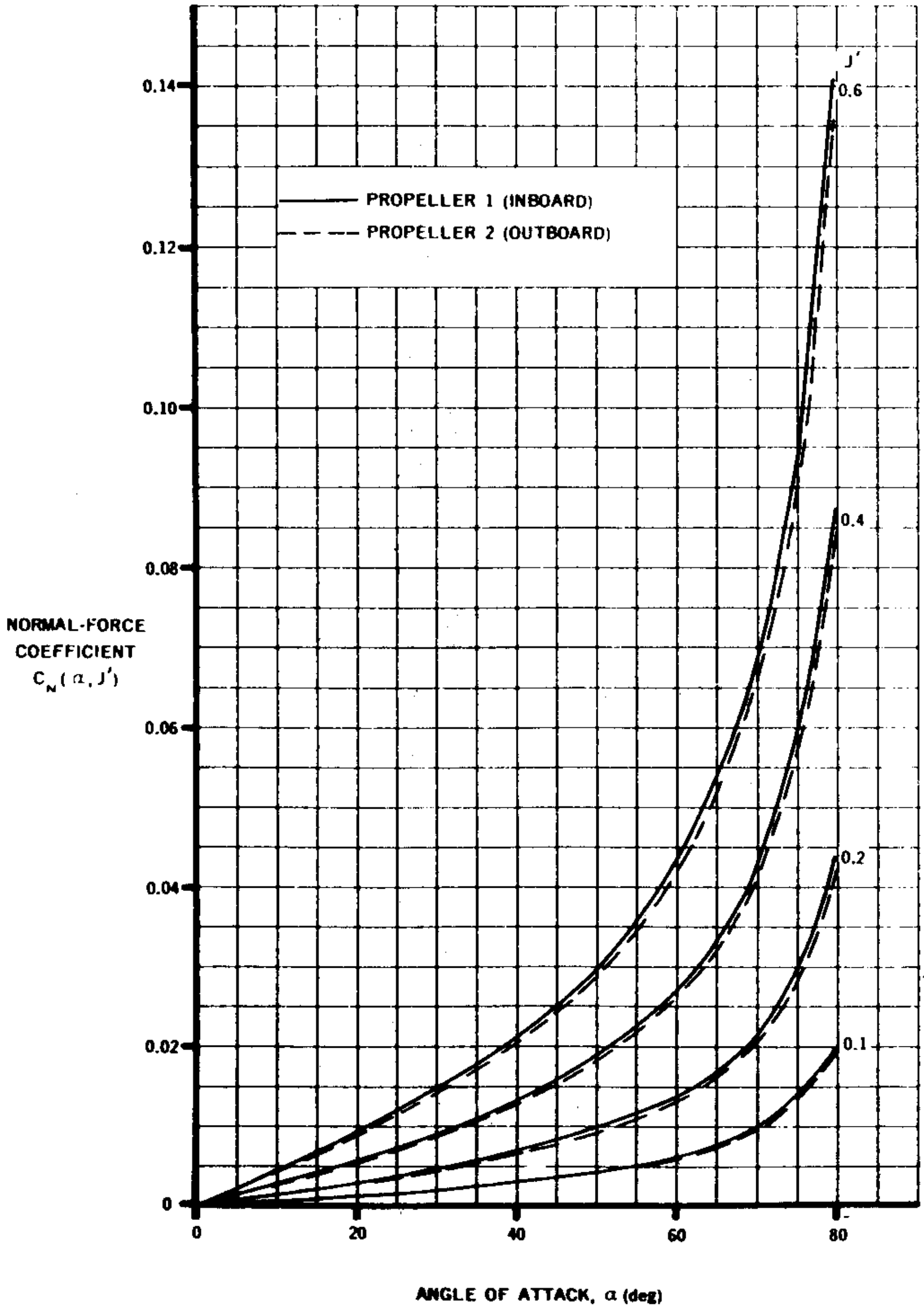

FIGURE 9.1.3-15 VARIATION OF PROPELLER NORMAL-FORCE COEFFICIENT WITH ANGLE OF ATTACK AND MODIFIED ADVANCE RATIO FOR INBOARD AND OUTBOARD PROPELLERS OF A HYPOTHETICAL 4-PROPELLER TILT-WING AIRPLANE. SAMPLE PROBLEM, METHOD 1

9.2 PROPELLER-WING CHARACTERISTICS

The methods of this section are for prediction of the power-on lift and drag forces of propeller-wing combinations of V/STOL aircraft and deal primarily with the low-speed, high-power flight regime where wing stalling tendencies at high angles of attack are delayed by power effects.

The usual approach to attaining V/STOL capabilities is to use power plant thrust to obtain lift at low speeds. Propeller-driven V/STOL configurations, other than those employing ducted propellers, consist basically of three types:

1. Deflected slipstream
2. Tilt wing
3. Combination tilt wing – deflected slipstream

These configurations differ in detail, but each employs interacting wing and thrust systems. In treating such configurations in the low-speed, high-power flight regime we must abandon the familiar distinction between lifting and thrusting systems and combine them.

Several factors dealing with propeller slipstream flow over a wing are of special significance. The local angles of attack of a propeller-wing combination in transition are determined by vector addition of the free-stream and propeller slipstream velocities. The propeller slipstream is a strong factor in reducing the local angles of attack and thereby minimizing the tendency of wing stall. Stalls may occur even in the presence of the slipstream if the slipstream velocity is low.

Since the velocity of the slipstream relative to that of the free stream is increased by increased disk loading, stalling tendencies are decreased by increasing the propeller disk loading. Wing stall can be avoided entirely by immersing the entire wing in the propeller slipstream, provided sufficient thrust is generated by the propellers.

Experimental studies have been conducted to determine the spanwise distribution of the lift increase due to the slipstream at different angles of attack with various free-stream-to-slipstream velocity ratios. The results of these tests, reported in reference 7, indicate that the lift increment due to the passage of a slipstream over a wing consists of two parts:

1. A direct lift gain which can be accurately predicted by potential flow theory.
2. A lift increment due to a "destalling" or boundary-layer-control effect. This "destalling" effect extends to portions of the wing outside the propeller slipstream and improves the wing stalling behavior.

The results also indicate that the limits of the direct slipstream influence are sharply defined and do not vary with wing angle of attack and slipstream strength.

Both references 7 and 61 indicate that the rotation of the propeller slipstream causes an upwash over the wing behind the upward moving blade. This area will generally be the first to stall on a wing that is fully immersed in propeller slipstreams. The effect of propeller rotation on maximum lift was investigated in reference 20, wherein it is concluded that slightly larger values of maximum lift can be generated when propellers rotate with the inboard tips moving up. This lift increase is attributed to a reduction in tip losses resulting from the propeller rotating in such a manner as to oppose the wing-tip vortex and to the fact that the upwash behind the upward moving blade is not entirely cancelled by the downflow at the wing tip.

Propeller-wing combinations in the transition region do not lend themselves to theoretical analysis. The Datcom methods for the prediction of lift and drag forces at forward speed with power on comprise semiempirical expressions from reference 52. These methods employ momentum theory as a starting point. They are based on power-off data and a correlation of slipstream-deflection data at zero forward speed. The correlation of slipstream-deflection data is based on numerous static investigations of a limited number of wing-flap systems. Effects of various parameters on the slipstream-deflection characteristics are summarized in reference 52.

The methods are applicable only in the unstalled flight regime. Comparison of experimental results with calculations made using the Datcom methods indicate that, in general, the estimation procedures give reasonably good results for steady level flight and for climbing flight. Through judicious use of the Datcom methods the lift and drag forces can be estimated for deflected-slipstream, tilt-wing, and combination tilt-wing – deflected-slipstream configurations. At the present time there are no methods available for the prediction of the pitching moment of a propeller-wing configuration in the transition flight regime.

Numerous static and forward speed investigations have been conducted on propeller-driven V/STOL configurations. However, the number of specific designs tested has been so limited that the substantiation of any semiempirical method developed for the prediction of forces and moments has not been possible. Furthermore, excessive wind-tunnel wall effects during simulated low-speed, high-power flight conditions invalidate many investigations.

A comprehensive tabulation of pertinent propeller-wing experimental data is presented as table 9.2-A. This table provides a brief outline of the test data contained in each report and indicates the basic parametric changes made. Additional reports, dealing with complete configurations, can be found in the VTOL-STOL summary table of Section 9.

A general notation list is included in this section for all propeller-wing combination sections. Coefficients are based on the dynamic pressure in the propeller slipstream unless otherwise noted. The conversion from coefficients based on slipstream dynamic pressure to coefficients based on free-stream dynamic pressure is presented at the end of the notation list.

The positive direction of forces and angles is shown in figure 9.2-9.

NOTATION

c	average wing chord, ft
ΔC_D	zero-lift drag increment due to flap deflection based on free-stream velocity
C_{D_f}	power-off zero-lift drag coefficient based on free-stream velocity
C_{D_o}	power-off drag coefficient based on free-stream velocity, $\frac{\text{Drag}}{q_\infty S}$
c_f	average flap chord, ft
C_{F_x}	negative-drag coefficient based on free-stream velocity, $\frac{F_x}{q_\infty S}$
C_{F_x}''	negative-drag coefficient based on slipstream velocity, $\frac{F_x}{q'' S}$
C_{L_o}	power-off lift coefficient based on free-stream velocity, $\frac{L}{q_\infty S}$
C_L''	lift coefficient based on slipstream velocity, $\frac{L}{q'' S}$
D	propeller diameter, ft
e	span efficiency factor
F	resultant force, lb
F_x	horizontal force, lb
$\frac{F}{T}$	thrust-recovery factor
i_W	wing incidence measured between thrust axis and wing chord plane, deg
J	advance ratio, $\frac{V_\infty}{nD}$
K	number of propellers

L	lift, lb
q_∞	free-stream dynamic pressure, lb/sq ft
q''	slipstream dynamic pressure, $q_\infty + \frac{T}{S_p}$, lb/sq ft
S	wing area, sq ft
S_p	propeller disk area, $\frac{\pi}{4} D^2$, sq ft
T	thrust per propeller or total thrust when used in thrust-recovery factor, lb
T_c	propeller thrust coefficient based on free-stream velocity and wing area, $\frac{KT}{q_\infty S}$
T_c''	propeller thrust coefficient based on slipstream velocity and propeller disk area, $\frac{T}{q'' S_p}$
α	angle of attack measured between free stream and thrust axis, deg
δ	flap deflection, deg
δ_e	equivalent flap deflection due to wing camber and incidence, deg
θ	slipstream turning angle measured from thrust axis, deg
θ_f	slipstream turning angle adjusted to the condition of zero camber and zero incidence, deg
$\Delta\theta$	increment of slipstream turning angle due to wing camber and incidence, deg

Conversion between systems:

(Unprimed coefficients are based on free-stream dynamic pressure.)

$$C_D = \frac{-C_{F_x}''}{1 - T_c''} \qquad C_{F_x}'' = \frac{-C_D}{1 + T_c \frac{S}{KS_p}} \qquad T_c = \frac{T_c''}{1 - T_c''} \frac{KS_p}{S}$$

$$C_L = \frac{C_L''}{1 - T_c''} \qquad C_L'' = \frac{C_L}{1 + T_c \frac{S}{KS_p}} \qquad T_c'' = \frac{T_c}{T_c + \frac{KS_p}{S}}$$

$$q_\infty = q'' (1 - T_c'')$$

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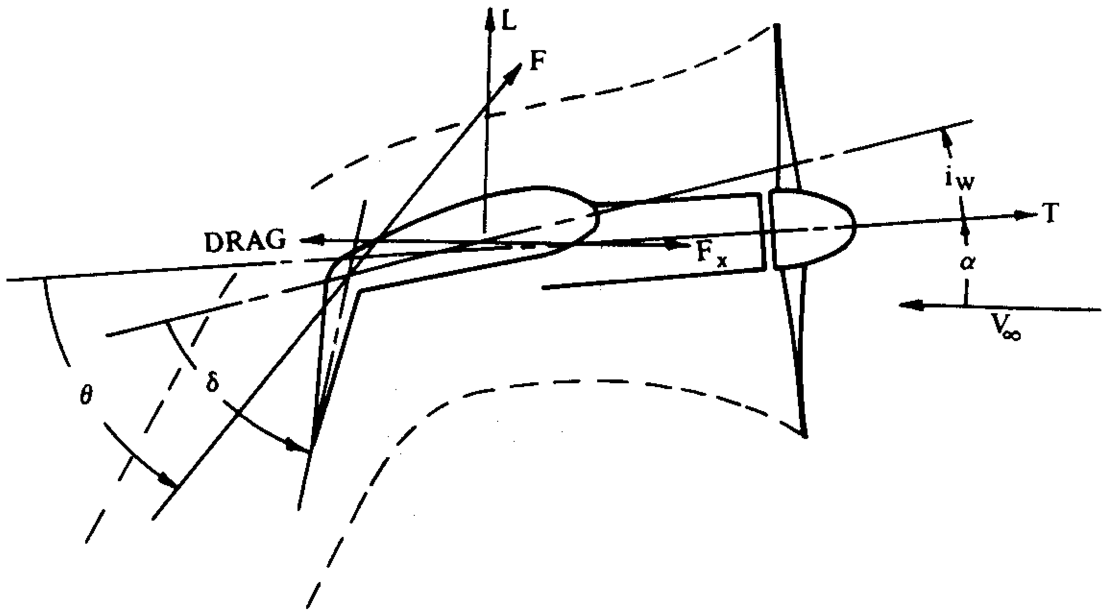


FIGURE 9.2-9 CONVENTIONS USED TO DEFINE POSITIVE SENSE OF FORCES AND ANGLES

TABLE 9.2-A
SUMMARY OF EXPERIMENTAL PROPELLER-WING DATA

REFERENCE NO.	YEAR OF PUBLICATION	WING ASPECT RATIO	WING AIRFOIL SECTION	TYPE OF FLAP	FLAP CHORD TO AIRFOIL CHORD RATIO (FLAP RETRACTION)	PROPELLER DIAMETER (FT)	BLADES PER PROPELLER	NUMBER PROPELLERS PER SEMISPAN	AUXILIARY TURNING AIDS	PROPELLER DIAMETER / WING CHORD	α RANGE	MAX. ADVANCE RATIO	SLIPSTREAM DYNAMIC PRESSURE (LB/FT²)	SLIPSTREAM REYNOLDS NUMBER (BASED ON WING MAC)	STATIC TURNING EFFECTIVENESS	TRANSITION PERFORMANCE	GROUND EFFECTS	PROPELLER FORCES	PROPELLER LOCATION VARIED	PROPELLER ROTATION MODE	PROPELLER RPM	SLIPSTREAM DYN. PRESS. SURVEY	DOWNWASH SURVEY	POWER	COMMENTS
	CONFIGURATION GEOMETRY											TEST CONDITIONS			TEST DATA										
4	66	8.53	NACA 63-318	DOUBLE SLOTTED	–	1.55	4	2	–	1.92	–15° → 15°					X		X			X			X	FULL-SPAN, TILT WING, 1/10-SCALE XC-142A. PROPELLERS OVERLAPPED. EFFECT OF AERODYNAMIC DERIVATIVES ON STABILITY CHARACTERISTICS. RESULTS OF ANALYTICAL APPROACH COMPARED WITH TEST IN PRINCETON DYNAMIC MODEL TRACK
5	68	8.53	NACA 63-318	DOUBLE SLOTTED	33	1.55	4	2	LE SLAT	1.88				(a) .463, .543 (b) – (c) –			X			X					.11-SCALE MODEL OF TILT-WING XC-142A IN 3 TEST SECTIONS OF VOUGHT AERONAUTICS DIV. TUNNEL: (A) 7 x 10 FT, (B) 15 x 20 FT, (c) 21 x 23 FT. PROPELLER OVERLAPPED. TUFT STUDIES OF FLOW FIELDS ON WING AND OF RECIRCULATION. EFFECT OF REYNOLDS NUMBER, WING INCIDENCE, PROPELLER BLADE PITCH ANGLE, TUNNEL WALL CORRECTIONS, AND TUFTS ON AERO CHAR. EFFECT OF RECIRCULATION ON PROPELLER THRUST. WIND-TUNNEL WALL CORRECTIONS EVALUATED. FLIGHT-TEST AND WIND-TUNNEL RESULTS COMPARED.
6	68	8.53	NACA 63-318	DOUBLE SLOTTED	.33	1.55	4	2	KRUGER FLAP	78											X				1/10-SCALE XC-142 TILT-WING MODEL IN PRINCETON DYNAMIC MODEL TRACK. PROPELLERS OVERLAPPED. STATIC AND DYNAMIC TESTS IN HOVER AND FORWARD FLIGHT TO DETERMINE LATERAL-DIRECTIONAL STABILITY CHARACTERISTICS.
7	58	4	NACA 64A418	–	–	.67	2	1/ SPAN		1.0	0 → 17°				X					X					STRAIGHT WING WITH ONE PROPELLER IN PUSHER CONFIGURATION, SPANNING THE UTIA 32- x 48-IN. LOW-SPEED TUNNEL. DEFLECTED-SLIPSTREAM TYPE. EFFECT OF SLIPSTREAM AND RATIO OF FREE-STREAM TO SLIPSTREAM VELOCITIES ON LIFT.
8	68	8.53	NACA 63_3-318	DOUBLE SLOTTED	.47	1.72	4	2	LE SLAT	1.92															FREE-FLIGHT TESTS OF 1/9-SCALE TILT-WING V/STOL. PROPELLERS OVERLAPPED. STATIC AND DYNAMIC STABILITY DERIVATIVES IN HOVER AND TRANSITION. CORRELATION WITH CALCULATED VALUES. QUALITATIVE MEASUREMENTS.
9	66	8.53	NACA 63_3-318	DOUBLE SLOTTED	.47	1.72	4	2	LE SLAT	1.92	–30° → 30°					X									1/9-SCALE, FULL-SPAN, TILT-WING MODEL. PROPELLERS OVERLAPPED. STATIC LONGITUDINAL, AND IN-PHASE AND OUT-OF-PHASE OSCILLATORY DERIVATIVES.
10	60	4.58	NACA 0015			1.17	3	1		1.77	0 → 40°			.064 TO .4							X				METHODS PREDICTING AERO STABILITY DERIVATIVES OF TILT-WING VTOL AIRCRAFT. TEST DATA FOR AERO FORCES ON WING ALONE AND FUSELAGE ALONE FOR VARIOUS THRUST COEFFICIENTS.
11	65	(a) 5.3 (b) 6.7 (c) 8.5				(a) 9.5 (b) 2.4 (c) 1.72	(a) 3 (b) 4 (c) 4	(a) 1 (b) 1 (c) 2		(a) 2.0 (b) – (c) 1.92															(A) VZ-2 RESEARCH PLANE IN FULL-SCALE TUNNEL AND 1/4-SCALE MODEL IN LANGLEY 30- x 60-FT TUNNEL; (B) 1/10-SCALE VTOL IN PRINCETON DYNAMIC MODEL TRACK; (C) 4-PROPELLER-OVERLAPPING MODEL IN LTV AND 1/9-SCALE NASA TEST COMPARED. LONG STABILITY DERIVATIVES. ANALOG COMPUTER STUDY ALSO COMPARED.
12	69	–	–	–	–	–	–	1, 2	–	–	–	–	–	–											LONGITUDINAL DYNAMIC CHARACTERISTICS OF 2 FULL-SPAN MODELS: (A) QUAD DUCTED PROPELLER MODEL; (B) 2-PROPELLER AND 4-PROPELLER TILTING-WING MODELS. PROPELLERS OVERLAPPED IN LATTER. EQUATIONS FOR DERIVATIVES COMPARED WITH PRINCETON TRACK TESTS.
13	67	8.53	NACA 63-318	DOUBLE SLOTTED	.33	1.55	4	2	KRUGER FLAPS	1.92	–15° → 15°														FULL-SPAN 1/10-SCALE MODEL OF THE LTV XC-142. PROPELLERS OVERLAPPED. TILT WING. LONGITUDINAL DYNAMIC STABILITY AT HIGH WING INCIDENCE MEASURED IN PRINCETON DYNAMIC MODEL TRACK. TUFT STUDY. PRIMARILY 2°-OF-FREEDOM MOTIONS, ALSO 1° AND 3° OF FREEDOM.
14	64	6.52	NACA 63A416	TRIPLE SLOTTED	.385	14.76	3	2	AILERONS	1.21															BREGUET 941. A DEFLECTED-SLIPSTREAM STOL. INTERCONNECTED PROPELLERS. NO PROPELLER OVERLAP. STATIC AND DYNAMIC STABILITY AND CONTROL. PERFORMANCE, TAKEOFF AND LANDING TECHNIQUES. FLYING QUALITIES COMPARED WITH AGARD REQ.
15	64	8.35	NACA 23017 WITH LE OF NACA 63-318	DOUBLE SLOTTED	.33	9.3	3	2	LE SLATS, KRUGER FLAPS	1.86	–16° → 22°					X									.6-SCALE TILT-WING XC-142 IN AMES 40- x 80-FOOT TUNNEL. PROPELLERS OVERLAPPED. LONG STABILITY AND CONTROL. EFFECT OF SPAN OF LE DEVICES ON ONSET OF AIR FLOW SEPARATION. EFFECT OF PROPELLER THRUST ON DESCENT PERFORMANCE. EFFECT OF WING TILT ANGLE, FLAP DEFLECTION AND LE DEVICES ON LONG CHAR.

TABLE 9.2-A (CONTD)

			CONFIGURATION GEOMETRY									TEST CONDITIONS				TEST DATA										
REFERENCE NO.	YEAR OF PUBLICATION	WING ASPECT RATIO	WING AIRFOIL SECTION	TYPE OF FLAP	FLAP CHORD TO AIRFOIL CHORD RATIO (FLAP RETRACTED)	PROPELLER DIAMETER (FT)	BLADES PER PROPELLER	NUMBER PROPELLERS PER SEMISPAN	AUXILIARY TURNING AIDS	PROPELLER DIAMETER / WING CHORD	α RANGE	MAX. ADVANCE RATIO	SLIPSTREAM DYNAMIC PRESSURE (LB/FT²)	SLIPSTREAM REYNOLDS NUMBER (BASED ON WING MAC)	STATIC TURNING EFFECTIVENESS	TRANSITION PERFORMANCE	GROUND EFFECTS	PROPELLER FORCES	PROPELLER LOCATION VARIED	PROPELLER ROTATION MODE	PROPELLER RPM	SLIPSTREAM DYN. PRESS. SURVEY	DOWNWASH SURVEY	POWER	COMMENTS
17	68	8.35	MOD NACA 23017	DOUBLE SLOTTED	.33	9.3	3	2	LE SLATS	1.86							X				X				LARGE-SCALE TILT-WING V/STOL TRANSPORT IN AMES 40- x 80-FT TUNNEL. PROPELLERS OVERLAPPED. FIXED GROUND PLANE. EFFECT OF GROUND HEIGHT ON FLAP EFFECTIVENESS AND YAW CONTROL IN HOVER. EFFECT OF GROUND HEIGHT, FLAPS, SLATS, WING TILT ON LONG AERO CHAR. PRESSURE DATA AT VARIOUS GROUND HEIGHTS, WING TILT ANGLES, THRUST COEFFICIENTS, AND PROPELLER RPM.
18	68	8.53	NACA 63-318	DOUBLE SLOTTED	.33	15.625	4	2	LE SLATS	1.94											X				FLIGHT TESTS ON XC-142A PROTOTYPE, A TILT-WING, DEFLECTED-SLIPSTREAM CARGO ASSAULT AIRCRAFT AT EDWARDS AFB. PROPELLERS OVERLAPPED. CATEGORY II PERFORMANCE EVALUATION OF STATIC AND DYNAMIC LONG STABILITY, LATERAL-DIRECTIONAL STABILITY, MANEUVERING STABILITY, TAKEOFF, CONVERSIONS, ETC.
19	54	4.55	NACA 0015	PLAIN	.30	2	3	2	–	1.32	$-10^\circ \rightarrow 90^\circ$	.122	8	.8				X			X			X	SEMISPAN WING IN SLIPSTREAM OF 2 LARGE-DIAM PROPELLERS. PROPELLERS OVERLAPPED. TILT WING AND PROPELLER TEST SEPARATELY AND IN COMBINATION IN LANGLEY 300-MPH 7- x 10-FT TUNNEL. PROPELLER-EFFICIENCY DATA. EFFECT OF PROPELLERS, THRUST, AND NACELLES ON AERO CHAR. EFFECT OF SLIPSTREAM ON VARIATION OF LIFT-CURVE SLOPE WITH THRUST.
20	55	4.55	NACA 0015	PLAIN	.60 .30	2	3	2, 1	2 VANES	1.33	–	0	8	–	X				X	X		X			SEMISPAN MODEL. PROPELLERS OVERLAPPED. EFFECTS OF PROPELLER BLADE ANGLE, MODE OF PROPELLER ROTATION, PROPELLER LOCATION, AND RATIO OF WING CHORD TO PROPELLER DIAMETER ON TURNING EFFECTIVENESS. LONG AND VERTICAL POSITION OF PROPELLERS VARIED. EFFECT OF WING CHORD FROM FLAT PLATE WINGS. SOME DATA WITH AUX VANES.
22	69	6.14	NACA 4420	SINGLE SLOTTED	.40	5.67	4	1	LE SLAT	2.5	$5^\circ \rightarrow 80^\circ$			1.9					X						LARGE-SCALE, SEMISPAN TILT-WING AND FUSELAGE IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF PROPELLER ROTATION DIRECTION, FENCES, SLATS, AND FLAP DEFLECTION ON AERO DATA. TABULATED AND PLOTTED. TUFT STUDIES.
23	66	4.88	NACA 4415	DOUBLE SLOTTED	.35	5.67	4	1	LE SLAT	2.0	$-20^\circ \rightarrow 90^\circ$			2.32, 1.91		X				X					LARGE-SCALE, SEMISPAN TILT-WING IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF FENCES, SLATS IN 2 POSITIONS, FLAP DEFLECTION, AND PROPELLER ROTATION DIRECTION ON AERO CHAR. TUFT STUDIES.
24	66	4.88	NACA 4415	DOUBLE SLOTTED	.35	5.67	4	1	LE SLATS	2.0	$0 \rightarrow 90^\circ$			2.38, 1.95		X				X					LARGE SEMISPAN TILT-WING AND FUSELAGE IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF FENCES, SLATS IN 2 POSITIONS, FLAP DEFLECTION, AND PROPELLER ROTATION DIRECTION ON AERO CHAR. TUFT STUDIES. LOADS ON FUSELAGE (LIFT ONLY).
25	67	4.88	NACA 4415	SINGLE SLOTTED	.40	5.67	4	1	LE SLATS	2.0	$0 \rightarrow 85^\circ$			2.38		X				X					LARGE-SCALE SEMISPAN TILT-WING AND FUSELAGE IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF FENCES, SLATS, FLAP DEFLECTION, AND PROPELLER ROTATION DIRECTION ON LONG AERO CHAR. TUFT STUDIES. LOADS ON FUSELAGE (LIFT ONLY).
26	67	4.88	NACA 4415	SINGLE SLOTTED	.40	5.67	4	1	LE SLATS	2.0	$5^\circ \rightarrow 85^\circ$			2.38		X				X					LARGE-SCALE SEMISPAN TILT-WING AND FUSELAGE IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF FENCES, SLATS IN 2 POSITIONS, FLAP DEFLECTION, AND PROPELLER ROTATION DIRECTION ON LONG AERO CHAR. TUFT STUDIES. LOADS ON FUSELAGE (LIFT ONLY)
27	67	4.88	NACA 4415	SINGLE SLOTTED	.40	5.67	4	1	LE SLATS	2.0	$5^\circ \rightarrow 85^\circ$			2.38		X				X					LARGE-SCALE SEMISPAN TILT-WING AND FUSELAGE IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF FENCES, SLATS, FLAP DEFLECTION, AND PROPELLER ROTATION DIRECTION ON LONG AERO CHAR. TUFT STUDIES. LOADS ON FUSELAGE (LIFT ONLY).
28	64	4.05	NACA 4415	FOWLER	.40	5.67	4	1	LE SLAT, DROOP NOSE, KRUEGER FLAP	1.67	$-20^\circ \rightarrow 90^\circ$					X									LARGE-SCALE SEMISPAN TILT-WING IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF VARIOUS LE DEVICES AND FLAP DEFLECTION ON LONG AERO CHAR. TUFT STUDIES.

TABLE 9.2-A (CONT'D)

REFERENCE NO.	YEAR OF PUBLICATION	WING ASPECT RATIO	WING AIRFOIL SECTION	TYPE OF FLAP	FLAP CHORD TO AIRFOIL CHORD RATIO (FLAP RETRACTED)	PROPELLER DIAMETER (FT)	BLADES PER PROPELLER	NUMBER PROPELLERS PER SEMISPAN	AUXILIARY TURNING AIDS	PROPELLER DIAMETER / WING CHORD	α RANGE	MAX. ADVANCE RATIO	SLIPSTREAM DYNAMIC PRESSURE (LB/FT²)	SLIPSTREAM REYNOLDS NUMBER (BASED ON WING MAC)	STATIC TURNING EFFECTIVENESS	TRANSITION PERFORMANCE	GROUND EFFECTS	PROPELLER FORCES	PROPELLER LOCATION VARIED	PROPELLER ROTATION MODE	PROPELLER RPM	SLIPSTREAM DYN. PRESS. SURVEY	DOWNWASH SURVEY	POWER	COMMENTS
29	64	4.05	NACA 4415	SINGLE SLOTTED	.40	5.67	4	1	LE SLAT, DROOP NOSE, KRUEGER FLAP	1.67	$-20^\circ \rightarrow 90^\circ$			2.8, 2.3		X									LARGE-SCALE SEMISPAN TILT-WING IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF VARIOUS LE DEVICES AND FLAP DEFLECTION ON LONG AERO CHAR. TUFT STUDIES
30	64	4.05	NACA 4415	SINGLE SLOTTED	.40	5.67	4	1	LE SLAT, KRUEGER FLAP.	1.67	$-20^\circ \rightarrow 90^\circ$			2.8, 2.3		X									LARGE-SCALE SEMISPAN TILT-WING IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF LE SLATS AND KRUEGER FLAPS ON LONG AERO CHAR. TUFT STUDIES.
31	69	6.1	NACA 4420	SINGLE SLOTTED	.40	5.67	4	1	LE SLAT	2.5	$5^\circ \rightarrow 80^\circ$		-	1.9						X					SEMISPAN TILT-WING AND FUSELAGE IN LANGLEY TUNNEL. TABULATED PRESSURE DISTRIBUTION SHOWING EFFECT OF FLAP DEFLECTION, PROPELLER ROTATION DIRECTION, SLATS, AND FENCES. TUFT STUDIES. PLOTS OF TYPICAL CHORDWISE PRESSURE DISTRIBUTION, SPANWISE SECTION NORMAL-FORCE COEFFICIENTS, AND CHORDWISE PRESSURE DISTRIBUTION AT VARIOUS SPANWISE STATIONS.
32	67	6.37	NACA 0015	SPLIT	.33	3.25	2			2.17	$0 \rightarrow 90^\circ$		8									X			SEMISPAN SEGMENTED WING ON SEMIFUSELAGE IN LOW-SPEED NAA TUNNEL. EFFECT OF PROPELLER SLIPSTREAM ON SPANWISE DISTRIBUTION OF LIFT, DRAG, PITCHING MOMENTS, AND TOTAL WING FORCES AND MOMENTS. STALL CHAR OF WING IMMERSED IN SLIPSTREAM. SURVEY OF VELOCITY FIELD IN PROPELLER SLIPSTREAM. EFFECTS OF FLAPS, THRUST, AND PROPELLER GEOMETRY. TUFT STUDIES. COMPUTER PROGRAM. THEORETICAL AND EXPERIMENTAL DATA COMPARED.
33	64							1, 2																	ANALYTIC INVESTIGATION OF AERO FORCES ON WING-PROPELLER COMBINATION. RESULTS APPLIED TO V/STOL AIRCRAFT. EFFECT OF PROPELLER SLIPSTREAM ON WING STALL TAKE-OFF AND LANDING PERFORMANCE.
34	67	8.51	NACA 63-318	DOUBLE SLOTTED	.33	1.41	4	2	LE SLAT	1.92			10	.51			X			X	X				1/11-SCALE TILT-WING IN LANGLEY 300-MPH 7- x 10-FT TUNNEL. PROPELLERS OVERLAPPED. MOVING-BELT GROUND PLANE. SMOKE-FLOW STUDY. EFFECT OF GROUND, GROUND HEIGHT, WING TILT ANGLE, FLAP DEFLECTION, HORIZONTAL-TAIL INCIDENCE, AND PROPELLER ROTATION DIRECTION ON AERO CHAR. EFFECT OF NOSE STRAKES, ASYMMETRIC RPM, AILERON DEFLECTION, AND SPOILERS.
35	67	8.28	NACA 63-318	DOUBLE SLOTTED	.33	1.41	4	2	LE SLAT	1.92	$-8^\circ \rightarrow 24^\circ$		10	.51			X				X				FULL-SPAN 1/11-SCALE TILT-WING MODEL IN LANGLEY 300-MPH 7- x 10-FT TUNNEL. PROPELLERS OVERLAPPED. MOVING-BELT GROUND PLANE. EFFECT OF THRUST, GROUND, GROUND HEIGHT, MOVING GROUND PLANE, WING INCIDENCE, AND HORIZONTAL-TAIL INCIDENCE ON AERO CHAR.
36	66	8.28	NACA 63-318	DOUBLE SLOTTED	.33	1.41	4	2	LE SLAT, DROOP NOSE	1.92	$-30^\circ \rightarrow 40^\circ$		10	.51		X	X	X			X				1/11-SCALE TILT-WING IN LANGLEY 300-MPH 7- x 10-FT TUNNEL. PROPELLERS OVERLAPPED. FIXED GROUND BOARD. EFFECT OF THRUST, WING INCIDENCE, HORIZONTAL-TAIL INCIDENCE, PROPELLER BLADE ANGLE, FLAPS, SLATS, NOSE DROOP, AND GROUND ON LONG AERO CHAR.
37	58	9.86	NACA 23017	SLOTTED		6.75	4	1	LE FLAP, BLOWING BLC, DROOPED AILERON	1.43	$-8^\circ \rightarrow 20^\circ$													X	LARGE-SCALE, STRAIGHT-WING MODEL IN AMES 40- x 80-FT TUNNEL. EFFECT OF THRUST, STABILIZER INCIDENCE, NOZZLE HEIGHT, FLAP AND AILERON JET MOMENTUM, FLAPS, AND LE FLAPS ON AERO CHAR. EFFECT OF DROOPED AILERON ON LATERAL CONTROL.
38	66	2.82	NACA 0015	SINGLE SLOTTED	.30	2	3	1		1.33	$0 \rightarrow 90^\circ$			.63							X				TILT-WING IN LANGLEY 300-MPH 7- x 10-FT TUNNEL, 17-FT SECTION OF 7- x 10-FT TUNNEL, AND FULL-SCALE TUNNEL. EFFECT OF TUNNEL SIZE, REYNOLDS NUMBER, AND FLAPS ON LONG AERO CHAR. DATA FROM FIRST 2 TUNNELS CORRECTED BY THEORY AND COMPARED WITH DATA FROM FULL-SCALE TUNNEL TO DETERMINE WALL EFFECTS AND VALIDITY OF WALL-CORRECTION THEORY (GIVEN IN APP I).

Column groups: CONFIGURATION GEOMETRY (wing aspect ratio through α range); TEST CONDITIONS (max. advance ratio through slipstream Reynolds number); TEST DATA (static turning effectiveness through power).

TABLE 9.2-A (CONTD)

REFERENCE NO.	YEAR OF PUBLICATION	CONFIGURATION GEOMETRY: WING ASPECT RATIO	WING AIRFOIL SECTION	TYPE OF FLAP	FLAP CHORD TO AIRFOIL CHORD RATIO (FLAP RETRACTED)	PROPELLER DIAMETER (FT)	BLADES PER PROPELLER	NUMBER PROPELLERS PER SEMISPAN	AUXILIARY TURNING AIDS	PROPELLER DIAMETER / WING CHORD	TEST CONDITIONS: α RANGE	MAX. ADVANCE RATIO	SLIPSTREAM DYNAMIC PRESSURE (LB/FT2)	SLIPSTREAM REYNOLDS NUMBER (BASED ON WING MAC)	TEST DATA: STATIC TURNING EFFECTIVENESS	TRANSITION PERFORMANCE	GROUND EFFECTS	PROPELLER FORCES	PROPELLER LOCATION VARIED	PROPELLER ROTATION MODE	PROPELLER RPM	SLIPSTREAM DYN. PRESS. SURVEY	DOWNWASH SURVEY	POWER	COMMENTS
39	66	7.64	NACA 4415	(a),(b),(c) PLAIN (d) SINGLE SLOTTED (e),(f) DOUBLE SLOTTED	(a) .15 (b) .25 (c) .375 (d) .40 (e) .22 (f) .44	2	3	2	1.67						X		X				X	X			A SEMISPAN TILT-WING VTOL MODEL WITH 6 FLAPS USED FOR YAW CONTROL. NO PROPELLER OVERLAP. TUFT STUDIES. EFFECT OF FLAP-CHORD-TO-PROPELLER-DIAMETER RATIO, TYPE OF FLAP, LENGTH OF FLAP CHORD, FLAP DEFLECTION, AILERON CUTOUTS, AND GROUND PROXIMITY ON AERO CHAR.
40	58	7.66	NACA 4415	SLIDING, FOWLER (SLOTTED)	.40	2.0	3	2, 1	LE SLAT	1.67	VARIES	0	8	–	X		X		X		X				SEMISPAN MODEL. EFFECTS OF PROPELLER POSITION AND OVERLAP ON SLIPSTREAM DEFLECTION CHAR (EFFECTS OF PROPELLER VERTICAL POSITION, CHORDWISE POSITION, AND OVERLAP). EFFECTS OF LE SLAT, NACELLE SIZE, EXTENSION OF NACELLES THROUGH FLAPS (FLAP SEGMENTATION), AND NUMBER OF PROPELLERS. EFFECT OF GROUND PROXIMITY ON PROPELLER STATIC THRUST EFFICIENCY. ANGLE BETWEEN THRUST AXIS AND GROUND PLANE VARIES WITH FLAP DEFLECTION.
41	65	7.67	NACA 23017, NACA 23012		.25	(a) 11.0 (b) 9.3		2	BLC, LE SLAT	(a) 1.02 (b) .87															FLIGHT AND SIMULATOR TESTS OF STOL SEAPLANE UF-XS COMPARED. DEFLECTED-SLIPSTREAM TYPE. NO PROPELLER OVERLAP. MOVING-BASE SIMULATOR. AUTOMATIC STABILIZATION EQUIPMENT IN PLANE. COMPARISON WITH FLIGHT TESTS OF OTHER STOL VEHICLES AND WITH BREGUET 941 SIMULATOR STUDIES. HANDLING QUALITIES RATHER THAN PERFORMANCE OF CHIEF CONSIDERATION.
42	65	–	–	–	–	–	–	–	–	–	–	–	–	–											EQUATIONS ESTIMATING LIFT AND LONG. FORCE COEFFICIENTS FOR STOL AND WINGS IN PROPELLER SLIPSTREAMS. COMPARISON WITH TEST DATA. EFFECTS OF PROPELLER SLIPSTREAM, PROPELLER THRUST, TAPER RATIO, SLATS, FLAP-CHORD-TO-WING-CHORD RATIO, PROPELLER-DIAMETER-TO-CHORD RATIO, AND WING CAMBER.
43	61			SLOTTED				2	LE SLAT						X	X							X		TILT-WING AND DEFLECTED-SLIPSTREAM CONFIG. NO PROPELLER OVERLAP. AERO CHAR OF VTOL IN HOVER AND TRANSITION. EFFECTS OF WING CHORD, SLATS, AND FLAPS ON POWER REQUIRED.
44	64	4.78	MOD NACA 4415	SLIDING	.33	2.33	3	1	LE DROOP	1.79	$-10^\circ \rightarrow 20^\circ$														1/4-SCALE, FULL-SPAN MODEL OF VZ-2. FULL-SPAN AILERONS. EFFECT OF FLAPS AND LE DROOP ON LONG. AERO CHAR. EFFECT OF FLAP DEFLECTION ON FLOW PATTERNS. TUFT TESTS. AILERON CONTROL EFFECTIVENESS.
45	60	4.86	NACA 0015	–	–	2.0	3	2	–	1.33	$-10^\circ \rightarrow 90^\circ$	.90	8	.80	X	X		X			X			X	SEMISPAN TILT-WING MODEL. PROPELLERS OVERLAPPED. INVESTIGATION OF WING-PROPELLER COMBINED AND SEPARATELY. NACELLE EFFECTS. PROPELLER EFFICIENCY. SPINNER CHARACTERISTICS. PITCHING-MOMENT INCREMENT DUE TO PROPELLERS. APPENDIXES: (1) TUNNEL-WALL CORRECTIONS, (2) SLIPSTREAM CHARACTERISTICS, (3) PERFORMANCE CALCULATIONS.
46	55	4.88	NACA 0015	SLOTTED	.60, .30	2.0	3	2, 1	VANE	1.33	$-40^\circ \rightarrow 90^\circ$	–	8	–	X	X					X				SEMISPAN DEFLECTED-SLIPSTREAM MODEL. PROPELLERS OVERLAPPED. TURNING EFFECTIVENESS OF LARGE-CHORD SLOTTED FLAPS. FORWARD-SPEED TEST WITH INBOARD PROPELLER ONLY. EFFECTS OF VANE AND WING INCIDENCE ON TURNING EFFECTIVENESS. COMPARISON OF TURNING EFFECTIVENESS AND PITCHING MOMENTS OF WING WITH PLAIN FLAPS VS SLOTTED FLAPS. EFFECT OF PROPELLER BLADE ANGLE ON STATIC CONDITION.
47	57	4.88	NACA 4415	SLIDING, SLOTTED	.60 .30	2.0	–	2	LE SLAT	1.33		0	4.8	–	X		X			X	X				SEMISPAN MODEL. PROPELLERS OVERLAPPED. EFFECTS OF FLAP DEFLECTION, GROUND PROXIMITY, LE SLAT, END PLATES, AND MODE OF PROPELLER ROTATION. EFFECT OF ATTITUDE OF THRUST AXIS TO GROUND PLANE FROM 0 TO 20°.
48	59	4.88	NACA 0015	SLOTTED	.60, .30	2.0	3	2, 1	VANE	1.33		0	4.8	–	X		X	X	X		X			X	SEMISPAN MODEL. PROPELLERS OVERLAPPED. EFFECTS OF GROUND PROXIMITY AND PROPELLER POSITION ON TURNING EFFECTIVENESS OF WING WITH LARGE-CHORD SLOTTED FLAPS. TUFT STUDIES DISCUSSED. GROUND EFFECT ON ISOLATED PROPELLER THRUST. WING INCIDENCE VARIED. 20° ANGLE BETWEEN THRUST AXIS AND GROUND PLANE.

TABLE 9.2-A (CONT'D)

REFERENCE NO.	YEAR OF PUBLICATION	WING ASPECT RATIO	WING AIRFOIL SECTION	TYPE OF FLAP	FLAP CHORD TO AIRFOIL CHORD RATIO (FLAP RETRACTED)	PROPELLER DIAMETER (FT)	BLADES PER PROPELLER	NUMBER PROPELLERS PER SEMISPAN	AUXILIARY TURNING AIDS	PROPELLER DIAMETER / WING CHORD	α RANGE	MAX. ADVANCE RATIO	SLIPSTREAM DYNAMIC PRESSURE (LB/FT²)	SLIPSTREAM REYNOLDS NUMBER (BASED ON WING MAC)	STATIC TURNING EFFECTIVENESS	TRANSITION PERFORMANCE	GROUND EFFECTS	PROPELLER FORCES	PROPELLER LOCATION VARIED	PROPELLER ROTATION MODE	PROPELLER RPM	SLIPSTREAM DYN. PRESS. SURVEY	DOWNWASH SURVEY	POWER	COMMENTS
			CONFIGURATION GEOMETRY								TEST CONDITIONS				TEST DATA										
49	54	4.55	NACA 0015	PLAIN	.60, .30	2.0	3	2, 1	2 VANES	1.33	$-30° \rightarrow 90°$	–	8	.80	X	X		X			X				SEMISPAN MODEL. TILT-WING AND DEFLECTED-SLIPSTREAM CONFIG. PROPELLERS OVERLAPPED. TURNING VANES ABOVE NOSE OF FIRST FLAP. EFFECT OF NO. OF PROPELLERS ON AERO CHAR. EFFECTS OF FLAP DEFLECTION AND ANGLE OF ATTACK ON PROPELLER NORMAL FORCE AND PITCHING MOMENTS. PERFORMANCE CALCULATIONS. EFFECT OF VANES.
50	56	4.55	NACA 0015	SLOTTED	.60, .30	2.0	3	2, 1	LE SLAT	1.33		0	4.8	–	X		X		X		X				SEMISPAN MODEL. PROPELLERS OVERLAPPED. EFFECT OF LE SLAT AS A LONG CONTROL DEVICE. SLAT POSITION VARIED. EFFECTS OF PROPELLER LOCATION. EFFECTS OF ONE AND TWO PROPELLERS IN GROUND-EFFECT REGION COMPARED. TUFT STUDIES DISCUSSED. 20° ANGLE BETWEEN THRUST AXIS AND GROUND PLANE.
51	56	2.67	NACA 4415	SLIDING, PLAIN	.50, .25	2.0	–	1	LE SLAT, END PLATE	1.33		0	4.8	–	X		X				X				SEMISPAN MODEL. TURNING EFFECTIVENESS OF A WING EQUIPPED WITH A SLIDING FLAP AND A LE SLAT. EFFECT OF SLIDING FLAP ON PITCHING MOMENTS. COMPARISON OF CHAR OF SLIDING-FLAP WING AND SLOTTED-FLAP WING OF REF 46 AND 48. 20° ANGLE BETWEEN THRUST AXIS AND GROUND PLANE.
53	57	4.89	NACA 4415	SLIDING, SLOTTED	.50, .30	2.0	–	2	LE SLAT	1.33	$-40° \rightarrow 120°$	1.5	4.8	62	X	X		X			X			X	SAME MODEL AS REF 47. AERO CHAR OF HYPOTHETICAL V/STOL MODEL. EFFECTS OF LE SLAT AND HORIZONTAL STABILIZER. NO CORRECTION FOR TUNNEL-WALL EFFECTS.
54	60	7.66	NACA 4415	SLIDING, FOWLER (SLOTTED)	.40	2.0	3	2, 1	LE SLAT	1.67	$-70° \rightarrow 90°$	1.10	8	.63		X	X				X	X	X	X	SEMISPAN MODEL. NO PROPELLER OVERLAP. SAME MODEL AS REF 40. LONG AERO CHAR OF TILT-WING, DEFLECTED-SLIPSTREAM CONFIG. PROPELLER-ALONE AND WING-ALONE DATA. EFFECT OF SLAT POSITION, FLAP DEFLECTION, GROUND PROXIMITY, AND DOWNWASH. EST PERFORMANCE OF HYPOTHETICAL AIRPLANE. APP ON CHAR OF 17-FT SECTION OF LANGLEY 300-MPH 7- x 10-FT TUNNEL.
56	68	–	–	–	–	–	–	–	–	–	–	–	–	–											WING LIFTING-SURFACE THEORY WITH INCLINED SLIPSTREAMS, INCLINED ACTUATOR DISC THEORY, AND FORTRAN COMPUTER PROGRAM. COMPARED WITH TEST DATA: SLIPSTREAM DOWNWASH ANGLE, SLIPSTREAM ROTATION ANGLE, SPAN LOAD DISTRIBUTION, AND DOWNWASH ANGLE. DESIGN CHARTS FOR 2-SLIPSTREAM AND 4-SLIPSTREAM CONFIG AT VARIOUS PROPELLER ANGLE OF ATTACK, FLAP DEFLECTION, ADVANCE RATIO, ANGLE OF ATTACK, AND THRUST COEFFICIENT.
58	56	5.42	NACA 4415	DOUBLE SLOTTED	.40	2	3	1		1.55	$-4° \rightarrow 44°$		7.5	.65							X		X		DEFLECTED-SLIPSTREAM WING-BODY STOL MODEL IN LANGLEY 300-MPH 7- x 10-FT TUNNEL. EFFECT OF TAIL AREA, TAIL HEIGHT, THRUST, AND TAIL INCIDENCE ON LONG AERO CHAR.
59	68																								WIND-TUNNEL TEST ON PROPELLER-WING-FLAP MODEL USED IN DEFLECTED-SLIPSTREAM STOL AIRCRAFT. EQUATIONS FOR EST AERO FORCES AND COMPARISON WITH TEST DATA.
61	63	5.24	NACA 4415	–	–	9.5	3	1	LE SLAT, LE DROOP	2.0	$-12° \rightarrow 34°$														VZ-2 TILT-WING IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF SLATS, NOSE DROOP, AND WING INCIDENCE ON AERO CHAR. TUFT STUDIES. STALL DIAGRAMS.
62	63	4.0	NACA 0015	SLOTTED	.50, .30	3.5	4	2	BLC	1.167	$0 \rightarrow 30°$	–	2	–	X	X	X	X			X			X	LARGE FULL-SCALE MODEL (12-FT SPAN). NO PROPELLER OVERLAP. MOBILE TEST RIG. EFFECTS OF BLOWING OVER NOSE OF REAR FLAP (.30C). GROUND-PROXIMITY EFFECTS OVER FIXED AND MOVING GROUND. α VARIED FOR FORWARD-SPEED TESTS. THRUST MEASURED. POWER RATIO GIVEN.
63	64	8.53	NACA 63_3-318	DOUBLE SLOTTED	.47	1.72	4	2	LE SLAT	1.91							X								1/9-SCALE TILT-WING V/STOL IN LANGLEY FULL-SCALE TUNNEL. PROPELLERS OVERLAPPED. FREE-FLIGHT TESTS IN HOVERING, FORWARD LEVEL FLIGHT, AND DESCENT AT VARIOUS ANGLES OF DESCENT AND WING INCIDENCES, AS WELL AS FORCE TESTS. EFFECTS OF GROUND PROXIMITY.
64	68	(a) 5.71 (b) 6.52 (c) 8.06	NACA 63_2-416	TRIPLE SLOTTED	~.24	9.3	3	2	LE SLAT	(a) 1.19 (b) 1.22 (c) 1.27										X					LARGE-SCALE DEFLECTED-SLIPSTREAM STOL IN AMES 40- x 80-FT TUNNEL. NO PROPELLER OVERLAP. 3 WING SPANS. EFFECTS ON LONG AERO CHAR OF WING SPAN, FLAP DEFLECTION, SLATS, PROPELLER ROTATION DIRECTION, AND SPANWISE VARIATION OF PROPELLER THRUST.

TABLE 9.2-A (CONT'D)

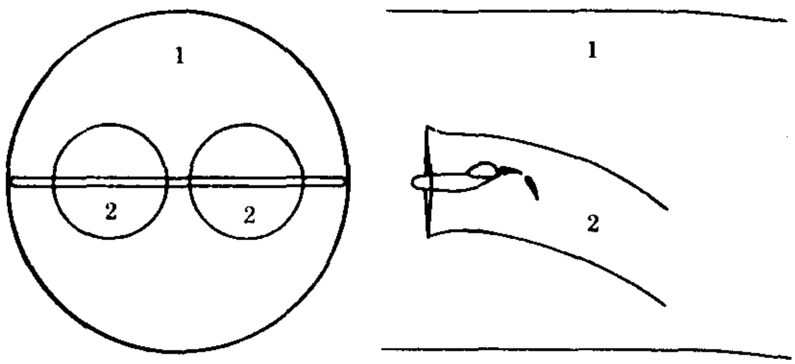
REFERENCE NO.	YEAR OF PUBLICATION	WING ASPECT RATIO	CONFIGURATION GEOMETRY: WING AIRFOIL SECTION	TYPE OF FLAP	FLAP CHORD TO AIRFOIL CHORD RATIO (FLAP RETRACTED)	PROPELLER DIAMETER (FT)	BLADES PER PROPELLER	NUMBER PROPELLERS PER SEMISPAN	AUXILIARY TURNING AIDS	PROPELLER DIAMETER / WING CHORD	TEST CONDITIONS: α RANGE	MAX. ADVANCE RATIO	SLIPSTREAM DYNAMIC PRESSURE (LB/FT²)	SLIPSTREAM REYNOLDS NUMBER (BASED ON WING MAC)	TEST DATA: STATIC TURNING EFFECTIVENESS	TRANSITION PERFORMANCE	GROUND EFFECTS	PROPELLER FORCES	PROPELLER LOCATION VARIED	PROPELLER ROTATION MODE	PROPELLER RPM	SLIPSTREAM DYN. PRESS. SURVEY	DOWNWASH SURVEY	POWER	COMMENTS
65	60	4.58	NACA 0015	–		1.167	3	1	–	1.76	0 → 90°			.0644 → .4				X			X				TILT-WING ASSAULT TRANSPORT MODEL IN OPEN-END TUNNEL TO GET STAB DERIVS FOR EQ OF MOTION. PROPELLER EFFECTS DURING HOVER AND TRANSITION.
66	65	4.74	NACA 4415	SINGLE SLOTTED	.34	9.67	3	1	DROOPED LE	1.84						X	X								FLIGHT TEST OF VZ-2 TILT-WING VTOL IN LANGLEY FULL-SCALE TUNNEL. FULL-SPAN AILERONS EFFECT OF FULL-SPAN FLAPS ON RATE OF DESCENT. GROUND EFFECTS.
67	68	8.53	NACA 63-318	DOUBLE SLOTTED	.33	1.55	4	2	LE SLAT	1.92			VAR-IES				X				X				1/10-SCALE TILT-WING MODEL IN PRINCETON DYNAMIC MODEL TRACK. SAME AS LTV XC-142A OF REF 13 WITH LE SLATS ADDED. PROPELLERS OVERLAPPED. GROUND EFFECTS. GROUND HEIGHT, THRUST COEFF, WING INCIDENCE, FLAP DEFLECTION, AND HORIZONTAL VELOCITY VARIED. LIFT, DRAG, PITCHING MOMENT IN STOL TAKE-OFF AND LANDING. COMPARISON OF WIND-TUNNEL AND MOVING-BELT TESTS.
68	69	8.53	NACA 63-318	DOUBLE SLOTTED	.33	1.55	4	2	LE SLAT	1.92											X				1/10-SCALE TILT-WING V/STOL OF XC-142A IN PRINCETON DYNAMIC MODEL TRACK. PROPELLERS OVERLAPPED. LAT-DIR DYNAMIC STAB CHAR IN DESCENT CONDITION. TIME HISTORIES OF RESPONSE TO VARIATIONS IN PROPELLER PITCH, FUSELAGE PITCH ATTITUDE, DESCENT ANGLE VELOCITY, AND DEGREES OF FREEDOM.
69	64	6.52	NACA 63A416	TRIPLE SLOTTED	.385	14.76	3	2	–	1.21															FLIGHT TEST OF BREGUET 941 PROTOTYPE ASSAULT TRANSPORT (DSS) NO PROPELLER OVERLAP. INTERCONNECTED PROPELLERS. STOL PERFORMANCE, HANDLING QUALITIES, AND OPERATIONAL TECHNIQUES. LIFT AND DRAG AT VARIOUS THRUST COEFFICIENTS IN TAKE-OFF, LANDING, AND WAVE-OFF CONFIGURATIONS.
70	63	10.09	NACA 64A318 (ROOT), 64A412 (TIP)		.25	13.5	4	2	BLOWING BLC, DROOPED AILERONS	.985	−8° → 12°														FLIGHT TESTS OF MODIFIED LOCKHEED C-130B (DSS). NO PROPELLER OVERLAP. STOL PERFORMANCE, HANDLING QUALITIES, AND OPERATIONAL TECHNIQUES. LIFT, DRAG, INCLUDING EFFECT OF BLC IN TAKE-OFF AND LANDING.
71	64	4.78	MOD NACA 4415	SINGLE SLOTTED	.33	2.33	3	1	KRUGER-TYPE FLAP	1.79										X					FLIGHT TESTS OF 1/4-SCALE VZ-2 TILT-WING VTOL IN LANGLEY FULL-SCALE TUNNEL. TIME HISTORIES AND PILOT RATINGS OF DYNAMIC LATERAL CONTROL IN DESCENT
72	58	2.67	NACA 4415	SLOTTED, PLAIN	.67 .33	2.0	–	1	BLC	1.33		0	4.8	–	X		X				X			X	SEMISPAN MODEL. EFFECTIVENESS OF BLOWING A JET SHEET OF AIR OVER A PLAIN REAR FLAP COMBINED WITH A SLOTTED FORWARD FLAP IN DEFLECTING PROPELLER SLIPSTREAM DOWNWARD. AIR EXHAUSTED OVER REAR FLAP ONLY. EFFECTS OF GROUND PROXIMITY. BLOWING SYSTEM CHARACTERISTICS. 20° ANGLE BETWEEN THRUST AXIS AND GROUND PLANE.
73	60	7.0	NACA 63A412	SLIDING, TE EXTENSION	.385	1.33	3	2	BLC	1.0	−30° → 80°	.6	6	–	X	X	X				X			X	SEMISPAN MODEL. NO PROPELLER OVERLAP. PROPELLERS DO NOT SPAN ENTIRE WING. NO DATA ANALYSIS. AERO CHAR OF JET-FLAPPED AND DEFLECTED-SLIPSTREAM CONFIG. PRESS SURVEY DATA. EFFECT OF GROUND PROXIMITY FOR STATIC AND FORWARD-SPEED CONDITIONS.
74	56	2.67	NACA 4415	SLIDING, PLAIN	.50, .26	2.0	–	1	LE SLAT, BLC, END PLATE	1.33		0	4.8	–	X		X		X		X				SEMISPAN MODEL. EFFECTIVENESS OF BLOWING A JET OF AIR OVER FLAPS IN DEFLECTING PROPELLER SLIPSTREAM DOWNWARD. EFFECTS OF LE SLAT, GROUND PROXIMITY, END PLATE, AND PROPELLER POSITION. BLOWING SYSTEM CHAR. RATIO OF RESULTANT FORCE OBTAINED BY BLOWING VS THAT OBTAINED BY USING EQUAL POWER IN THE PROPELLER. 20° ANGLE BETWEEN THRUST AXIS AND GROUND PLANE.
75	57	4.0	NACA 4415	PLAIN	.50, .20	2.0, 1.67, 1.33	–	1	BLC	2.00		0	4.8	.39, .47, .59	X		X								SEMISPAN MODEL. EFFECTS OF PROPELLER DIAMETER ON ABILITY OF FLAPPED WING, WITH AND WITHOUT BLC TO DEFLECT PROPELLER SLIPSTREAM DOWNWARD. BLOWING SYSTEM CHAR. EFFECTS OF GROUND PROXIMITY. 20° ANGLE BETWEEN THRUST AXIS AND GROUND PLANE. R_f VARIES WITH PROPELLER DIAMETER.

TABLE 9.2-A (CONTD)

		Configuration Geometry									Test Conditions				Test Data										
REFERENCE NO.	YEAR OF PUBLICATION	WING ASPECT RATIO	WING AIRFOIL SECTION	TYPE OF FLAP	FLAP CHORD TO AIRFOIL CHORD RATIO (FLAP RETRACTED)	PROPELLER DIAMETER (FT)	BLADES PER PROPELLER	NUMBER PROPELLERS PER SEMISPAN	AUXILIARY TURNING AIDS	PROPELLER DIAMETER / WING CHORD	α RANGE	MAX. ADVANCE RATIO	SLIPSTREAM DYNAMIC PRESSURE (LB/FT²)	SLIPSTREAM REYNOLDS NUMBER (BASED ON WING MAC)	STATIC TURNING EFFECTIVENESS	TRANSITION PERFORMANCE	GROUND EFFECTS	PROPELLER FORCES	PROPELLER LOCATION VARIED	PROPELLER ROTATION MODE	PROPELLER RPM	SLIPSTREAM DYN. PRESS. SURVEY	DOWNWASH SURVEY	POWER	COMMENTS
76	63	(a) 4.62 (b) 7.39 (c) 12.31	(a),(b) NACA 4415 (c)NACA 4424	(a) SINGLE SLOTTED (b),(c) –	(a) 4.0 (b) – (c) –	2.0		1	LE SLAT	(a) 3 (b) 4.8 (c) 8	$0 \rightarrow 10^\circ$		8	(a) .350 (b) .218 (c) .131						X					3 SEMISPAN TILT-PROPELLER VTOL MODELS IN LANGLEY 300-MPH 7- x 10-FT TUNNEL. EFFECT OF WING-CHORD-TO-PROPELLER-DIAMETER RATIO, PROPELLER ROTATION DIRECTION, PROPELLER INCIDENCE, THRUST COEFF, AND FLAP DEFLECTION ON AERO CHAR. EFFECT OF WING-CHORD-TO-PROPELLER-DIAMETER RATIO, WING SPAN, PROPELLER ROTATION DIRECTION, WING ANGLE OF ATTACK, PROPELLER INCIDENCE, AND LE SLAT ON POWER REQUIRED, PITCHING MOMENT, AND THRUST ANGLE OF ATTACK. TRANSITION REGIME.
79	59	(a) 7.5 (b) 5.0 (c) 3.33	NACA 0015	–	–	2.0	–	1	LE SLAT	2.96	$-10^\circ \rightarrow 110^\circ$	1.0	8	(a) .352 (b) .53 (c) .795		X					X			X	SEMISPAN MODEL. EFFECT OF CHANGES IN WING CHORD AND LE SLATS ON LONG. AERO CHAR. OF WING-PROPELLER TILT-WING CONFIG. TUFT-GRID PHOTOGRAPHS. PROPELLER EFFICIENCY. R_ℓ VARIES WITH WING CHORD.
90	68	2.82	NACA 0015	–	–	2.0	3	1	–	1.33															TILT WING ON PRINCETON DYNAMIC MODEL TRACK (PROPELLER + NACELLE). AERO CHAR IN TRANSITION AND HOVER. GRAPHS OF LIFT, HORIZ FORCE, AND PITCHING MOMENT VS THRUST FOR VARIOUS WING ANGLES.
82	61	5.64	NACA 23017	SINGLE SLOTTED	–	4.77	3	2	BLC, LE SLAT	.92							X								LARGE-SCALE TILT-WING, DEFLECTED-SLIPSTREAM VTOL. NO PROPELLER OVERLAP. EFFECTS ON AERO CHAR OF WING TILT, LE FLAP, GROUND HEIGHT, THRUST-COEFFICIENT VARIATION, FLAP DEFLECTION, AND BLOWING.
83	64	5.54	NACA 23017	SINGLE SLOTTED	–	4.77	3	2	LE SLAT BLC ON TE, BLC NOSE FLAP	.92	$-28^\circ \rightarrow 28^\circ$							X		X					LARGE-SCALE TILT-WING, DEFLECTED-SLIPSTREAM VTOL. NO PROPELLER OVERLAP. WING FLOW PATTERNS FROM TUFT STUDIES. EFFECTS OF THRUST, FLAPS, SLATS, BLOWING, AND WING TILT ON AERO CHAR. EFFECTS OF WING TILT, FLAPS, SLATS, PROPELLER ROTATION DIRECTION, AND STALL CONTROL DEVICES ON BUFFET BOUNDARY AND DESCENT CHAR.
84	65	5.0	NACA 23021	FOWLER	.40	15.17	3	1	LE SLAT, DROOPED LE	2.21					X	X					X				TILT-WING MODIFIED GRUMMAN JRF-5 VTOL IN AMES 40- x 80-FT TUNNEL. GROUND TEST STAND. EFFECTS OF WING TILT, FLAPS, BLADE FLAP DEFLECTION, VELOCITY, AND LE DEVICES ON LONG CHAR IN TRANSITION. TUFT STUDIES. EFFECT OF ROTOR CYCLIC CONTROL ON LONG AND LATERAL CHAR.
85	63	(a) 6.04 (b) 7.84	–	SINGLE SLOTTED	.30	1.833	3	1		(a) 1.96 (b) 2.40	$0 \rightarrow 90^\circ$							X							SEMISPAN TILT WING AND FUSELAGE. EFFECTS OF FLAP DEFLECTION, THRUST COEFFICIENT, AND NACELLE SHAPE ON AERO CHAR.

9.2.1 PROPELLER-WING-FLAP LIFT VARIATION WITH POWER AND ANGLE OF ATTACK

The methods for calculating power-on lift and drag forces of tilt-wing and deflected-slipstream configurations are those developed by Kuhn in reference 1. The methods treat the flow system of a propeller-wing-flap configuration as two separate mass flows, each deflected through a different angle by the wing. The two mass flows are (1) the mass flow deflected downward by the wing through small to moderate angles and (2) the mass flow in slipstreams created by the action of the propellers and deflected downward through large angles by either tilting the thrust axis or deflecting the flaps. These flow systems are illustrated in sketch (a).



SKETCH (a)

The forces generated in deflection of these mass flows are the familiar lift, induced drag, and profile drag of a wing in a free stream; the propeller thrust which accelerates the propeller slipstream; and a force which accounts for deflection of the propeller slipstream by the wing. Kuhn has analyzed the forces arising from the deflection of each mass flow separately and combined them to arrive at a semiempirical method based on simple momentum theory to estimate the lift and drag forces of propeller-wing-flap configurations. The method uses static slipstream deflection data and power-off wing-flap data as the basis for the calculations.

Kuhn develops expressions for both the lift and drag forces in cruising and high-speed flight by neglecting the forces due to the propeller slipstream and treating the deflection of the mass flow affected by the wing within the assumption of simple momentum thoery. Using this assumption at very low cruising speeds requires that the stream tube be deflected through large angles with a minimum loss in order to produce enough lift to support the airplane. Although the validity of extrapolation of simple momentum theory to large angles appears to be a rather gross assumption, the theory gives reasonable results as long as stall can be avoided.

At zero forward speed, only the propeller slipstreams are available to produce thrust and lift. At this end of the speed range Kuhn develops expressions for the lift and drag forces from available static experimental data on the effectiveness of wing-flap systems in deflecting propeller slipstreams. These expressions are presented in terms of propeller thrust, slipstream characteristics, and the turning effectiveness parameters θ and $\frac{F}{T}$. The slipstream characteristics are obtained using simple momentum theory as applied to propellers.

At transition speeds both flow regions are considered. The resulting expressions approach the power-off wing expressions as velocity is increased and thrust reduced to zero, and approach the zero-forward-speed expressions as the speed is reduced to zero. The method thus provides a logical means of interpolating between these end points.

In treating the flow in the two systems, the fact that the propeller slipstreams occupy space within the large wing stream tube is compensated for by assuming the propeller slipstream to be fully contracted at the wing and that the contraction does not alter the diameter of the stream tube affected by the wing.

To determine the velocity increments necessary to calculate momentum changes, Kuhn assumes that the propeller slipstreams are deflected through the turning angle θ obtained at zero forward speed, that the stream tube affected by the wing is deflected through the downwash angle ϵ obtained under power-off conditions, and that both θ and ϵ remain constant with changes in speed and power.

In order to apply the Datcom methods, it is necessary to have experimental results for or to be able to estimate power-off lift and drag-force characteristics of the wing, as well as slipstream deflection characteristics of the propeller-wing-flap configuration at zero forward speed. The slipstream deflection characteristics for a given propeller-wing-flap configuration require experimental static-thrust data, which will more than likely not be available during the preliminary design phase. Therefore design charts, taken from reference 1, for the slipstream deflection characteristics are provided.

The method presented in this Section is for estimation of the lift of propeller-wing-flap configurations at combined forward speed and power-on conditions. The method is applicable only in the unstalled region of flight.

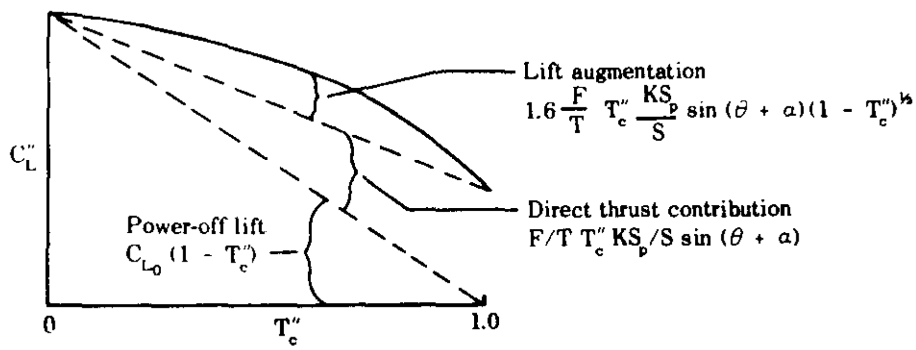
DATCOM METHOD

The lift of a propeller-wing-flap configuration at combined forward speed and power-on conditions is given in reference 1 as

$$C_L'' = C_{L_o} (1 - T_c'') + \frac{F}{T} T_c'' \frac{KS_p}{S} \sin (\theta + \alpha) \left[1 + 1.6 (1 - T_c'')^{1/2} \right] \quad 9.2.1\text{-a}$$

where all the parameters are defined in the general notation list of Section 9.2. The coefficients, except for C_{L_o}, are based on the dynamic pressure in the propeller slipstream, and the positive direction of forces and angles is shown in Figure 9.2-6.

The first term of equation 9.2.1-a represents the power-off lift contribution. The last term represents both the direct propeller thrust contribution and the lift augmentation of the wing due to the propeller slipstream. The significance of these terms is illustrated in sketch (b).



SKETCH (b)

The procedure to be followed in evaluating equation 9.2.1-a is outlined in the following steps.

Step 1. Determine the slipstream turning angle θ by

$$\theta = \theta_f + \Delta\theta \qquad 9.2.1\text{-b}$$

where

θ_f is the slipstream turning angle under conditions of zero incidence and zero camber

$\Delta\theta$ is the slipstream turning-angle increment due to wing camber and incidence between the wing-chord plane and the thrust axis

θ_f is obtained by

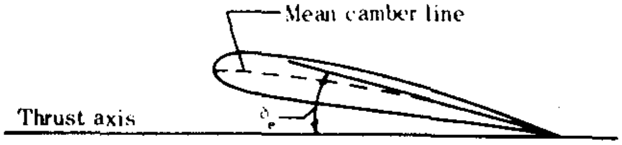
$$\theta_f = \frac{\theta}{\delta}\,\delta \qquad 9.2.1\text{-c}$$

where $\frac{\theta}{\delta}$ is obtained from figure 9.2.1-18a as a function of the ratio of the total extended flap chord to the propeller diameter $\frac{c_f}{D}$, and δ is the total flap deflection. For a multiple-flapped configuration the total flap deflection is the sum of the flap deflection of each individual flap.

$\Delta\theta$ is obtained by

$$\Delta\theta = \frac{\theta}{\delta}\,\delta_e \qquad 9.2.1\text{-d}$$

where $\frac{\theta}{\delta}$ is obtained from Figure 9.2.1-18a as a function of the ratio of the wing chord to the propeller diameter $\frac{c}{D}$, and δ_e is an equivalent flap deflection angle defined as the angle between the thrust axis and the mean camber line at the wing trailing edge (see sketch (c)).



SKETCH (c)

In using this procedure to determine the slipstream turning angle, it is necessary that the value be obtained over the linear part of the curve of variation of turning angle with flap deflection.

In order to define the region of linearity for a given flap configuration, a curve of the variation of the maximum turning angle θ_{max} with the ratio of the total flap chord to the propeller diameter $\frac{c_f}{D}$ is given as figure 9.2.1-18b. A comparison of Figures 9.2.1-18a and 9.2.1-18b indicates that the slope $\frac{\theta}{\delta}$ is dependent only on the total flap chord; whereas the maximum turning angle is dependent upon both the total flap chord and the type of flap. The slope $\frac{\theta}{\delta}$ will become nonlinear as θ_{max} for a given flap configuration is approached. For the purpose of the Datcom the range of the linear variation of θ with δ is defined as

$$\frac{\theta_f}{\theta_{max}} \leq 0.95$$

Step 2. Determine the thrust-recovery factor $\frac{F}{T}$ from figure 9.2.1-19 as a function of the turning angle θ (obtained in Step 1), the flap configuration, and the propeller arrangement.

Step 3. Determine the power-off lift coefficient C_{L_o}.

A wing which is stalled in the power-off condition would frequently be unstalled at some moderate to high propeller thrust coefficient. In order to estimate the power-on data in this region, it is necessary to use the lift values that would exist if the wing were unstalled in the power-off condition. Where possible, experimental power-off data should be used and extrapolated for this purpose. Under these conditions the power-off lift coefficient can be estimated by

$$C_{L_o} = C_{L_{\alpha_o}} 57.3 \sin (\alpha - \alpha_o) \qquad 9.2.1\text{-e}$$

where $C_{L_{\alpha_o}}$ is the extrapolated power-off lift-curve slope of the wing-flap configuration, per degree, and α_o is the extrapolated power-off zero-lift angle of attack.

If power-off data for the given configuration are not available or if the power-off data do not exhibit any region of unstalled flow, the following procedure can be used:

(a) Determine the unflapped wing zero-lift angle of attack from Section 4.1.3.1.

(b) Determine the wing-flap incremental lift from Section 6.1.4.1.

(c) Determine the power-off lift-curve slope of the flapped wing from Section 6.1.4.2.

(d) Using the parameters determined in (a), (b), and (c) construct the power-off lift curve of the flapped wing to obtain α_o.

(e) The power-off lift coefficient of the flapped wing at angle of attack is then obtained using equation 9.2.1-e.

Step 4. The propeller thrust coefficient T_c'' will usually be specified; however, if necessary this parameter can be estimated using the method of Section 9.1.1. $\left(\text{Note that } T_{c_{9.2.1}} = T_{c_{9.1.1}} \frac{S_p}{S}, \text{ and } T_c'' = \frac{T_{c_{9.1.1}}}{T_{c_{9.1.1}} + K}.\right)$

Step 5. The lift coefficient is then obtained from equation 9.2.1-a.

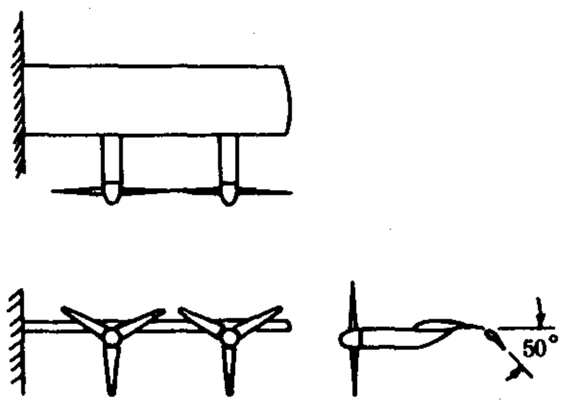
The sample problems illustrate the use of the Datcom method in estimating the lift coefficients of both deflected-slipstream and tilt-wing configurations.

Comparison of experimental data, in the unstalled flight regime, with calculations made using the Datcom method is presented for deflected-slipstream and tilt-wing configurations in Table 9.2.1-A.

Sample Problems

1. Deflected-Slipstream Configuration

Given: A propeller-wing-flap deflected-slipstream configuration of reference 2.



Wing Characteristics

$S = 10.96$ sq ft $\quad A = 7.66 \quad$ NACA 4415 airfoil section

$i_W = 0^{\circ} \quad c = 1.2$ ft (flap retracted) $\quad c = 1.68$ ft (Fowler flap extended)

Flap Characteristics

Fowler flap $\quad \frac{c_f}{c} = 0.286$ (flap extended) $\quad \delta = 50^{\circ}$

Propeller Characteristics

$K = 4$ (2 propellers per semispan, no overlap) $\quad D = 2.0$ ft

$S_p = 3.14$ sq ft

Additional Characteristics

$T_c'' = 0.90 \quad \delta_e = 7.4^{\circ}$

Compute:

Step 1. Determine the slipstream turning angle θ.

$$\frac{c_f}{D} = \frac{c_f}{c}\,\frac{c}{D} = (0.286)\left(\frac{1.68}{2.0}\right)$$

$$= 0.24$$

$\frac{\theta}{\delta} = 0.50$ (figure 9.2.1-18a at $\frac{c_f}{D} = 0.24$)

$\theta_f = \frac{\theta}{\delta}\,\delta = (0.50)(50)$ (equation 9.2.1-c)

$$= 25^{\circ}$$

Assuming the wing to be a large-chord flap

$$\frac{c}{D} = \frac{1.2}{2.0} = 0.60$$

$\frac{\theta}{\delta} = 0.803$ (figure 9.2.1-18a at $\frac{c}{D} = 0.6$)

$\Delta\theta = \frac{\theta}{\delta}\,\delta_e = (0.803)(7.4)$ (equation 9.2.1-d)

$$= 5.94$$

$\theta = \theta_f + \Delta\theta = 25 + 5.94$ (equation 9.2.1-b)

$$= 30.94^{\circ}$$

Determine if the $\frac{\theta}{\delta}$ value for this wing-flap configuration is in the linear range.

$\theta_{max} = 26.5^\circ$ (figure 9.2.1-18b at $\frac{c_f}{D} = 0.24$)

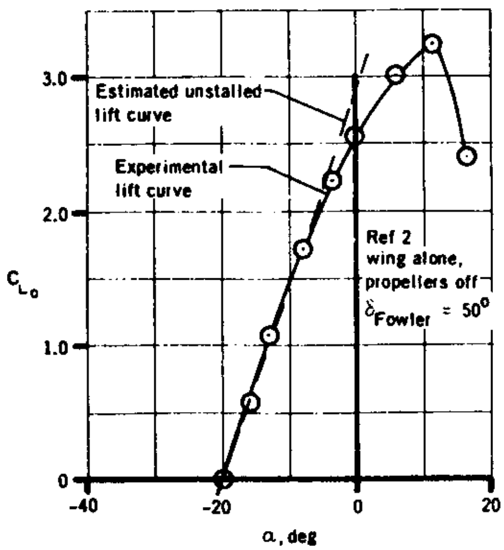
$\frac{\theta_f}{\theta_{max}} = \frac{25}{26.5} = 0.943$ which is within the range of the linear variation of θ with δ as defined by the Datcom.

Step 2. Determine the thrust-recovery $\frac{F}{T}$.

$\frac{F}{T} = 0.96$ (figure 9.2.1-19)

Step 3. Determine the power-off lift coefficient C_{L_o}.

The experimental power-off lift curve is extrapolated to obtain



$\alpha_o = -20^\circ$

$C_{L_{\alpha_o}} = 0.145$ per deg

The lift curve that would exist if the wing were unstalled in the power-off condition is estimated by

$C_{L_o} = C_{L_{\alpha_o}}\ 57.3 \sin(\alpha - \alpha_o)$ (equation 9.2.1-e)

α deg	$(\alpha - \alpha_o)$ deg	$\sin(\alpha - \alpha_o)$	C_{L_o}
-20	0	0	0
-10	10	0.1736	1.442
0	20	0.3420	2.842
10	30	0.5000	4.154
20	40	0.6428	5.341

Solution:

$$C_L'' = C_{L_o}(1 - T_c'') + \frac{F}{T} T_c'' \frac{KS_p}{S} \sin(\theta + \alpha) \left[1 + 1.6(1 - T_c'')^{1/2}\right] \text{(equation 9.2.1-a)}$$

$$= C_{L_o}(1 - 0.9) + (0.96)(0.9)\frac{(4)(3.14)}{(10.96)} \sin(\theta + \alpha)\left[1 + 1.6(1 - 0.9)^{1/2}\right]$$

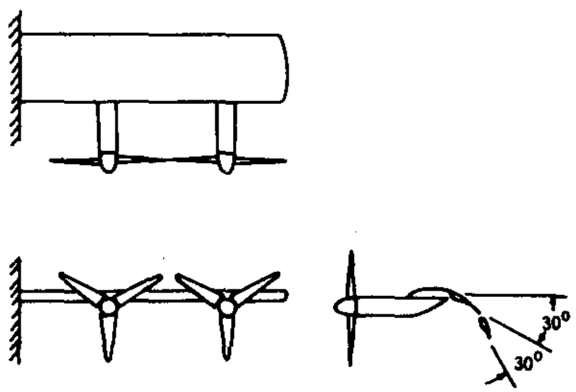
$$= 0.10\, C_{L_o} + 1.491 \sin(\theta + \alpha)$$

① α deg	② C_{L_o}	③ (θ + α) deg	④ sin (θ + α) sin ③	⑤ 0.10 C_{L_o} 0.10 ②	⑥ 1.491 ④	⑦ C_L'' ⑤ + ⑥
-20	0	10.94	0.1898	0	0.2830	0.2830
-10	1.442	20.94	0.3574	0.1442	0.5329	0.6771
0	2.842	30.94	0.5141	0.2842	0.7665	1.0507
10	4.154	40.94	0.6553	0.4154	0.9771	1.3925
20	5.341	50.94	0.7764	0.5341	1.1576	1.6917

These results are compared with experimental data in table 9.2.1-A.

2. Deflected-Slipstream Configuration

Given: A propeller-wing-flap deflected-slipstream configuration of reference 2.



Wing Characteristics

$S = 10.96$ sq ft $\qquad A = 7.66 \qquad$ NACA 4415 airfoil section

$i_W = 0 \qquad c = 1.2$ ft (flaps retracted)

$c = 1.68$ ft (sliding flap and Fowler flap extended)

Flap Characteristics

Combination sliding and Fowler flap

$\frac{c_f}{c} = 0.566$ (sliding flap and Fowler flap extended; effective chord of sliding flap measured to flap knee)

$$\left.\begin{aligned} \delta_{sliding} &= 30^\circ \\ \delta_{Fowler} &= 30^\circ \end{aligned}\right\} \delta = \delta_{sliding} + \delta_{Fowler} = 60^\circ$$

Propeller Characteristics

$K = 4$ (2 propellers per semispan, no overlap) $D = 2.0$ ft

$S_p = 3.14$ sq ft

Additional Characteristics

$T_c'' = 0.90 \qquad \delta_e = 7.4^\circ$

Compute:

Step 1. Determine the slipstream turning angle θ.

$$\frac{c_f}{D} = \left(\frac{c_f}{c}\right)\left(\frac{c}{D}\right) = (0.566)\left(\frac{1.68}{2.0}\right)$$

$$= 0.475$$

$\frac{\theta}{\delta} = 0.72$ (figure 9.2.1-18a at $\frac{c_f}{D} = 0.475$)

$\theta_f = \frac{\theta}{\delta}\,\delta = (0.72)(60)$ (equation 9.2.1-c)

$$= 43.2^\circ$$

Assuming the wing to be a large-chord flap

$$\frac{c}{D} = \frac{1.2}{2.0} = 0.60$$

$\frac{\theta}{\delta} = 0.803$ (figure 9.2.1-18a at $\frac{c}{D} = 0.60$)

$\Delta\theta = \frac{\theta}{\delta}\,\delta_e\ (0.803)(7.4)$ (equation 9.2.1-d)

$$= 5.94^\circ$$

$\theta = \theta_f + \Delta\theta = 43.2 + 5.94$ (equation 9.2.1-b)

$$= 49.14^\circ$$

Determine if the $\frac{\theta}{\delta}$ value for this wing-flap configuration is in the linear range.

$\theta_{max} = 53.5^\circ$ (upper curve of figure 9.2.1-18b at $\frac{c_f}{D} = 0.475$)

$\frac{\theta_f}{\theta_{max}} = \frac{43.2}{53.5} = 0.807$ which is within the range of linear variation of θ with δ as defined by the Datcom.

Step 2. Determine the thrust-recovery factor $\frac{F}{T}$.

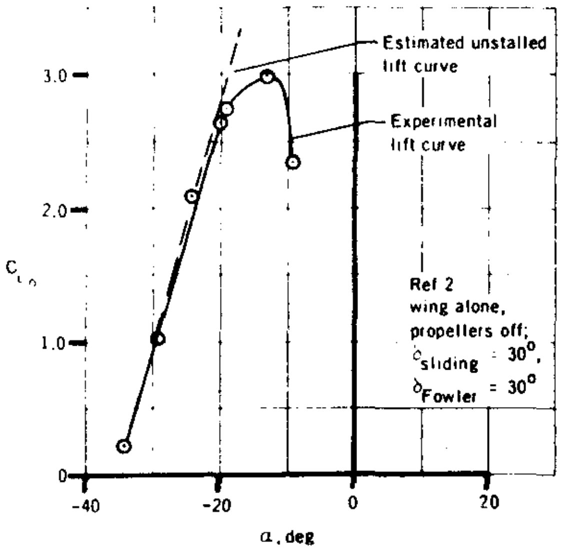
$\frac{F}{T} = 0.90$ (figure 9.2.1-19)

Step 3. Determine the power-off lift coefficient C_{L_o}.

The experimental power-off lift curve is extrapolated to obtain

$\alpha_o = -35^\circ$

$C_{L_{\alpha_o}} = 0.180$ per deg



The lift curve that would exist if the wing were unstalled in the power-off condition is estimated by

$$C_{L_o} = C_{L_{\alpha_o}} 57.3 \sin(\alpha - \alpha_o)$$

(equation 9.2.1-e)

α deg	$\alpha - \alpha_o$ deg	$\sin(\alpha - \alpha_o)$	C_{L_o}
-40	-5	-0.0872	-0.8990
-35	0	0	0
-20	15	0.2588	2.6693
-10	25	0.4226	4.3587
0	35	0.5736	5.9161
10	45	0.7071	7.2930
20	55	0.8192	8.4492

Solution:

$$C_L'' = C_{L_o}(1 - T_c'') + \frac{F}{T} T_c'' \frac{KS_p}{S} \sin(\theta + \alpha) \left|1 + 1.6(1 - T_c'')^{1/2}\right| \quad \text{(equation 9.2.1-a)}$$

$$= C_{L_o}(1 - 0.9) + (0.90)(0.90)\frac{(4)(3.14)}{(10.96)} \sin(\theta + \alpha) \left|1 + 1.6(1 - 0.9)^{1/2}\right|$$

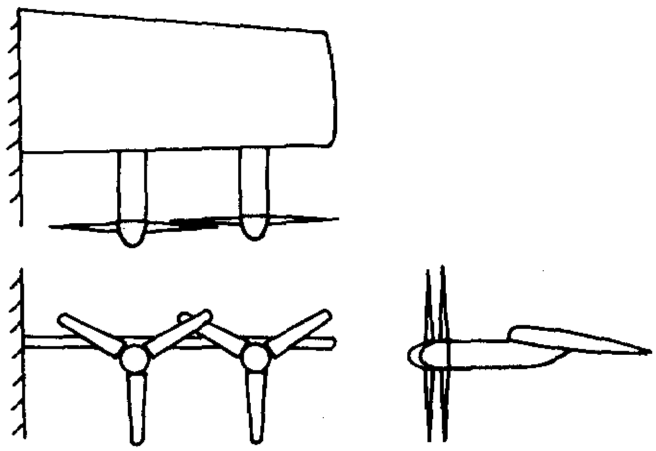
$$= 0.10\, C_{L_o} + 1.3978 \sin(\theta + \alpha)$$

① α deg	② C_{L_o}	③ $(\theta + \alpha)$ deg	④ $\sin(\theta + \alpha)$ sin ③	⑤ $0.10\, C_{L_o}$ 0.10 ②	⑥ 1.3978 ④	⑦ C_L'' ⑤ + ⑥
-40	-0.8990	9.14	0.1588	-0.0899	0.2220	0.1321
-35	0	14.14	0.2443	0	0.3415	0.3415
-20	2.6693	29.14	0.4869	0.2669	0.6806	0.947
-10	4.3587	39.14	0.6312	0.4359	0.8823	1.318
0	5.9161	49.14	0.7563	0.5916	1.0571	1.649
10	7.2930	59.14	0.8585	0.7293	1.2000	1.929
20	8.4492	69.14	0.9344	0.8449	1.3061	2.151

These results are compared with experimental data in table 9.2.1-A.

3. Tilt-Wing Configuration

Given: The propeller-wing configuration of reference 5.



Wing Characteristics

$S = 11.0$ sq ft $A = 4.89$ $i_W = 5^\circ$ NACA 4415 airfoil section

$c = 1.5$ ft

Propeller Characteristics

$K = 4$ (2 propellers per semispan, overlapped) $D = 2.0$ ft

$S_p = 3.14$ sq ft

Additional Characteristics

$T_c'' = 0.69$ $\delta_e = 12.4^\circ$

Compute:

Step 1. Determine the slipstream turning angle θ.

$\theta_f = 0$

$\frac{c}{D} = \frac{1.5}{2.0} = 0.75$

$\frac{\theta}{\delta} = 0.89$ (figure 9.2.1-18a at $\frac{c}{D} = 0.75$)

$\Delta\theta = \frac{\theta}{\delta}\,\delta_e = (0.89)(12.4)$ (equation 9.2.1-d)

$= 11.0^\circ$

$\theta = \theta_f + \Delta\theta$ (equation 9.2.1-b)

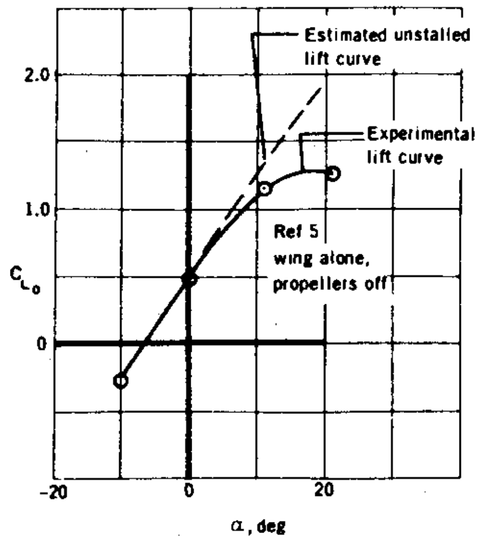
$= 11.0^\circ$

Step 2. Determine the thrust-recovery factor $\frac{F}{T}$.

$\frac{F}{T} = 1.0$ (figure 9.2.1-19)

Step 3. Determine the power-off lift coefficient C_{L_o}.

The experimental power-off lift curve is extrapolated to obtain



$\alpha_o = -6.5°$

$C_{L_{\alpha_o}} = 0.075$ per deg

The lift curve that would exist if the wing were unstalled in the power-off condition is estimated by

$C_{L_o} = C_{L_{\alpha_o}}\ 57.3 \sin(\alpha - \alpha_o)$ (equation 9.2.1-

α deg	$(\alpha - \alpha_o)$ deg	$\sin(\alpha - \alpha_o)$	C_{L_o}
-10	-3.5	-0.0611	-0.2624
-6.5	0	0	0
0	6.5	0.1132	0.4865
10	16.5	0.2840	1.2205
20	26.5	0.4462	1.9175

Solution:

$$C_L'' = C_{L_o}(1 - T_c'') + \frac{F}{T} T_c'' \frac{KS_p}{S} \sin(\theta + \alpha) \quad 1 + 1.6(1 - T_c'')^{1/2} \quad \text{(equation 9.2.1-a}$$

$$= C_{L_o}(1 - 0.69) + (1.0)(0.69)\frac{(4)(3.14)}{(11.0)} \sin(\theta + \alpha) \quad 1 + 1.6(1 - 0.69)^{1/2}$$

$$= 0.31\ C_{L_o} + 1.4897 \sin(\theta + \alpha)$$

①	②	③	④	⑤	⑥	⑦
α deg	C_{L_o}	$(\theta + \alpha)$ deg	$\sin(\theta + \alpha)$ sin ③	$0.31\ C_{L_o}$ 0.31 ②	1.4897 ④	C_L'' ⑤ + ⑥
-10	-0.2624	1.0	0.0175	-0.0813	0.0261	-0.0552
-6.5	0	4.5	0.0785	0	0.1169	0.1169
0	0.4865	11.0	0.1908	0.1508	0.2842	0.4350
10	1.2205	21.0	0.3584	0.3784	0.5339	0.9123
20	1.9175	31.0	0.5150	0.5944	0.7672	1.3616

These results are compared with experimental data in table 9.2.1-A.

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3. Kuhn, R. E., and Draper, J. W.: Investigation of Effectiveness of Large-Chord Slotted Flaps in Deflecting Propeller Slipstreams Downward for Vertical Take-Off and Low-Speed Flight. NACA TN 3364, 1955. (U)

4. Kuhn, R. E., and Draper, J. W.: An Investigation of a Wing-Propeller Configuration Employing Large-Chord Plain Flaps and Large Diameter Propellers for Low-Speed Flight and Vertical Take-Off. NACA TN 3307, 1954. (U)

5. Kuhn, R. E., and Hayes, W. C., Jr.: Wind-Tunnel Investigation of Effect of Propeller Slipstreams on Aerodynamic Characteristics of a Wing Equipped with a 50-Percent-Chord Sliding Flap and a 30-Percent-Chord Slotted Flap. NACA TN 3918, 1957. (U)

TABLE 9.2.1-A
DATA SUMMARY AND SUBSTANTIATION
PROPELLER-WING-FLAP LIFT COEFFICIENT

Ref.	Configuration Characteristics	T_c''	α deg	C_{L_o}*	C_L'' Calc	C_L'' Test	$\Delta C_L''$ (Calc-Test)
2	Deflected-slipstream configuration	0.6	-20	0	0.2520	0.34	-0.09
	Wing		-10	1.442	1.0514	1.25	-0.20
	$S = 10.96$ sq ft		0	2.842	1.8195	1.90	-0.08
	$A = 7.66$		10	4.154	2.5318	2.41	-0.12
	Airfoil: NACA 4415	0.9	-20	0	0.2830	0.28	0
	$i_W = 0$		-10	1.442	0.6771	0.71	-0.03
	$\frac{c}{D} = 0.60$		0	2.842	1.0507	1.07	-0.02
			10	4.154	1.3925	1.39	0
	$\delta_e = 7.4^\circ$		20	5.341	1.6917	1.62	0.07
	Propeller	0.95	-20	0.	0.2693	0.26	0.01
	$K = 4$ (no overlap)		-10	1.442	0.5792	0.59	-0.01
	$D = 2.0$ ft		0	2.842	0.8716	0.87	0
	Flap		10	4.154	1.1375	1.14	0
	Fowler flap		20	5.341	1.3687	1.35	0.02
	$\frac{c_f}{D} = 0.24$ (flap extended)						
	$\delta = 50^\circ$						
	Additional						
	$\frac{F}{T} = 0.96$						
	$\theta = 30.96^\circ$						
2	Deflected-slipstream configuration	0.6	-40	-0.8990	-0.162	-0.20	0.04
	Wing		-20	2.6693	1.674	1.56	0.11
	$S = 10.96$ sq ft		-10	4.3587	2.529	2.21	0.32
	$A = 7.66$	0.9	-40	-0.8990	0.132	-0.05	0.18
	Airfoil: NACA 4415		-20	2.6693	0.947	0.91	0.04
	$i_W = 0$		-10	4.3587	1.318	1.28	0.04
	$\frac{c}{D} = 0.60$		0	5.9161	1.649	1.56	0.09
			10	7.2930	1.929	1.71	0.22
	$\delta_e = 7.4^\circ$		20	8.4492	2.151	1.70	0.45
	Propeller	0.95	-40	-0.8990	0.166	0.02	0.15
	$K = 4$ (no overlap)		-20	2.6693	0.781	0.68	0.10
	$D = 2.0$ ft		-10	4.3587	1.004	1.0	0
	Flap		0	5.9161	1.302	1.26	0.04
	Sliding + Fowler flap		10	7.2930	1.506	1.46	0.05
			20	8.4492	1.665	1.53	0.13
	$\frac{c_f}{D} = 0.475$ (flaps extended)		30	9.3476	1.773	1.48	0.29
	δ sliding $= 30^\circ$						
	δ Fowler $= 30^\circ$						
	Additional						
	$\frac{F}{T} = 0.90$						
	$\theta = 49.14^\circ$						

* Estimated unstalled power-off lift coefficient

TABLE 9.2.1-A (CONTD)

Ref.	Configuration Characteristics	T_c''	α deg	$C_{L_o}^*$	C_L'' Calc	C_L'' Test	$\Delta C_L''$ (Calc-Test)
3	**Deflected-slipstream configuration**	0.5	-20	-0.1600	0.009	0	0.01
	Wing		-10	0.6380	0.515	0.50	0.01
	$S = 10.25$ sq ft		0	1.4165	1.004	1.075	-0.03
	$A = 4.55$		10	2.1522	1.464	1.575	-0.11
	Airfoil: NACA 0015		20	2.8224	1.878	1.775	0.10
	$i_W = 0$		30	3.4064	2.236	-	-
	$\frac{c}{D} = 0.755$	0.71	-20	-0.1600	0.064	0.10	-0.04
	$\delta_e = 0$		-10	0.6380	0.428	0.47	-0.04
	Propeller		0	1.4165	0.778	0.95	-0.17
	$K = 2$		10	2.1522	1.105	1.24	-0.14
	$D = 2.0$ ft		20	2.8224	1.398	1.375	0.02
	Flap		30	3.4064	1.649	-	-
	Slotted flap	0.91	-20	-0.1600	0.099	0.12	-0.02
	$\frac{c_f}{D} = 0.226$		-10	0.6380	0.305	0.325	-0.02
	$\delta = 60^\circ$		0	1.4165	0.502	0.55	-0.05
	Additional		10	2.1522	0.684	0.75	-0.07
	$\frac{F}{T} = 0.96$		20	2.8224	0.845	0.875	-0.03
	$\theta = 28.2^\circ$		30	3.4064	0.980	0.895	0.08
4	**Deflected-slipstream configuration**	0.5	-20	0.43	0.536	0.655	-0.12
	Wing		-10	0.81	0.929	0.93	0
	$S = 10.25$ sq ft		0	1.162	1.293	1.30	-0.01
	$A = 4.55$		10	1.482	1.618	1.52	0.10
	Airfoil: NACA 0015		20	1.755	1.894	1.65	0.24
	$i_W = 0$	0.71	-20	0.43	0.522	0.600	-0.08
	$\frac{c}{D} = 0.755$		-10	0.81	0.855	1.07	-0.18
	$\delta_e = 0$		0	1.162	1.220	1.23	-0.01
	Propeller		10	1.482	1.518	1.565	-0.05
	$K = 4$ (overlapped)		20	1.755	1.769	1.515	0.25
	$D = 2.0$ ft	0.91	-20	0.43	0.444	0.420	0.02
	Flap		-10	0.81	0.735	0.70	0.04
	Two plain flaps (60-percent-		0	1.162	1.004	0.935	0.07
	chord flap and 30-percent-		10	1.482	1.242	1.175	0.07
	chord flap)		20	1.755	1.442	1.38	0.06
	$\frac{c_f}{D} = 0.453$						
	$\delta_{60} = 30^\circ$						
	$\delta_{30} = 20^\circ$						
	Additional						
	$\frac{F}{T} = 0.94$						
	$\theta = 35^\circ$						

* Estimated unstalled power-off lift coefficient

TABLE 9.2.1-A (CONTD)

Ref	Configuration Characteristics	T_c''	α deg	C_{L_o} *	C_L'' Calc	C_L'' Test	$\Delta C_L''$ (Calc-Test)
4	Tilt-wing configuration	0.5	-10	-0.6217	-0.538	-0.55	0.01
	Wing		0	0	0	0.08	-0.08
	$S = 10.25$ sq ft		10	0.6217	0.538	0.63	-0.09
	$A = 4.55$		20	1.2248	1.059	1.08	-0.02
	Airfoil: NACA 0015		30	1.7906	1.548	1.33	0.22
	$i_W = 0$	0.71	-10	-0.6217	-0.461	-0.46	0
	$\frac{c}{D} = 0.75$		0	0	0	0.08	-0.08
			10	0.6217	0.461	0.55	-0.09
	$\delta_e = 0$		20	1.2248	0.909	0.98	-0.07
	Propeller		30	1.7906	1.329	1.27	0.06
	$K = 4$ (overlapped)		40	2.3020	1.709	1.40	0.31
	$D = 2.0$ ft	0.91	-10	-0.6217	-0.342	-	-
	Additional		0	0	0	0.08	-0.08
	$\frac{F}{T} = 1.0$		10	0.6217	0.342	0.42	-0.08
			20	1.2248	0.675	0.73	-0.06
	$\theta = 0$		30	1.7906	0.986	1.00	-0.01
			40	2.3020	1.268	1.21	0.07
			50	2.7432	1.511	1.27	0.24
2	Tilt-wing configuration	0.6	-20	-1.102	-0.7760	-	-
	Wing		-10	-0.418	-0.2651	-	-
	$S = 10.96$ sq ft		0	0.279	0.2548	0.17	0.08
	$A = 7.66$		10	0.9676	0.7669	0.78	-0.01
	Airfoil: NACA 4415		20	1.627	1.256	1.23	0.03
	$i_W = 0$		30	2.237	1.707	1.44	0.27
	$\frac{c}{D} = 0.60$	0.9	-20	-1.102	-0.4865	-0.56	0.07
			-10	-.418	-0.1518	-0.28	0.13
	$\delta_e = 7.4^o$		0	0.279	0.1886	0.08	0.11
	Propeller		10	0.9676	0.5233	0.45	0.07
	$K = 4$ (no overlap)		20	1.627	0.8421	0.78	0.06
	$D = 2.0$ ft		30	2.237	1.135	1.05	0.09
	Additional		40	2.779	1.394	1.20	0.19
	$\frac{F}{T} = 1.0$	0.95	-20	-1.102	-0.4133	-	-
			-10	-.418	-0.1256	-	-
	$\theta = 5.94^o$		0	0.279	0.1669	0.07	0.10
			10	0.9676	0.4543	0.34	0.11
			20	1.627	0.7279	0.59	0.14
			30	2.237	0.9796	0.80	0.18
			40	2.779	1.201	0.97	0.23

*Estimated unstalled power-off lift coefficient

TABLE 9.2.1-A (CONTD)

Ref	Configuration Characteristics	T_c''	α deg	C_{L_o} *	C_L'' Calc	C_L'' Test	$\Delta C_L''$ (Calc-Test)
5	Tilt-wing configuration	0.49	-10	-0.2623	-0.109	-0.20	0.09
	Wing		0	0.4865	0.481	0.40	0.08
	$S = 11.0$ sq ft		10	1.2205	1.056	0.95	0.11
	$A = 4.85$		20	1.9175	1.599	1.52	0.08
	Airfoil: NACA 4415	0.69	-10	-0.2624	-0.0552	-0.20	0.15
	$i_W = 5^{\circ}$		0	0.4865	0.4350	0.32	0.12
	$\frac{c}{D} = 0.75$		10	1.2205	0.9123	0.86	0.05
	$\delta_e = 12.40^{\circ}$		20	1.9175	1.3616	1.29	0.07
	Propeller						
	$K = 4$ (overlapped)						
	$D = 2.0$ ft						
	Additional						
	$\frac{F}{T} = 1.0$						
	$\theta = 11.0^{\circ}$						

*Estimated unstalled power-off lift coefficient

$$\text{Av error} = \frac{\sum |\Delta C_L''|}{n} = 0.092$$

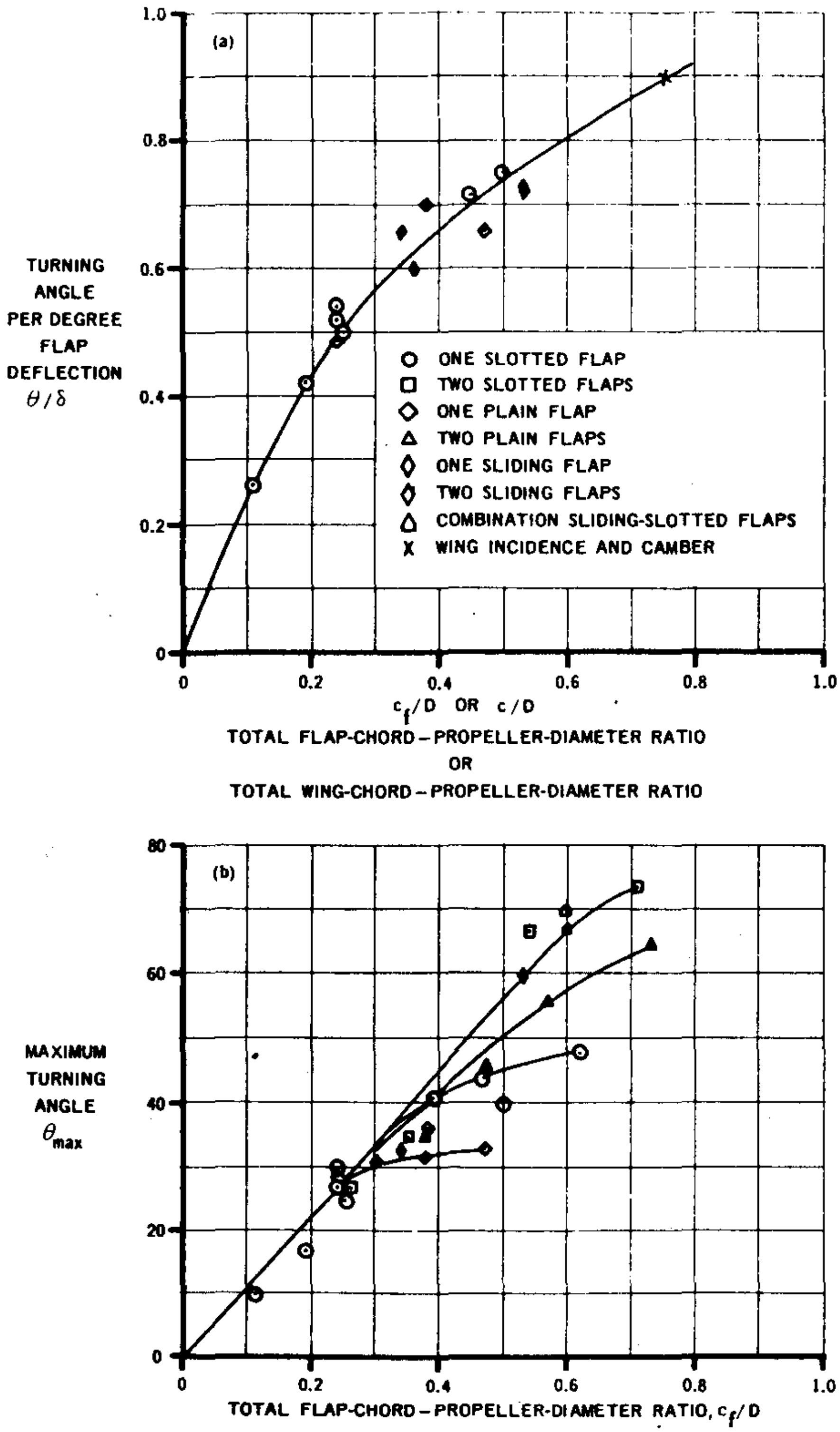


FIGURE 9.2.1-18 VARIATION OF TURNING ANGLE WITH THE RATIO OF TOTAL FLAP CHORD TO PROPELLER DIAMETER FOR VARIOUS CONFIGURATIONS

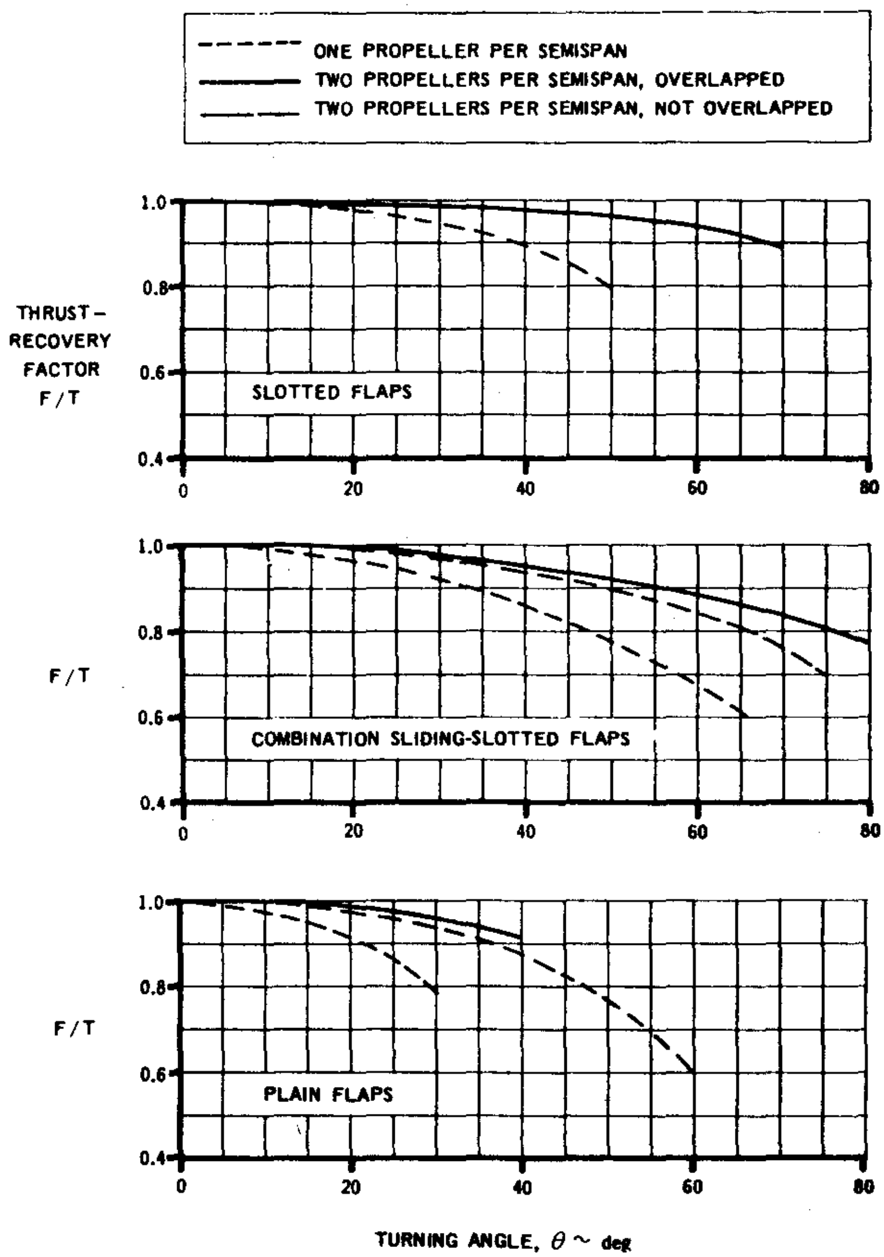


FIGURE 9.2.1-19 VARIATION OF THE AVERAGE THRUST-RECOVERY FACTOR FOR VARIOUS FLAP AND PROPELLER CONFIGURATIONS

9.2.3 PROPELLER-WING-FLAP DRAG VARIATION WITH POWER AND ANGLE OF ATTACK

This Section presents a method for estimating the drag force of propeller-wing-flap configurations at combined forward speed and power-on conditions. The method is applicable only in the unstalled region of flight. The discussion in Section 9.2.1 is directly applicable to this Section, and the reader is referred to that discussion for a general description of the fundamental phenomena.

DATCOM METHOD

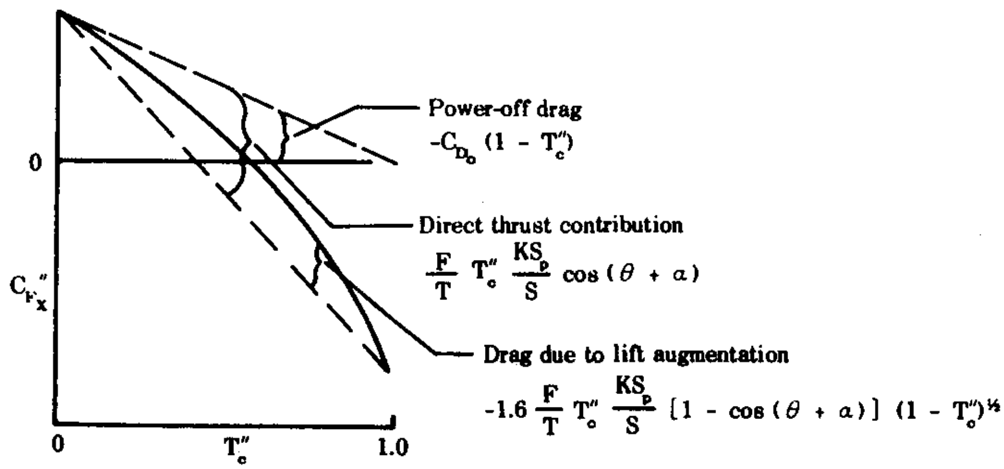
The negative drag force of a propeller-wing-flap configuration at combined forward speed and power-on conditions is given in reference 1 as

$$C_{F_X}'' = -C_{D_O}\,(1 - T_c'') + \frac{F}{T}\,T_c''\,\frac{KS_p}{S}\cos(\theta + \alpha)$$

$$-1.6\,\frac{F}{T}\,T_c''\,\frac{KS_p}{S}\left|1 - \cos(\theta + \alpha)\right|\,(1 - T_c'')^{1/2} \qquad \text{9.2.3-a}$$

where all the parameters are defined in the general notation list of Section 9.2. The coefficients, except for C_{D_O}, are based on the dynamic pressure in the propeller slipstream, and the positive direction of forces and angles is shown in Figure 9.2-6.

The first term of equation 9.2.3-a represents the power-off drag contribution, the second term represents the component of thrust opposing the drag, and the third term represents the drag resulting from the lift augmentation due to the propeller slipstream. The significance of these terms is illustrated in sketch (a).



SKETCH (a)

The procedure to be followed in evaluating equation 9.2.3-a is outlined in the following steps.

Step 1. Determine the slipstream turning angle θ as in Step 1 of the method outline of Section 9.2.1.

In using this procedure to determine the slipstream turning angle it is necessary that the value be obtained over the linear part of the curve of variation of turning angle with flap deflection. The range of linear variation is defined in Step 1 of the method outline of Section 9.2.1.

Step 2. Determine the thrust-recovery factor $\frac{F}{T}$ as in Step 2 of the method outline of Section 9.2.1.

Step 3. Determine the power-off drag coefficient C_{D_o}.

A wing which is stalled in the power-off condition would frequently be unstalled at some moderate to high propeller thrust coefficient. In order to estimate the power-on data in this region, it is necessary to use the drag values that would exist if the wing were unstalled in the power-off condition. Where possible, experimental power-off data should be used for this purpose. Under these conditions the power-off drag coefficient can be estimated by

$$C_{D_o} = C_{D_f} + \frac{{C_{L_o}}^2}{\pi A e} \qquad 9.2.3\text{-b}$$

where

C_{D_f} is the power-off zero-lift drag coefficient. (For the purpose of the Datcom this coefficient is taken as the minimum experimental power-off drag coefficient in order to simplify the definition of the drag polar.)

C_{L_o} is the power-off lift coefficient obtained as in Step 3 of the method outline of Section 9.2.1

e is the span efficiency factor for the configuration. For the purpose of the Datcom $e = 0.85$.

If power-off data for the given configuration are not available or if power-off test data do not exhibit any region of unstalled flow, the following procedure should be used:

(a) Determine the power-off lift variation and α_o as in Step 3 of the method outline of Section 9.2.1.

(b) Determine the power-off zero-lift drag coefficient for the unflapped wing from Section 4.1.5.1.

(c) Determine the zero-lift drag increment due to flap deflection from Section 6.1.7.

then

$$C_{D_f} = C_{D_{f(4.1.5.1)}} + (\Delta C_D)_{(6.1.7)} \qquad 9.2.3\text{-c}$$

(d) The power-off drag coefficient of the flapped wing at angle of attack is then obtained from equation 9.2.3-b.

Step 4. The propeller thrust coefficient T_c'' will usually be specified; however, if necessary this parameter can be estimated using the method of Section 9.1.1.

$$\left(\text{Note that } T_{c_{9.2.1}} = T_{c_{9.1.1}} \frac{S_p}{S}, \text{ and } T_c'' = \frac{T_{c_{9.1.1}}}{T_{c_{9.1.1}} + K}.\right)$$

Step 5. The drag force coefficient is then obtained from equation 9.2.3-a.

The sample problems illustrate the use of the Datcom method in estimating the horizontal-force coefficients of both deflected-slipstream and tilt-wing configurations.

Comparison of experimental data, in the unstalled flight regime, with calculations made using the Datcom method is presented for deflected-slipstream and tilt-wing configurations in Table 9.2.3-A.

Sample Problems

1. Deflected-Slipstream Configuration

Given: A propeller-wing-flap deflected-slipstream configuration of reference 2. This is the same configuration as that of sample problem 1 of Section 9.2.1. The characteristics are repeated below.

Wing Characteristics

$S = 10.96$ sq ft $\quad A = 7.66 \quad$ NACA 4415 airfoil section

$i_W = 0 \quad c = 1.2$ ft (flap retracted) $\quad c = 1.68$ ft (Fowler flap extended)

Flap Characteristics

Fowler flap $\frac{c_f}{c} = 0.286$ (flap extended) $\quad \delta = 50^\circ$

Propeller Characteristics

$K = 4$ (2 propellers per semispan, no overlap) $\quad D = 2.0$ ft

$S_p = 3.14$ sq ft

Additional Characteristics

$T_c'' = 0.90 \quad \delta_e = 7.4^\circ$

Compute:

Step 1. Determine the slipstream turning angle θ.

$\theta = 30.94^\circ$ (sample problem 1, Section 9.2.1)

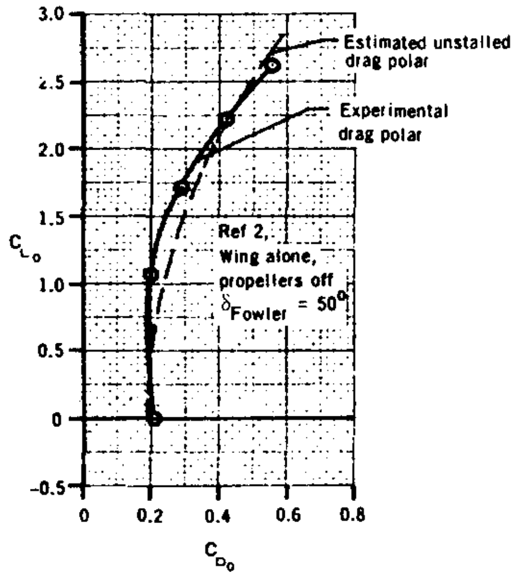
Also note that the variation of θ with δ for this wing-flap configuration was shown to be within the range of linear variation as defined by the Datcom.

Step 2. Determine the thrust-recovery factor $\frac{F}{T}$.

$\frac{F}{T} = 0.96$ (sample problem 1, Section 9.2.1)

Step 3. Determine the power-off drag coefficient C_{D_o}.

The power-off drag coefficient is obtained using the experimental zero-lift drag coefficient, and the power-off lift coefficient at angle of attack as determined in sample problem 1 of Section 9.2.1.



$C_{D_f} = 0.19$ (minimum experimental power-off drag coefficient)

The drag polar that would exist if the wing were unstalled in the power-off condition is estimated by

$$C_{D_o} = C_{D_f} + \frac{{C_{L_o}}^2}{\pi A e} \quad \text{(equation 9.2.3-b)}$$

α deg	C_{L_o} Problem 1 9.2.1	$\frac{{C_{L_o}}^2}{\pi Ae}$	C_{D_o}
-20	0	0	0.1900
-10	1.422	0.1017	0.2917
0	2.842	0.3949	0.5849
10	4.154	0.8436	1.0336
20	5.341	1.3946	1.5846

Solution:

$$C_{F_X}'' = -C_{D_o}(1 - T_c'') + \frac{F}{T} T_c'' \frac{KS_p}{S} \cos(\theta + \alpha)$$

$$- 1.6 \frac{F}{T} T_c'' \frac{KS_p}{S} \left|1 - \cos(\theta + \alpha)\right| (1 - T_c'')^{1/2} \quad \text{(equation 9.2.3-}$$

$$= -C_{D_o}(1 - 0.9) + (0.96)(0.9) \frac{(4)(3.14)}{(10.96)} \cos(\theta + \alpha)$$

$$-1.6(0.96)(0.9) \frac{(4)(3.14)}{(10.96)} \left|1 - \cos(\theta + \alpha)\right| (1 - 0.9)^{1/2}$$

$$= -0.10\, C_{D_o} + 0.990 \cos(\theta + \alpha) - 0.501 \left|1 - \cos(\theta + \alpha)\right|$$

①	②	③	④	⑤	⑥	⑦	⑧
α deg	C_{D_o}	$(\theta + \alpha)$ deg	$\cos(\theta + \alpha)$ cos ③	0.10 ②	0.990 ④	$0.501 \cdot [1 - ④]$	C_{F_x}'' -⑤ + ⑥ - ⑦
-20	0.1900	10.94	0.9818	0.0190	0.9720	0.0091	0.9439
-10	0.2917	20.94	0.9340	0.0292	0.9247	0.0331	0.8624
0	0.5849	30.94	0.8578	0.0585	0.8492	0.0712	0.7195
10	1.0336	40.94	0.7555	0.1034	0.7479	0.1225	0.5220
20	1.5846	50.94	0.6302	0.1585	0.6239	0.1853	0.2801

These results are compared with experimental data in table 9.2.3-A.

2. Deflected-Slipstream Configuration

Given: A propeller-wing-flap deflected-slipstream configuration of reference 2. This is the same configuration as that of sample problem 2 of Section 9.2.1. The characteristics are repeated below.

Wing Characteristics

$S = 10.96$ sq ft $\quad A = 7.66 \quad$ NACA 4415 airfoil section

$i_W = 0 \quad c = 1.2$ ft (flaps retracted) $\quad c = 1.68$ ft (sliding flap and Fowler flap extended)

Flap Characteristics

$\frac{c_f}{c} = 0.566$ (sliding flap and Fowler flap extended; effective chord of sliding flap measured to flap knee)

$$\left.\begin{array}{l}\delta_{sliding} = 30^\circ \\ \delta_{Fowler} = 30^\circ\end{array}\right\} \delta = \delta_{sliding} + \delta_{Fowler} = 60^\circ$$

Propeller Characteristics

$K = 4$ (2 propellers per semispan, no overlap) $\quad D = 2.0$ ft

$S_p = 3.14$ sq ft

Additional Characteristics

$T_c'' = 0.90 \qquad \delta_e = 7.4^\circ$

Compute:

Step 1. Determine the slipstream turning angle θ.

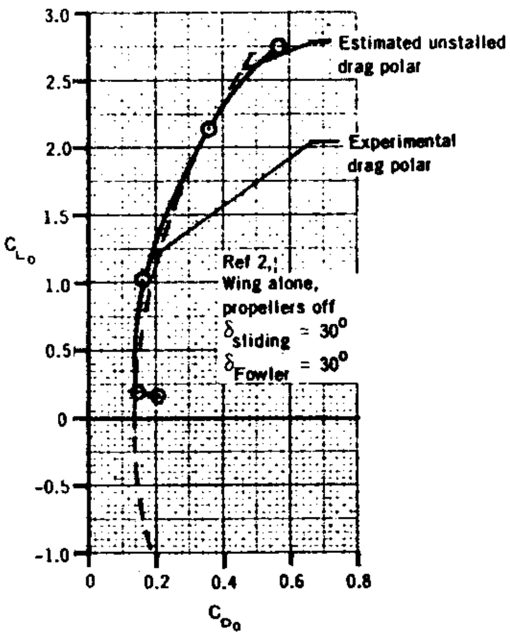
$\theta = 49.14^\circ$ (sample problem 2, Section 9.2.1) Also note that the variation of θ with δ for this wing-flap configuration was shown to be within the range of linear variation as defined by the Datcom.

Step 2. Determine the thrust-recovery factor $\frac{F}{T}$.

$\frac{F}{T} = 0.90$ (sample problem 2, Section 9.2.1)

Step 3. Determine the power-off drag coefficient C_{D_o}.

The power-off drag coefficient is obtained using the experimental zero-lift drag coefficient, and the power-off lift coefficient at angle of attack determined in sample problem 2 of Section 9.2.1.



$C_{D_f} = 0.14$ (minimum experimental power-off drag coefficient)

The drag polar that would exist if the wing were unstalled in the power-off condition is estimated by

$$C_{D_o} = C_{D_f} + \frac{{C_{L_o}}^2}{\pi A e} \quad \text{(equation 9.2.3-b)}$$

α deg	C_{L_o} Problem 2 9.2.1	$\frac{{C_{L_o}}^2}{\pi A e}$	C_{D_o}
-40	-0.8990	0.0395	0.1795
-35	0	0	0.1400
-20	2.6693	0.3483	0.4883
-10	4.3587	0.9288	1.0688
0	5.9161	1.7111	1.8511
10	7.2930	2.6002	2.7402
20	8.4492	3.4900	3.6301

Solution:

$$C_{F_x}'' = -C_{D_o}\,(1 - T_c'') + \frac{F}{T} T_c'' \frac{KS_p}{S} \cos(\theta + \alpha) - 1.6 \frac{F}{T} T_c'' \frac{KS_p}{S} \left[1 - \cos(\theta + \alpha)\right] (1 - T_c'')^{1/2}$$

(equation 9.2.3-a)

$$= -C_{D_o}\,(1 - 0.9) + (0.90)(0.90) \frac{(4)(3.14)}{(10.96)} \cos(\theta + \alpha) - 1.6\,(0.90)(0.90) \frac{(4)(3.14)}{(10.96)} \left[1 - \cos(\theta + \alpha)\right] (1 - 0.9)^{1/2}$$

$$= -0.10\, C_{D_o} + 0.9282 \cos(\theta + \alpha) - 0.4697 \left[1 - \cos(\theta + \alpha)\right]$$

(1) α deg	(2) C_{D_o}	(3) (θ + α) deg	(4) cos(θ + α) cos (3)	(5) 0.10 (2)	(6) 0.9282 (4)	(7) 0.4697 ·[1 - (4)]	(8) C_{F_x}'' -(5) + (6) - (7)
-40	0.1795	9.14	0.9873	0.0180	0.9164	0.0060	0.8924
-35	0.1400	14.14	0.9697	0.0140	0.9001	0.0142	0.8719
-20	0.4883	29.14	0.8734	0.0488	0.8107	0.0595	0.7024
-10	1.0688	39.14	0.7756	0.1069	0.7199	0.1054	0.5076
0	1.8511	49.14	0.6542	0.1851	0.6072	0.1624	0.2597
10	2.7402	59.14	0.5129	0.2740	0.4761	0.2288	-0.0267
20	3.6301	69.14	0.3561	0.3630	0.3305	0.3024	-0.3349

These results are compared with experimental data in table 9.2.3-A

3. Tilt-Wing Configuration

Given: The propeller-wing configuration of reference 5. This is the same configuration as that of sample problem 3 of Section 9.2.1. The characteristics are repeated below.

Wing Characteristics

$S = 11.0$ sq ft $\quad A = 4.89 \quad i_W = 5^\circ$ NACA 4415 airfoil section

$c = 1.5$ ft

Propeller Characteristics

$K = 4$ (2 propellers per semispan, overlapped) $D = 2.0$ ft

$S_p = 3.14$ sq ft

Additional Characteristics

$T_c'' = 0.69 \quad \delta_e = 12.4^\circ$

Compute:

Step 1. Determine the slipstream turning angle θ.

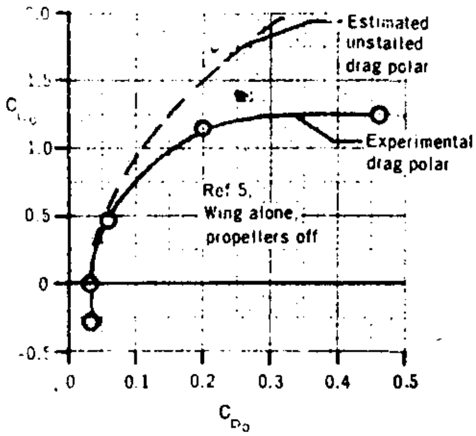
$\theta = 11.0^\circ$ (sample problem 3, Section 9.2.1)

Step 2. Determine the thrust-recovery factor $\frac{F}{T}$.

$\frac{F}{T} = 1.0$ (sample problem 3, Section 9.2.1)

Step 3. Determine the power-off drag coefficient C_{D_o}

The power-off drag coefficient is obtained using the experimental zero-lift drag coefficient, and the power-off lift coefficient at angle of attack determined in sample problem 3 of Section 9.2.1.



$C_{D_f} = 0.035$

The drag polar that would exist if the wing were unstalled in the power-off condition is estimated by

$$C_{D_o} = C_{D_f} + \frac{C_{L_o}^{\,2}}{\pi A e} \quad \text{(equation 9.2.3-b)}$$

α deg	C_{L_o} Problem 3 9.2.1	$\frac{C_{L_o}^{\,2}}{\pi A e}$	C_{D_o}
-10	-0.2624	0.0053	0.0403
-6.5	0	0	0.0350
0	0.4865	0.0181	0.0531
10	1.2205	0.1141	0.1491
20	1.9175	0.2816	0.3166

Solution:

$$C_{F_x}'' = -C_{D_o}\,(1 - T_c'') + \frac{F}{T}\,T_c''\,\frac{KS_p}{S}\cos(\theta + \alpha) - 1.6\,\frac{F}{T}\,T_c''\,\frac{KS_p}{S}\Big[1 - \cos(\theta + \alpha)\Big]\,(1 - T_c'')^{1/2}$$

(equation 9.2.3-a)

$$= -C_{D_o}\,(1 - 0.69) + (1.0)(0.69)\,\frac{(4)(3.14)}{(11.0)}\cos(\theta + \alpha) - (1.6)(1.0)(0.69)\,\frac{(4)(3.14)}{(11.0)}\Big[1 - \cos(\theta + \alpha)\Big]\,(1 - 0.69)^{1/2}$$

$$= -0.31\,C_{D_o} + 0.7879\cos(\theta + \alpha) - 0.7018\Big[1 - \cos(\theta + \alpha)\Big]$$

① α deg	② C_{D_o}	③ $(\theta + \alpha)$ deg	④ $\cos(\theta + \alpha)$ cos ③	⑤ 0.31 ②	⑥ 0.7879 ④	⑦ 0.7018 ·[1 - ④]	⑧ C_{F_x}'' -⑤ + ⑥ -⑦
-10	0.0403	1.0	0.9998	0.0125	0.7877	0.0001	0.7751
-6.5	0.0350	4.5	0.9969	0.0109	0.7855	0.0022	0.7724
0	0.0531	11.0	0.9816	0.0165	0.7734	0.0129	0.7440
10	0.1491	21.0	0.9336	0.0462	0.7356	0.0466	0.6428
20	0.3166	31.0	0.8572	0.0981	0.6754	0.1002	0.4771

These results are compared with experimental data in table 9.2.3-A.

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TABLE 9.2.3-A

DATA SUMMARY AND SUBSTANTIATION

PROPELLER-WING-FLAP DRAG COEFFICIENT

Ref	Configuration Characteristics	T_c''	α deg	C_{D_o} *	$C_{F_x''}$ Calc	$C_{F_x''}$ Test	$\Delta C_{F_x''}$ (Calc-Test)
2	Deflected-slipstream configuration (See reference 2, table 9.2.1-A)	0.6	-20	0.1900	0.552	0.43	0.12
			-10	0.2917	0.448	0.37	0.08
			0	0.5849	0.229	0.19	0.04
			10	1.0336	-0.086	-0.19	0.10
		0.9	-20	0.1900	0.944	0.84	0.10
			-10	0.2917	0.862	0.79	0.07
			0	0.5849	0.720	0.65	0.07
			10	1.0336	0.522	0.43	0.09
			20	1.5846	0.280	0.11	0.17
		0.95	-20	0.1900	1.009	0.92	0.09
			-10	0.2917	0.936	0.87	0.07
			0	0.5849	0.813	0.75	0.06
			10	1.0336	0.645	0.57	0.07
			20	1.5846	0.440	0.32	0.12
2	Deflected-slipstream configuration (See reference 2, table 9.2.1-A)	0.6	-40	0.1795	0.545	0.27	0.27
			-20	0.4883	0.323	0.18	0.14
			-10	1.0688	-0.012	-0.05	0.04
		0.9	-40	0.1795	0.892	0.72	0.17
			-20	0.4883	0.702	0.68	0.02
			-10	1.0688	0.508	0.53	-0.02
			0	1.8511	0.260	0.30	-0.04
			10	2.7402	-0.027	0	-0.03
			20	3.6301	-0.335	-0.20	0.14
		0.95	-40	0.1795	0.968	0.83	0.14
			-20	0.4883	0.847	0.78	0.07
			-10	1.0688	0.709	0.65	0.06
			0	1.8511	0.526	0.45	0.08
			10	2.7402	0.309	0.18	0.13
			20	3.6301	0.068	-0.06	0.13
			30	4.4117	-0.187	-0.21	0.02

*Estimated unstalled power-off drag coefficient

TABLE 9.2.3-A (CONTD)

Ref	Configuration Characteristics	T_c''	α deg	C_{D_o}*	C_{F_x}'' Calc	C_{F_x}'' Test	$\Delta C_{F_x}''$ (Calc Test)
3	Deflected-slipstream configuration (See reference 3, table 9.2.1-A)	0.5	-20	0.1521	0.212	0.17	0.04
			-10	0.1835	0.171	0.15	0.02
			0	0.3151	0.062	0.045	0.02
			10	0.5312	-0.106	-0.145	0.04
			20	0.8056	-0.318	-0.37	0.05
			30	1.1050	-0.555	-0.49	-0.06
		0.71	-20	0.1521	0.366	0.285	0.08
			-10	0.1835	0.326	0.275	0.05
			0	0.3151	0.234	0.19	0.04
			10	0.5312	0.097	0.025	0.07
			20	0.8056	-0.075	-0.15	0.07
			30	1.1050	-0.271	-0.25	-0.02
		0.91	-20	0.1521	0.513	0.425	0.09
			-10	0.1835	0.479	0.40	0.08
			0	0.3151	0.413	0.345	0.07
			10	0.5312	0.318	0.23	0.09
			20	0.8051	0.199	0.08	0.12
			30	1.1050	0.061	-0.02	0.08
4	Deflected-slipstream configuration (See reference 4, table 9.2.1-A)	0.5	-20	0.1652	0.4571	0.46	0
			-10	0.2040	0.3638	0.36	0
			0	0.2611	0.2272	0.23	0
			10	0.3308	0.0532	0.08	-0.03
			20	0.4035	-0.1487	-0.21	0.06
		0.71	-20	0.1652	0.7261	0.72	0.01
			-10	0.2040	0.6232	0.65	-0.03
			0	0.2611	0.4726	0.50	-0.03
			10	0.3308	0.2799	0.275	0
			20	0.4035	0.0534	0.18	-0.13
		0.91	-20	0.1652	0.9910	0.97	0.02
			-10	0.2040	0.8941	0.885	0.01
			0	0.2611	0.7524	0.76	-0.01
			10	0.3308	0.5703	0.60	-0.03
			20	0.4035	0.3545	0.38	-0.03

*Estimated unstalled power-off drag coefficient

TABLE 9.2.3-A (CONTD)

Ref	Configuration Characteristics	T_c''	α deg	C_{D_o} *	C_{F_x}'' Calc	C_{F_x}'' Test	$\Delta C_{F_x}''$ (Calc-Test)
4	Tilt-wing configuration (See reference 4, table 9.2.1-A)	0.5	-10	0.04181	0.572	0.57	0
			0	0.01	0.608	0.62	-0.01
			10	0.04181	0.572	0.58	-0.01
			20	0.1335	0.467	0.41	0.06
			30	0.2739	0.301	0.1	0.20
		0.71	-10	0.04181	0.833	0.80	0.03
			0	0.01	0.867	0.82	0.05
			20	0.1335	0.734	0.66	0.07
			30	0.2739	0.574	0.42	0.15
			40	0.4461	0.362	0.14	0.22
		0.91	-10	0.04181	1.086	1.08	0.01
			0	0.01	1.114	1.08	0.03
			10	0.04181	1.086	1.05	0.04
			20	0.1335	1.004	0.94	0.06
			30	0.2739	0.869	0.76	0.11
			40	0.4461	0.689	0.55	0.14
			50	0.6294	0.469	0.32	0.15
2	Tilt-wing configuration (See reference 2, Table 9.2.1-A)	0.6	-20	0.0794	0.6145	-	-
			-10	0.0285	0.6727	0.56	0.11
			0	0.0238	0.6706	0.57	0.10
			10	0.0658	0.6080	0.46	0.15
			20	0.1494	0.4885	0.21	0.28
			30	0.2647	0.3183	-0.11	0.43
		0.9	-20	0.0794	0.9770	0.76	0.22
			-10	0.0285	1.0247	0.86	0.16
			0	0.0238	1.0206	0.92	0.10
			10	0.0658	0.9650	0.86	0.11
			20	0.1494	0.8601	0.71	0.15
			30	0.2647	0.7092	0.50	0.21
			40	0.3976	0.5185	0.26	0.26
		0.95	-20	0.0794	1.0405	-	-
			-10	0.0285	1.0836	-	-
			0	0.0238	1.0795	0.93	0.15
			10	0.0658	1.0285	0.88	0.15
			20	0.1494	0.9324	0.79	0.14
			30	0.2647	0.7940	0.65	0.14
			40	0.3976	0.6186	0.46	0.16

*Estimated unstalled power-off drag coefficient

TABLE 9.2.3-A (CONTD)

Ref	Configuration Characteristics	T_c''	α deg	C_{D_o} *	C_{F_x}'' Calc	C_{F_x}'' Test	$\Delta C_{F_x}''$ (Calc-Test)
5	Tilt-wing configuration (See reference 5, table 9.2.1-A)	0.49	-10	0.0403	0.539	0.54	0
			0	0.0531	0.510	0.52	-0.01
			10	0.1491	0.402	0.40	0
			20	0.3166	0.225	0.16	0.06
		0.69	-10	0.0403	0.775	0.75	0.02
			0	0.0531	0.744	0.71	0.03
			10	0.1491	0.643	0.64	0
			20	0.3166	0.477	0.43	0.05

*Estimated unstalled power-off drag coefficient Av. Error $= \dfrac{\sum \Delta C_{F_x}''}{n} = 0.082$

9.3 DUCTED-PROPELLER CHARACTERISTICS

The estimation of ducted-propeller aerodynamics can be approached in three phases, each representing a VTOL aircraft flight regime. These are static operation (hovering), axial flow (approximately zero duct angle of attack as in cruise or vertical climb), and nonaxial flow (high duct angles of attack as in transition). The most important and most difficult problem is the prediction of the aerodynamic characteristics in the presence of strong power effects at high angles of attack and low speeds during transition.

The methods presented in this section are for predicting forces and moments on isolated ducted propellers as functions of power and angle of attack. The static and axial-flow regimes are trivial, and no attempt is made to deal with the characteristics in these regimes. It is virtually impossible to present quantitative information on the effects of the various geometric and aerodynamic variables involved because of the complexity of the problem and the general lack of appropriate data. However, a qualitative discussion of the ducted-propeller problem is given with primary emphasis on the nonaxial flow regime.

A ducted propeller consists of a propeller enclosed in an axially symmetric duct as shown in figure 9.3-12. The purpose of the duct is to increase the thrust-generating capability of the entire unit in the static and low subsonic speed regimes for a given propeller diameter and power input. If the chordwise cross section of the duct is reasonably faired, the unit can function as a ring wing as well as a thrusting propeller.

Differing from flying platforms or "flying jeeps," ducted-propeller units are typically mounted on the tips of low-aspect-ratio wings with the capability of rotating from 0 to 90 degrees. Since much of the ducted-propeller work has been the application to particular vehicle designs, the emphasis has been on propeller design and development of auxiliary devices to augment thrust and to provide control moments. This work is thus of little interest here because the lift and pitching moments are not affected significantly. The development of various auxiliary devices is reported in reference 84, and additional information pertaining to experimental investigations is given in table 9.3-A.

The duct complicates the problem of predicting the aerodynamic characteristics because of the strong mutual interference effects and the increased number of geometric variables. A preliminary list of geometric variables includes duct aspect ratio, duct section parameters (thickness ratio, camber, leading-edge radius, etc.), diffuser angle, propeller activity factor, propeller pitch setting, propeller solidity, propeller section parameters (twist, camber, taper, thickness, etc.), blade tip clearance, center-body location relative to the duct, center-body shape, ratio of hub diameter to propeller diameter, and propeller location within the duct. Aside from this seemingly endless list of geometric variables, there are the aerodynamic variables of angle of attack, Reynolds number, advance ratio, and Mach number.

The ducted propeller in the nonaxial flow regime has received very little theoretical attention in comparison to that given to the static and axial-flow regimes. The theoretical work available in the literature is generally classified under one of three general categories of analysis: (1) method of singularities, (2) momentum considerations, and (3) methods which seek to avoid the mathematical complexities of the method of singularities and yet yield more detailed results than simple momentum theory. The method of singularities is relatively complex, and almost all solutions in the literature are restricted to special classes of duct profiles. The method involves replacing the annular airfoil by a vortex distribution on its camber line, determining the axial and radial velocity components induced by this vortex distribution, and relating these velocity components to the shape of the airfoil by satisfying the potential flow streamline condition. Two approaches to the problem can be defined: (1) given the vortex distribution, find the corresponding shape and determine its aerodynamic characteristics, and (2) given the shape, find the corresponding vortex distribution, from which the aerodynamic characteristics can be determined. In either case, an iteration process is required if other than a first approximation is desired. The effects of geometric parameters and propellers are induced by the use of additional distributed singularities. The theoretical basis on which the method of singularities rests is developed and discussed in reference 57.

An approximate theory for nonaxial flow, based on the method of singularities, is developed by Burggraf in reference 1. Burggraf represents the ducted propeller as a short, thin, cylindrical duct with a uniformly loaded actuator disk across its exit plane. Each section of the duct is treated as a thin two-dimensional airfoil, and solutions are obtained by means of conformal transformations. An analysis with less restricted geometry has been made by Kriebel and summarized in reference 55. Kriebel treats the duct as a thin cylinder (but not necessarily short) and represents the propeller as a uniformly loaded actuator disk located at the duct inlet. The vorticity distribution bound to the duct and trailing from it is found in terms of a Fourier series by the method of singularities. The results are obtained by solving for the coefficients of the Fourier series representing the duct-bound vorticity distribution. Both Burggraf and Kriebel include the nonaxial flow case by assuming the vorticity shed by both the actuator disk and the duct to be concentrated on a circular cylinder which extends axially downstream, even at angles of attack. Because of this assumption, the exit velocity must be large relative to the cross-flow component of the free-stream velocity, i.e.,

$$V_e >> V_\infty \sin \alpha_D ,$$

a restriction which requires high actuator disk loadings at high angles of attack.

Momentum theory in itself is not sufficient to predict the performance of a ducted propeller, since the relationships between thrust and power are in terms of the area and velocity of the final wake. At the present time, there appears to be no available way of relating wake characteristics to duct design without using the method of singularities. To avoid this difficulty some assumption must be made which relates the duct exit characteristics to the final wake. The most common assumption, forming what is generally termed "simple momentum theory," is that the final wake area is equal to the duct exit area. This implies that the exit velocity profile is uniform and the static pressure at the exit is equal to that at infinity. The nonaxial flow case is generally based on the additional assumption that the internal mass flow exits parallel to the duct axis, an assumption which is valid only for low duct aspect ratios and high exit-velocity ratios. Examples of simple momentum theory as applied to nonaxial flow are given in references 85 and 58.

Moser and Livingston, in reference 70, develop semiempirical expressions for the aerodynamic characteristics of ducted propellers in nonaxial flow by adapting blade element theory and modifications to it to take some account of duct influence. This method is shown to be reasonable for analyzing ducted-propeller characteristics where the deflection of the airstream is relatively small.

Minassian, in reference 65, treats the ducted propeller in nonaxial flow as a ring wing. He assumes that the propeller causes the internal pressures on the duct to cancel one another and then applies two-dimensional airfoil characteristics to predict normal-force variation with angle of attack. This work is restricted to rough approximations at low angles of attack and high advance ratios.

Wind-tunnel tests cover a wide variety of ducted propellers in the nonaxial flow regime; however, the data are often of questionable accuracy because of wall-interference effects and data accuracy limitations at the tunnel speeds required to simulate low-speed flight. Testing small models in an effort to avoid wall-interference effects has not proved satisfactory because of the errors associated with low Reynolds numbers and balance-system sensitivity. The uncertainties of wind-tunnel test data, coupled with the geometric and aerodynamic variables involved, preclude generalization and verification of any valid prediction methods. Although a large number of experimental investigations have been conducted, it is still difficult to draw any general conclusions pertaining to the effects of geometric or aerodynamic variations. However, the results that are available can serve at least to give a practical orientation to some aspects of the ducted propeller problem. Accordingly, a qualitative discussion of the effects of a number of the important variables is given.

Duct Leading-Edge Radius

The duct leading-edge radius is critical in that it must be large enough to prevent inlet flow separation at high power and/or angle of attack and yet not so large as to produce an excessive drag penalty in cruise flight. Leading-edge lip stall reduces lift and pitching moment and increases the power required.

Diffuser

A properly designed diffuser increases the diameter of the fully developed stream tube, thereby increasing the static thrust and efficiency of a given ducted propeller. Tests of two unpowered ducts (reference 36) in nonaxial flow indicate that diffusion of the duct afterbody results in an appreciable increase in lift-curve slope and maximum-lift stall angle of attack. Reference 36 also indicates that diffusion causes the center of pressure to move forward. These effects can be attributed to the increased internal mass flow through the duct resulting from increased positive circulation.

Although substantial diffusion may be beneficial in the static flow regime, it can lead to internal flow separation during essentially axial flow with an attendant drag increase.

Exit Stators

In addition to providing a structural tie between the center body and the duct, exit stators, because of twist and camber, also serve as guide vanes to eliminate the slipstream rotation resulting from the high thrust loading of the ducted propeller. This flow straightening converts the rotational kinetic energy to pressure and increased axial velocity. If flow straightening is not provided, the propeller efficiency is severely reduced.

Propeller Twist

The effect of propeller twist on static performance has been a source of controversy. The results reported in references 12 and 64 indicate that a relatively flat, untwisted blade is best for static and low-speed operation, because of the better match with the theoretical ring vortex circulation about the duct, resulting in gains in static efficiency. However, these reports make no statement regarding blade pitch optimization, and it is difficult to distinguish between the effects of blade twist and those of blade pitch. On the other hand, the results reported in references 19 and 56, which did use blade pitch optimization, show no such corresponding improvement and indicate that blade twist is relatively unimportant. Moser and Livingston, in reference 70, also indicate that the effects of blade twist are relatively unimportant except at the highest collective pitch tested.

Propeller Tip Clearance

Ducted-propeller efficiency increases with decreasing tip clearance. Excessive tip clearance will aggravate a condition of flow reversal that occurs on the duct in the propeller plane even for small tip clearances. At moderate to high angles of attack, the flow reversal condition on the lower inside surface of the duct can cause premature inlet lip separation, resulting in reductions in both lift and pitching moment accompanied by increased power requirements.

Propeller Position

The effect of propeller position on ducted-propeller forces and moments in nonaxial flow is relatively undefined. Reference 19 indicates that at a given thrust level, moving the propeller forward reduces the lift and pitching-moment coefficients. However, data of reference 57 indicate that forward movement of the propeller plane increases the radial variation in duct velocity distribution (greater velocities near the duct), which would be expected to increase the pitching moments in nonaxial flow.

It is stated in reference 55 that analytical results indicate that in axial flow the pressure jump acting upon the internal duct surface downstream of the propeller plane is maximum when the propeller plane is located at the minimum duct internal cross-sectional area. For this location of the propeller in axial flow, the disk area and disk thrust are minimum for a given disk loading, and the duct-to-disk thrust ratio and the propulsive efficiency are maximum.

Exit-Velocity Ratio and Angle of Attack

The exit-velocity ratio and angle of attack determine the basic flow pattern for a given ducted propeller. As the duct angle of attack is increased beyond the unpowered stall angle, the exit-velocity ratio must be increased to prevent stalling of the duct lower leading edge. Because of the predominance of power effects as duct angle of attack is increased, the separation that occurs on the top aft portion of the duct usually has a minor effect on force and moment data.

Reynolds Number

Reynolds-number effects are of extreme importance in ducted-propeller design because of the low airspeed of operation and the short streamwise lengths of ducted-propeller elements. The separation that occurs on the lower inside surface of the duct leading edge at high angles of attack and low exit-velocity ratios is a low Reynolds-number characteristic. At low Reynolds number, laminar flow is followed by separation rather than by attached turbulent flow, resulting in substantial losses in both lift and pitching moment at a given power setting.

A comprehensive tabulation of pertinent ducted-propeller experimental data in the nonaxial flow regime is presented as table 9.3-A. This table provides a brief outline of the test data contained in each report and indicates the basic parametric changes. Similar tables pertaining to the static- and axial-flow regimes are given in reference 84. It should be recognized that the ducted propeller problem cannot be satisfactorily handled by treating isolated effects with all other variables fixed. The effect of a geometric or aerodynamic variation on the characteristics of a ducted propeller of different design will very likely be quite different from that indicated by the test results of available reports.

A general notation list is included in this section for all ducted propeller sections. Figures 9.3-12 and 9.3-13 illustrate the geometric data required by the methods of these sections. Figure 9.3-13 also illustrates the positive sense of forces, moments, and angles.

NOTATION

A_D	duct aspect ratio, $\frac{d_e}{c}$
c	duct chord, ft
C_{D_e}	external duct drag coefficient, $\frac{-F_{x_e}}{q_\infty S_D}$
C_{F_x}	duct negative-drag coefficient, $\frac{F_x}{q_\infty S_D}$

$C_{F_{x_e}}$ external duct negative-drag coefficient, $\frac{F_{x_e}}{q_\infty S_D}$

C_L duct lift coefficient, $\frac{L}{q_\infty S_D}$

C_m duct pitching-moment coefficient, $\frac{M}{q_\infty S_D\ c}$

d_{CB} duct center-body diameter at the exit plane, ft

d_e duct exit diameter, ft

d_p propeller diameter, ft

F_x duct negative-drag force, lb $\left(F_x = C_{F_x} q_\infty S_D\right)$

J advance ratio, $\frac{V_\infty}{nd_p}$

L duct lift force, lb $(L = C_L q_\infty S_D)$

M duct pitching moment, ft-lb $(M = C_m q_\infty S_D\ c)$

m_i duct internal mass flow, $\frac{\text{slugs}}{\text{sec}}$

N ducted-propeller normal force, lb

n propeller rotational speed, rps

q_∞ free-stream dynamic pressure, $\frac{\text{lb}}{\text{sq ft}}$

S_D duct planform area, sq ft $(S_D = d_e\ c)$

T ducted-propeller thrust, lb

T_i total internal thrust, lb

T_{net} total net thrust, lb $(T_{net} = T_i - C_{D_e} q_\infty S_D)$

V_e duct exit velocity, $\frac{ft}{sec}$

V_i velocity increment of internal mass flow due to power, $\frac{ft}{sec}$

V_{i_o} internal mass-flow velocity with power off, $\frac{ft}{sec}$

V_∞ free-stream velocity, $\frac{ft}{sec}$

$\frac{V_e}{V_\infty}$ exit-velocity ratio

$\bar{x}$ chordwise distance from the reference center to the unstalled duct center of pressure, positive for the center of pressure ahead of the reference center, ft

x_{cp} chordwise distance from the duct leading edge to the center of pressure of the unstalled duct, positive aft of the duct leading edge, ft

x_m chordwise distance from the duct leading edge to the reference center, positive aft of the duct leading edge, ft

α_D angle of attack between duct axis and free-stream direction, deg

δ_{i_f} net turning angle of the internal flow including power effects, deg

δ_{i_o} turning angle of the internal flow with power off, deg

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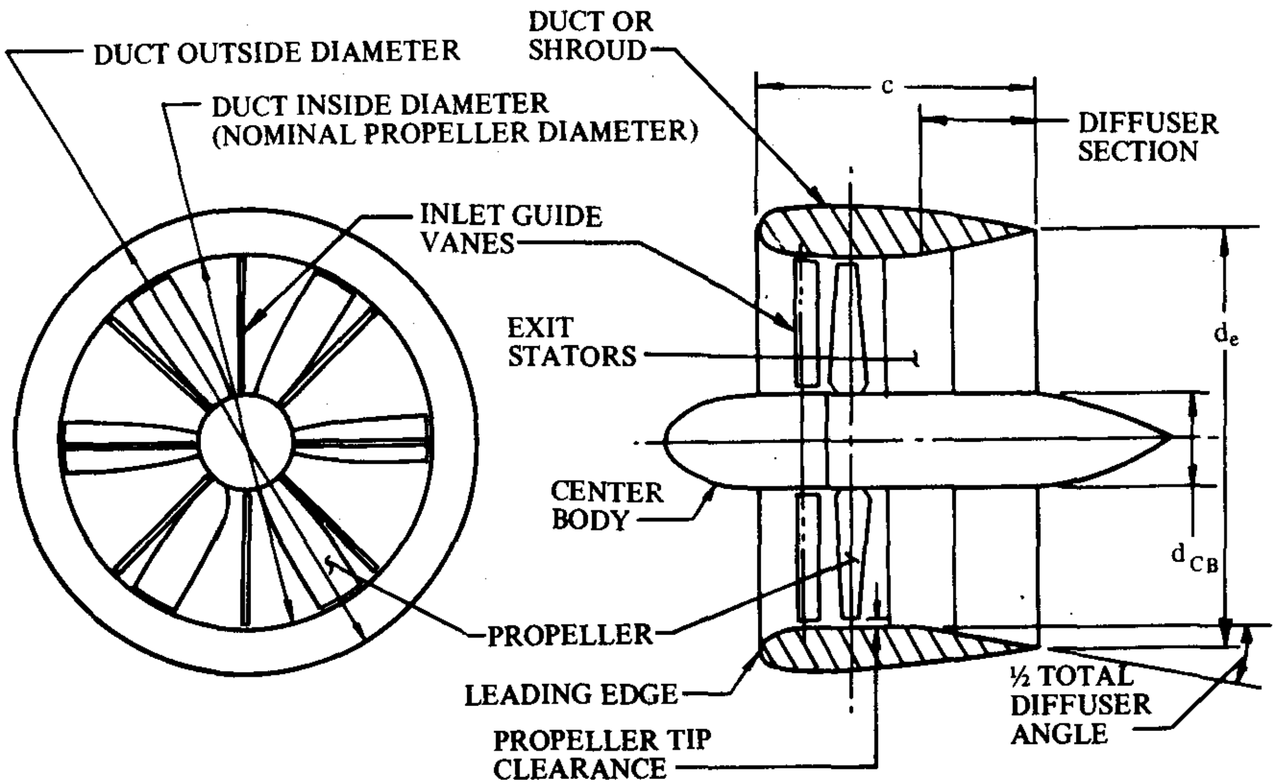

FIGURE 9.3-12 DUCTED-PROPELLER GEOMETRY

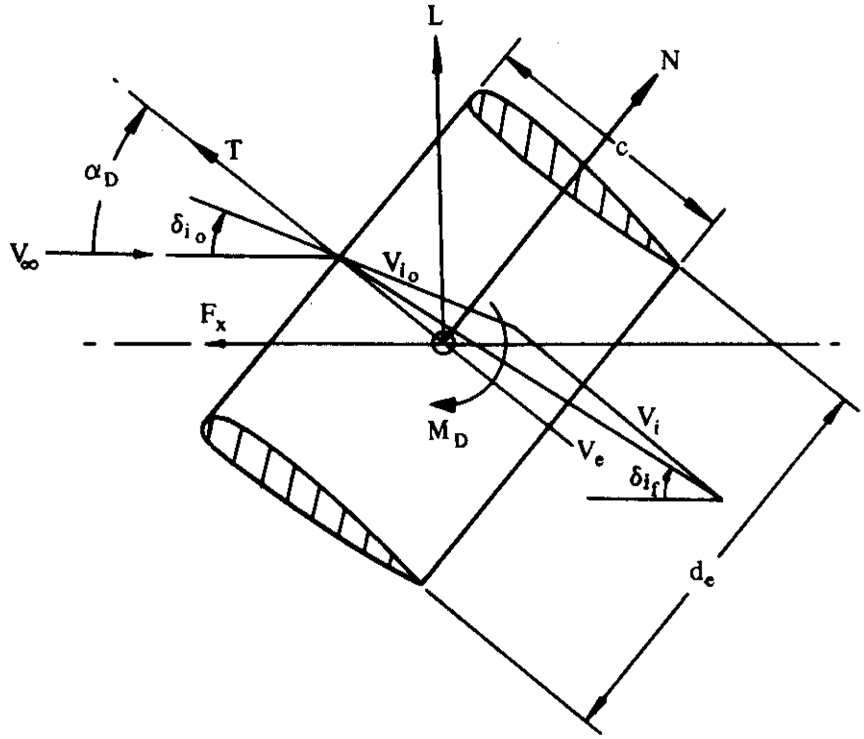

FIGURE 9.3-13 DEFINITION SKETCH FOR DUCTED-PROPELLER FLOW GEOMETRY – WIND-AXIS SYSTEM

TABLE 9.3-A
SUMMARY OF EXPERIMENTAL DUCTED PROPELLER DATA
NON-AXIAL FLOW

REFERENCE NO.	YEAR OF PUBLICATION	DUCT SHAPE*	DUCT ASPECT RATIO	TOTAL NO. PROP. BLADES PER DUCT	NOMINAL PROP. DIAM. (FT)	PROP. DISK AREA / TUNNEL AREA (%)	MAX. $\dot{m}$ / MIN. $\dot{m}_{TUNNEL}$ (%)	α_0 RANGE	MAX. TESTED &/OR DESIGN DISK LOADING (LB/FT^2)	MAX. V_e/V_∞	MAX. ADVANCE RATIO J	R_t RANGE × 10^{-6}	DUCT FORCE, MOMENTS	PROP. FORCES, MOMENTS	DUCT PRESS. DISTRIBUTION	VELOCITY SURVEY	STATIC DATA	PROP.-REMOVED DATA	EXIT-VANE TESTS	INLET GUIDE VANE TEST	COMMENTS
		GEOMETRY				TUNNEL DATA		TEST CONDITIONS					DATA IN ADDITION TO L, D, M, RPM, & POWER								
2	60	–	–	–	–	–	–	–	–	–	–	–									REVIEW AND CONSTRUCTION OF COMPARATIVE PERFORMANCE CHARTS USING DATA FROM A MAJORITY OF THE REPORTS ON THE REFERENCE LIST. HOVERING, TRANSITION, AND CRUISE. 2-DIMENSIONAL WATER-FLOW STUDIES.
8	68	MA	1.575, 1.647, 1.714, 2.103	3,4	2.5	1.83, 9.26	–	–	–	–	~2	–	X	X	X	X	X		X	X	SINGLE SHROUDED PROPELLER TESTED IN UAC 18-FT OCTAGONAL TUNNEL FOR HOVER UP TO M = .2 AND IN 8-FT TUNNEL FOR CRUISE. BLADE PITCH 20° – 55°. DIFFUSION ANGLE NOT GIVEN. RPM MEASURED. EFFECTS OF DUCT EXIT AREA RATIO, LIP SHAPE, DUCT CHORD LENGTH, PROPELLER POSITION, DUCT EXTERNAL SHAPE, INLET-VANE ANGLES, EXIT-VANE ANGLES, AND PROPELLER PARAMETERS, SUCH AS PLANFORM DISTRIBUTION, NO. OF BLADES, AND TIP CLEARANCE. TESTS RUN THROUGH RANGE OF PROP POWER LOADINGS AND FREE-STREAM MACH NOS. EFFECT OF EACH PARAMETER SEPARATELY.
9	67	MA	1.575, 1.647, 1.714, 2.103	3,4	2.5	1.83, 9.26	–	–	–	1.876 → 1.08	–	–	X	X	X	X	X		X	X	SAME CONFIG AS ABOVE. 15° → 42° BLADE TWIST. DIFFUSION VARIED, UP TO 12° (HALF-ANGLE) POWER SURVEY. THRUST DATA ONLY. EFFECTS ON PERFORMANCE OF DUCT EXIT AREA, DUCT CHORD LENGTH, PROPELLER POSITION, SHROUD EXTERNAL SHAPE, INLET-VANE ANGLES, EXIT-VANE ANGLES, AND PROPELLER PARAMETERS, SUCH AS PLANFORM DISTRIBUTION, NO. OF BLADES, AND TIP CLEARANCE. PRESSURE AND VELOCITY DATA USED TO COMPUTE PROP THRUST AND POWER-LOADING DISTRIBUTION AND DUCT DRAG AND SLIPSTREAM CONTRACTION. PRESS DATA SHOW EFFECT OF BLADE ANGLE, MACH NO., AND TIP SPEED. MAX AND MIN DUCT EXIT VELOCITIES GIVEN FOR BASIC CONFIG AND ALSO TO SHOW EFF OF VARYING RPM, BLADE ANGLE, MACH NO., DUCT EXIT AREA, DUCT CHORD LENGTH, INLET VANES, TIP CLEARANCE, NO. OF BLADES, AND PROP PLANFORM.
10	62	–	–	3	2.5	–	–	–	–	–	–	–	X	X	X		X	X			A DUCTED PROPELLER WITH FORWARD AND AFT GUIDE VANES AND BLC TESTED IN UAC TUNNEL. HAMILTON STANDARD VARIABLE CAMBER PROPELLER. DIFFUSION VARIES → 11° (HALF-ANGLE) AND 30° WITH BLC. PROP EFF PLOTS. THRUST FOR DUCT, PROP, AND TOTAL. ADVANTAGES OF DUCTED PROPELLER, METHODS OF DETERMINING PERFORMANCE, AND TEST DATA VERIFYING PREDICTED PERFORMANCE. HOVER, CRUISE, AND TRANSITION.
13	65	MA	2.26	3	8	–	–	0, 90°	76.5	–	–	–	X	X		X	X				FULL-SCALE HALF-MODEL SIMULATION OF DUAL TANDEM DUCTED-PROP VTOL AIRCRAFT TESTED OVER SAND AND STONE TO TEST ENGINE PROTECTIVE DEVICES. ISOLATED DUCT ALSO TESTED. 19°, 22.5°, 26° BLADE PITCH. DIFFUSION ANGLE NOT GIVEN. GROUND EFFECT. STATIC PRESSURE. EFFECTS OF PROP BLADE ANGLE, DUCT HEIGHT, POWER, AND DISTANCE BETWEEN DUCTS. THRUST AND TORQUE SHOW EFFECT OF RPM ALSO. APPENDIX INCLUDES PROP BLADE STRESS STUDIES MADE IN KELLETT DOWNWASH TEST FACILITY SHOWING EFF OF GROUND AND ADJACENT COMPONENTS ON VIBRATORY STRESSES ON BLADES OF DUCTED PROP.
14	69	MA	1.90	3	1.017	–	–	50° → 80°	–	–	–	–	X								3 TILT-WING CONFIG. LONG STABILITY CHAR (HORIZ-FORCE, VERTICAL-FORCE, PITCHING, AND VELOCITY-STABILITY DERIVS.) COMPARED WITH QUAD-DUCTED PROP CONFIG AND 2 HELICOPTERS. RPM MEASURED. HOVER AND TRANSITION. EQ FOR DERIVS.
15	64	MA	1.77	4	1.146	–	–	0° → 90°	–	–	–	–	X								VTOL CONFIG WITH 4 TILTING DUCTED PROPELLERS IN TANDEM. LIFT, LONG FORCE, AND PITCHING MOMENTS. RPM MEASURED. DIFFUSION ANGLE NOT GIVEN. EFFECT OF DIFFERENTIAL THRUST AND DIFFERENTIAL INCIDENCE ON AERO STAB AND CONTROL CHAR IN TRANSITION. TUFT GRID PICTURES.
16	60	BM	2.88	2	1.5	–	–	−10° → 90°	–	–	–	–			X	X					A TILTING DUCTED PROP AND A FAN-IN-WING IN MIT 7-1/2- × 10-FT TUNNEL. INCREMENTS IN LIFT, DRAG, AND PITCHING MOMENT, AND POWER COEFFICIENT TABULATED FOR TILT ANGLES OF −10° TO 90°, A BLADE PITCH SETTING OF 20°, AND TUNNEL VELOCITY OF 0 TO 40 MPH. MAX MASS FLOW VARIES FROM .288 TO .887 SLUGS/SEC. NO DIFFUSION. RPM MEASURED. TRANSITION REGIME. DUCT INFLOW VELOCITIES AND INLET PRESS DISTRIB. TUFT STUDY.
18	57	MA	.333, .667, 1.0, 1.5, 3.0	0	–	–	–	−4° → 90°	–	–	–	.704 → 2.11					X	X			5 ANNULAR AIRFOILS OF EQUAL PROJECTED AREAS IN LANGLEY 8- × 8-FT TUNNEL. NO DIFFUSION. LOW-SPEED STATIC LONG STAB CHAR. MAX L/D. LIFT-CURVE SLOPES AND DRAG POLARS COMPARED WITH CALC VALUES. TUFT GRID TESTS.

*MA = Modified Airfoil; BM = Bellmouth; NBM = Notched Bellmouth; + D = Plus Diffuser; TWC = Thin Walled Cylinder

TABLE 9.3-A (CONTD)

GEOMETRY							TUNNEL DATA		TEST CONDITIONS					DATA IN ADDITION TO L, D, M, RPM, & POWER								

REFERENCE NO.	YEAR OF PUBLICATION	DUCT SHAPE*	DUCT ASPECT RATIO	TOTAL NO. PROP. BLADES PER DUCT	NOMINAL PROP. DIAM. (FT)	PROP. DISK AREA / TUNNEL AREA (%)	MAX. q_j / MIN. q_{TUNNEL} (%)	α_0 RANGE	MAX. TESTED &/OR DESIGN DISK LOADING (LB/FT^2)	MAX. V_e/V_∞	MAX. ADVANCE RATIO J	R_1 RANGE $\times 10^{-6}$	DUCT FORCE, MOMENTS	PROP. FORCES, MOMENTS	DUCT PRESS. DISTRIBUTION	VELOCITY SURVEY	STATIC DATA	PROP.-REMOVED DATA	EXIT-VANE TESTS	INLET GUIDE VANE TEST	COMMENTS
19	59	MA, MA+D, BM, MA	4.0, 4.0+, 4.0, 6.66	4,6	2.0	0.93	6.8	$0 \rightarrow 90°$	62/25	7.4	0.47	$.072 \rightarrow .37$	X			X	X	X	X		2- AND 3-BLADED COUNTER ROTATING PROPELLERS. PROP TWIST AND BLADE PITCH VARIED. SPINNER ROTATES. PROP TIP CLEARANCE, CENTER-BODY LENGTH, PROP -LOCATION, AND EXIT-VANE EFFECTIVENESS INVESTIGATED. EXIT-VELOCITY SURVEY DATA. TEST POINTS PRIMARILY AROUND HORIZ-FORCE EQUILIBRIUM CONDITION.
20	59																				SUMMARY PLOTS OF TRANSITION DATA FROM REF 19 AND STATIC TEST DATA OF A HIGH-ASPECT-RATIO DUCT (DUCT 3 OF REF 19).
21	67	MA	1.844	8	4	0.44	–	$0 \rightarrow 90°$	–	–	0.95	–	X	X			X		X		FULL-SCALE V/STOL MODEL WITH 4 TILTING DUCTED FANS IN DUAL-TANDEM ARRANGEMENT IN AMES 40- x 80-FT. TUNNEL. BLADE PITCH ANGLE 23° (AT TIP). 11° DIFFUSION ANGLE (HALF-ANGLE). EFFECT OF GROUND HEIGHT ON LONG AERO CHAR. IN HOVER, TRANSITION, AND CRUISE, AT VARIOUS DUCT DEFLECTION, FORWARD SPEEDS, ADVANCE RATIOS, AND DUCT VANE DEFLECTIONS. RPM MEASURED. THRUST COEFF FOR ISOLATED DUCTED FAN AS FUNCTION OF ADVANCE RATIO AND DUCT DEFLECTION. EFFECT OF GROUND HEIGHT ON POWER AT VARIOUS DUCT DEFLECTIONS, FORWARD SPEEDS, AND ADVANCE RATIOS. PITCH CONTROL EFFECTIVENESS OF DUCT EXIT VANES.
22	66	MA	1.644	8	4	0.44	–	$20° \rightarrow 80°$	336.5/–	–	1.23	–	X				X	X	X	X	LARGE-SCALE V/STOL MODEL WITH 4 TILTING DUCTED FANS IN DUAL-TANDEM ARRANGEMENT IN AMES 40- BY 80-FT TUNNEL. BLADE PITCH ANGLE 23° (AT TIP). 11° DIFFUSION (HALF-ANGLE). RPM MEASURED. THRUST COEFF OF ISOLATED DUCTED PROP AS FUNCTION OF ADVANCE RATIO AND DUCT INCIDENCE. EFFECTS ON LONG AERO CHAR IN HOVER, TRANSITION, AND CRUISE, OF DUCT INCIDENCE, DIFFERENTIAL FORE-AFT DUCT INCIDENCE, MOMENT CENTER, FRONT DUCT THRUST, WING TIPS OUTBOARD OF REAR DUCTS, DUCT STALL, AT VARIOUS ADVANCE RATIOS AND DUCT INCIDENCES. EFF OF SIDESLIP, VERTICAL TAIL, DIFFERENTIAL LEFT-RIGHT DUCT EXIT-VANE DEFLECTION ON LAT-DIR AERO CHAR AT VARIOUS ADVANCE RATIOS AND DUCT INCIDENCES. DUCT INCIDENCE, POWER, AND DIFFERENTIAL EXIT-VANE DEFLECTIONS REQ FOR TRANSITION. MAX DESCENT VELOCITIES AND DUCT STALL MARGINS IN TRANSITION. CONTROL POWER VARIATION WITH DUCT EXIT-VANE SETTINGS.
23	62	MA	1.46	3	1.25	0.43	6.4	$0 \rightarrow 90°$	25/–	15.0	0.80	$.037 \rightarrow .72$					X	X			5/16-SCALE MODEL OF VZ4 DUCT AND SEMISPAN WING EXCEPT DUCT INTERNAL ELEMENTS (PROP, VANES, ETC.). ALL DATA INCLUDE WING LOADS. NO BLADE PITCH VARIATION. GROUND EFFECT DATA. SPINNER ROTATES. 11° DIFFUSION (HALF-ANGLE).
27	58	MA, BM	2.0	4	2.5	9.6, 1.89	9.6	$0 \rightarrow 6°$	37/– 103/–	1.0+	4.3	$1.4 \rightarrow 4.2$	X	X			X	X			NEARLY AXIAL FLOW, M = 0 TO 0.6. DUCT LE AT OPEN END OF 18-FT OCTAGONAL W-T TEST SECTION. PROP NORMAL FORCE NOT MEASURED. ONLY STATIC DATA ON BELLMOUTH DUCT. BLADE PITCH VARIED. SPINNER ROTATES. 5° DIFFUSION. SHARP-RADIUS INLET.
28	62	MA	1.64	3	1.25	0.43	8.2	$-10° \rightarrow 110°$	25/–	19.0	.695	$.042 \rightarrow .76$		X			X	X			5/16-SCALE MODEL OF VZ4 DUCT. DIVISION OF LOADS BETWEEN PROP AND DUCT. LOWER FORWARD LE RADIUS INCREASED DURING TEST TO PREVENT SEPARATION. NO BLADE PITCH VARIATION. 11° DIFFUSION. (HALF-ANGLE)
29	62	MA, BM	1.74	6	1.12	0.34	4.6	$0 \rightarrow 90°$	61/–	12.4	0.70	$.096 \rightarrow .70$		X			X	X	X		SEMISPAN MODEL. DIVISION OF LOADS INVESTIGATION. BELLMOUTH CONFIG IS A MODIFICATION OF MOD AIRFOIL CONFIG. NO BLADE PITCH VARIATION. GROUND-EFFECT DATA. SPINNER ROTATES. 11° DIFFUSION.
32	65	MA	1.90	3	7.0	.054		$0 \rightarrow 100°$			2.1		X	X	X		X				FULL-SCALE, DUCTED-FAN MODEL OF X-22A IN AMES 40- x 80-FT TUNNEL. TRANSITION, HOVER, AND CRUISE. BLADE ANGLE 15° – 50° (.75R). 8° DIFFUSION (ONE SIDE). THRUST PRESS., LIFT, DRAG, AND PITCHING MOMENT. HINGE MOMENTS. EFF OF ELEVONS.
35	57	BM															X			X	PROGRESS REPT. DUCT OF REF 41 DISCUSSED. INLET-GUIDE-VANE TEST PLOTS.
36	60	MA, MA, MA+D	1.46, 2.0, 2.16	–*	1.16	1.61	–	$0 \rightarrow 90°$	–	–	–	$.54 \rightarrow .73$						X			PROPELLER-OUT DATA FOR MA DUCT OF REFS 42 AND 43, AND MA AND MA+D DUCTS OF REF 46. HUB DIAMETER AND NOSE LENGTH INVESTIGATED.
37	59	MA, BM, NBM													X						DUCT AND CENTER-BODY SURFACE PRESSURE SURVEYS OF DUCTS OF REFS 40, 41, AND 42.

*MA = Modified Airfoil; BM = Bellmouth; NBM = Notched Bellmouth; +D = Plus Diffuser; TWC = Thin Walled Cylinder

			GEOMETRY			TUNNEL DATA		TEST CONDITIONS					DATA IN ADDITION TO L, D, M, RPM, & POWER								
REFERENCE NO.	YEAR OF PUBLICATION	DUCT SHAPE*	DUCT ASPECT RATIO	TOTAL NO. PROP. BLADES PER DUCT	NOMINAL PROP. DIAM. (FT)	PROP. DISK AREA / TUNNEL AREA (%)	MAX. q_1 / MIN. q_{TUNNEL} (%)	α_D RANGE	MAX. TESTED &/OR DESIGN DISK LOADING (LB/FT²)	MAX. V_e/V_o	MAX. ADVANCE RATIO J	R_j RANGE × 10^{-6}	DUCT FORCE, MOMENTS	PROP. FORCES, MOMENTS	DUCT PRESS. DISTRIBUTION	VELOCITY SURVEY	STATIC DATA	PROP.-REMOVED DATA	EXIT-VANE TESTS	INLET GUIDE VANE TEST	COMMENTS
38	60	MA, BM, NBM													X						DUCT AND CENTER-BODY SURFACE PRESSURE SURVEYS OF DUCTS OF REFS 43, 44, AND 46.
40	58	NBM	1.29	17	1.16	1.51	16.6	0 → 90°	227/227	11.0	7.0	.16 → .79	X								THRUST ONLY. NOTCHED INLET VERSION OF DUCT IN REF 42. NO BLADE PITCH VARIATION. SPINNER ROTATES. NO DIFFUSION.
41	58	BM	1.29	17	1.16	1.51	16.6	0 → 90°	227/227	11.0	5.0	.16 → .79	X				X				THRUST ONLY. BELLMOUTH INLET VERSION OF DUCT OF REF 42. NO BLADE PITCH VARIATION. SPINNER ROTATES. NO DIFFUSION.
42	58	MA	1.46	17	1.16	1.51	16.6	0 → 30°	227/227	7.2	5.0	.22 → 1.16	X				X				THRUST ONLY. NO BLADE PITCH VARIATION. NO DIFFUSION.
43	59	MA	1.46	10	1.16	1.51	8.36	0 → 30°	160/160	5.5	5.0	.22 → 1.24	X								THRUST ONLY. BLADE PITCH VARIED. SPINNER ROTATES. NO DIFFUSION.
44	59	NBM	1.29	10	1.16	1.51	8.36	0 → 90°	160/160	8.15	4.0	.16 → .79	X								THRUST ONLY. NOTCHED INLET VERSION OF DUCT OF REF. 43. BLADE PITCH VARIED. SPINNER ROTATES. NO DIFFUSION.
45	59	BM	1.29	10	1.16	1.51	8.36	0 → 90°	160/160	8.15	6.3	.16 → .79	X								THRUST ONLY. BELLMOUTH INLET VERSION OF DUCT OF REF 43. BLADE PITCH VARIED. SPINNER ROTATES. NO DIFFUSION.
46	60	MA, MA+D BM, BM+D	2.0, 2.15, 2.0, 2.15	2	1.16	1.51	5.86	0 → 40°	70/35	3.9	2.2	.16 → 1.56	X				X	X			THRUST ONLY. BLADE PITCH VARIED. SPINNER ROTATES. MODIFIED AIRFOIL AND BELLMOUTH DUCTS WITH AND WITHOUT DIFFUSION. BELLMOUTH DUCTS RUN STATICALLY ONLY.
47	65	TWC	1.90	3	(a) 3.8, (b) 9.9	– –	– –	– –	– –	– –	(a) .302, (b) .249	– –			X			X			THEORETICAL PREDICTIONS OF DUCT PRESSURE DISTRIBUTIONS COMPARED WITH DATA FROM (a) 1/3-SCALE AND (b) FULL-SCALE MODELS OF BELL X-22A TESTED IN DTMB 8- x 10-FT TUNNEL AND AMES 40- x 80-FT TUNNEL, RESPECTIVELY. STATIC PRESS DISTRIBUTION ON INNER AND OUTER SURFACES OF DUCT, ALSO FOR DUCT WITH PROPELLER REMOVED, AND WITH PROPELLER AND HUB REMOVED. SPEED, ANGLE OF ATTACK, AND POWER INPUT VARIED.
48	64	(a) TWC (b) MA (c) MA (d) MA (e) MA (f) MA	a) 5.09 b) 2.89 c) 2.00 d) 1.38 e) 1.95 f) 2.06	3	1.333	–	–	−10° → 10°	–	–	1.65	–	X				X				ADJUSTABLE-PITCH PROPELLER AND SPINNER WITH 5 DUCTS, SOME UNCAMBERED WITH VARIED CHORD-DIAM RATIOS, AND SOME WITH POSITIVE AND NEGATIVE CAMBER AND A CONSTANT CHORD-DIAM RATIO. (a) HAS NO DIFFUSION. EFFECTS OF THRUST, DUCT LENGTH, AND CAMBER ON STATIC STAB CHAR. LIFT AND LONGITUDINAL-FORCE COEFF, PITCHING MOMENT, C_{L_α} AND C_{m_α}. COMPARISON WITH THEORY. POWER SURVEY. PROPULSIVE EFFICIENCY. EQ FOR FORCES AND MOMENTS IN APPENDIX.
52	66	MA	a) 1.645 b) 1.904	(a) 8 (b) 3	(a) 4 (b) 7.06	(a) .44 (c) 1.37	–	–	–	–	(a) .541 (b) .882	.13 → 1.06	X	X	X	X	X	X	X	X	2 LARGE-SCALE DUCTED-PROPELLER MODELS OF DOAK VZ-4DA AND BELL X-22A TESTED IN AMES 40- x 80-FT TUNNEL. 15° BLADE PITCH AT TIP IN (a), VARIABLE BLADE PITCH IN (b), ~ 9° DIFFUSION (HALF-ANGLE). THRUST OF DUCTED PROPELLER, DUCT, AND PROPELLER FOR VARIED ADVANCE RATIOS. NORMAL FORCE AND PITCHING MOMENT. PRESS FOR RANGE OF ANGLE OF ATTACK, ADVANCE RATIOS, AND DUCTED-PROPELLER THRUST COEFF. COMPUTED AND MEASURED B-L THICKNESS. DUCT STALL BOUNDARY FOR (a) FROM TUFTS, SOUND, AND PITCHING-MOMENT DATA. EFFECTS OF ELEVONS (ACROSS DUCT EXIT PLANE) AND PROP BLADE PITCH ON THRUST AND PRESS FOR (b).
53	63	–	–	–	–	–	–	–	–	–	–	–		X				X			STATIC AND DYN STAB DERIVS OF DUCTED PROPS IN HOVER AND CRUISE PREDICTED. EXPER DATA (FROM REFS 19, 27, 56, 70, 79, et al.) ON PROP THRUST COEFF, DUCT NORMAL FORCE, AND PROPULSIVE EFFICIENCY COMPARED WITH THEORY.
56	49	MA	1.60	8	.7875	~27	–	–	–	–	1.5	→ 1.2	X	X	X	X	X	X	X		2 PROPELLERS DIFFERING IN BLADE TWIST PLUS NACELLE PLUS 15 DUCTS, WHICH DIFFER IN CHORD LENGTH, EXTENDED CHORD, THICKNESS RATIO, AND CAMBER. BLADE PITCH 15° TO 55°. NO DIFFUSION. THRUST, SOME DRAG, AND TORQUE. EFFECT OF SHAPE OF PROPELLER AND SHROUD SEPARATELY, OF NOSE SPLIT-RING FLAP, OF EXIT STATORS PRIMARILY ON POWER AND THRUST AS A FUNCTION OF ADVANCE RATIO AND BLADE PITCH. RPM MEASURED. CALC AND EXPER VALUES OF EFFICIENCY AND STATIC THRUST FACTOR OF MERIT COMPARED. PHOTOS OF SMOKE TESTS.

*MA = Modified Airfoil; BM = Bellmouth; NBM = Notched Bellmouth; +D = Plus Diffuser; TWC = Thin Walled Cylinder

TABLE 9.3-A (CONTD)

		GEOMETRY				TUNNEL DATA		TEST CONDITIONS					DATA IN ADDITION TO L, D, M, RPM, & POWER								
REFERENCE NO.	YEAR OF PUBLICATION	DUCT SHAPE*	DUCT ASPECT RATIO	TOTAL NO. PROP. BLADES PER DUCT	NOMINAL PROP. DIAM. (FT)	PROP. DISK AREA / TUNNEL AREA (%)	MAX. m_j / MIN. m_{TUNNEL} (%)	α_D RANGE	MAX. TESTED &/OR DESIGN DISK LOADING (LB/FT²)	MAX. V_e/V_∞	MAX. ADVANCE RATIO J	R_f RANGE × 10^{-6}	DUCT FORCE, MOMENTS	PROP. FORCES, MOMENTS	DUCT PRESS. DISTRIBUTION	VELOCITY SURVEY	STATIC DATA	PROP.-REMOVED DATA	EXIT-VANE TESTS	INLET GUIDE VANE TEST	COMMENTS
59	64	MA	(a)10.2 (b)5.176	2,3	2	–	–	$-10^\circ \rightarrow 10^\circ$	–	–	–	–	X								2 DUCTS, EACH TESTED WITH 2 PROPS IN DTMB 8- x 10-FT TUNNEL. $15^\circ \rightarrow 35^\circ$ BLADE PITCH ANGLE. DIFFUSION ANGLE NOT GIVEN. CRUISE, LIFT, PITCHING MOMENT, THRUST, PROPULSIVE EFFICIENCY.
60	66	MA	–	8	(a) 4 (b) ~1.2	(a) .44 (b) –	–	$15^\circ \rightarrow 70^\circ$	–	–	1.30	–	X						X		LARGE DUAL-TANDEM, TILTING DUCTED-PROPELLER VTOL MODEL OF DOAK VZ-4DA IN AMES FULL-SCALE TUNNEL, AND A .3-SCALE MODEL OF THE SAME IN THE LANGLEY TUNNEL. DIFFUSION ANGLE NOT GIVEN. PITCHING MOMENT IN TRANSITION, SIDE-FORCE, YAWING MOMENT, AND ROLL-YAW COUPLING. DUCT ANGLE AND POWER REQUIRED AS FUNCTION OF FLIGHT SPEED. GROUND EFFECT. SOME DATA IN HOVER AND CRUISE ALSO.
61	66	–	–	–	0.5	–	–	–	–	–	–	–	X								SEMISPAN MODEL WITH 2 DUCTED PROPELLERS MOUNTED AHEAD OF A WING WITH DOUBLE-SLOTTED FLAPS IN LANGLEY TUNNEL. DIFFUSION ANGLE NOT GIVEN. EFFECTS OF EXHAUST SPLIT, SLIPSTREAM DEFLECTION, AND FENCES ON LIFT-THRUST AND DRAG-THRUST RATIOS IN HOVER. EFFECT OF FENCES ON JET-INDUCED LIFT. THRUST REQUIRED IN TRANSITION.
63	54	–	–	4	5.33	–	–	$0 \rightarrow 180^\circ$	–	–	–	$0 \rightarrow 1.8$		X							1/3-SCALE MODEL PROPELLER IN LANGLEY FULL-SCALE TUNNEL. EFFECT OF BLADE ANGLE (0 TO 26° AT .75R) ON THRUST AND POWER COEFF IN HOVER. EFFECTS OF BLADE ANGLE ($0 \rightarrow 67.5^\circ$), ADVANCE RATIO, AND PROP ANGLE OF ATTACK ON THRUST AND POWER COEFFICIENTS, PROPELLER EFFICIENCY, NORMAL-FORCE, YAWING-MOMENT, AND PITCHING-MOMENT COEFFICIENTS. COMPARISON OF THEORY AND EXPER. PROP NORMAL-FORCE, THRUST, AND POWER COEFFICIENTS AND PROP EFFICIENCY FOR VARIOUS BLADE ANGLES, ADVANCE RATIOS, AND ANGLES OF ATTACK. CRUISE, TRANSITION, AND HOVER.
67	62	MA	1.64	8	4.0	0.39	1.8	$0 \rightarrow 90^\circ$	125/100	4.8	0.91	$.86 \rightarrow 3.07$									VZ4 SEMISPAN WING PLUS DUCT (PROTOTYPE COMPONENTS). DUCT AND DUCT-WING DATA TAKEN AT 4 WING ANGLE-OF-ATTACK SETTINGS. DUCT STALL BOUNDARIES DEFINED. 2 BLADE PITCH ANGLES TESTED. 11° DIFFUSION (HALF-ANGLE).
68	66	–	–	(a) – (b) – (c) 3	(a) 3 (b) 5 (c) 7	–	–	–	–	–	1.2	–	X				X	X			3 SIZES OF ISOLATED DUCTED PROPELLERS IN AMES TUNNEL, THE 7-FT PROPELLER A FULL-SCALE MODEL OF THOSE IN X-22A, THE 3-FT PROPELLER WITH 3 LIPS. VARIABLE BLADE PITCH. DIFFUSION ANGLE NOT GIVEN. PRESSURE LOSSES FOR 3- AND 5-FT PROPELLERS. NACELLE DRAG FOR 3-FT PROPELLER AND ITS EFFECT ON THRUST. EFFECT OF TIP CLEARANCE ON THRUST AND POWER COEFFICIENTS AND ON STATIC PERFORMANCE. DUCT ANGLE OF ATTACK FOR INNER AND OUTER TIP STALL.
69	67	MA	1.90	3	7	1.40	–	$0 \rightarrow 90^\circ$	–	–	2.17	–	X		X		X	X	X		LARGE-SCALE DUCTED PROPELLER LIKE THOSE ON BELL X-22A TESTED IN AMES 40- x 80-FT TUNNEL. $14^\circ \rightarrow 46^\circ$ BLADE PITCH. 9° DIFFUSION (HALF-ANGLE). RPM MEASURED. TOTAL THRUST, POWER COEFF , AND PROPULSIVE EFFICIENCY FOR RANGE OF BLADE ANGLES AND ADVANCE RATIOS. TOTAL LIFT, DRAG, AND PITCHING MOMENT, ALSO WITH PROP REMOVED. STATIC EFFICIENCY SHOWN AS FIGURE OF MERIT. THRUST VALUES COMPARED WITH THEORY. DUCT LIP STALL.
70	59	BM	3.0	2	1.5	3.22	10.9	$70^\circ \rightarrow 100^\circ$	23/–	3.4	0.27	$.09 \rightarrow 0.14$			X	X	X				ARTICULATED BLADES WITH OFFSET LAG HINGES. BLUNT AFTERBODY, NO SPINNER. ANALYSIS OF DUCTED PROPS. BLADE PITCH VARIED. NO DIFFUSION. GROUND-EFFECT DATA.
71	65	MA	4.0	(a) 4 (b) 2 (c) 2	8	–	–	90°	(a) 22/– (b) 23/– (c) 23/–	–	–	–	X	X	X	X	X		X		FULL-SCALE DUCT AND 3 PROPELLERS ON MOBILE TEST RIG. BLADE PITCH AT .75R FOR (a) $9.8^\circ \rightarrow 11.8^\circ$, (b) 13.6°, (c) 13.3°, 13.6°. BLADE TWIST. NO DIFFUSION. RPM MEASURED. TOTAL THRUST AND FOR PROP ALONE. TOTAL PITCHING MOMENT. EFFECT OF DUCT, ENGINE COWLINGS, THRUST VECTORING VANES, DUCT LIP EXTENSION, TIP CLEARANCE, BLADE TWIST, AND GROUND PROXIMITY. DUCT PRESSURES COMPARED WITH THEORY. EFFECT OF VANES ON AIR-TURNING ANGLE. HOVER CONDITION.
72	65	MA	(a) 2.40 (b) 2.48 (c) 2.28 (d) 2.34 (e) 2.53 (f) 2.28 (g) 2.33	2	6	–	–	4°, 8°	(a) 38.9/– (b) 36.8/– (c) 35.0/– (d) 34.1/– (e) 41.0/– (f) 39.0/– (g) 36.5/–	–	–	–	X	X	X	X		X			TRACTOR AND PUSHER DUCTED PROPELLERS WITH 4 PROPELLERS IN NAE MOBILE TEST RIG. TRACTOR DUCTS HAVE MODIFIED LE AND 6° AND 10° DIFFUSION (HALF-ANGLE). PUSHER DUCTS OF 5.7 PERCENT THICKNESS-DIAM RATIO HAVE 3° DIFFUSION (HALF-ANGLE), OF 8.3 PERCENT THICKNESS-DIAM RATIOS 5° AND 10° DIFFUSION (HALF-ANGLE). BLADE TWIST. RPM MEASURED. HOVER AND CRUISE CONDITIONS. THRUST FOR DUCTED AND PROP , ALONE AND COMBINED. EFFECTS OF DUCT, DIFFUSER ANGLE, AND MOD LE, INCIDENCE, PROP LOCATION, TIP CLEARANCE, AND TIP CHORD OF BLADES.

*MA = Modified Airfoil; BM = Bellmouth; NBM = Notched Bellmouth; +D = Plus Diffuser; TWC = Thin Walled Cylinder

REFERENCE NO.	YEAR OF PUBLICATION	DUCT SHAPE*	GEOMETRY: DUCT ASPECT RATIO	GEOMETRY: TOTAL NO. PROP. BLADES PER DUCT	GEOMETRY: NOMINAL PROP. DIAM. (FT)	TUNNEL DATA: PROP. DISK AREA / TUNNEL AREA (%)	TUNNEL DATA: MAX. m_t / MIN. m_{TUNNEL} (%)	TEST CONDITIONS: α_D RANGE	TEST CONDITIONS: MAX. TESTED &/OR DESIGN DISK LOADING (LB/FT^2)	TEST CONDITIONS: MAX. V_e/V_∞	TEST CONDITIONS: MAX. ADVANCE RATIO J	TEST CONDITIONS: R_l RANGE × 10^{-6}	DUCT FORCE, MOMENTS	PROP. FORCES, MOMENTS	DUCT PRESS. DISTRIBUTION	VELOCITY SURVEY	STATIC DATA	PROP.-REMOVED DATA	EXIT-VANE TESTS	INLET GUIDE VANE TEST	COMMENTS
7[illegible]	63	MA	1.77	4	1.146	–	–	0 → 75°	–	–	–	–	X						X		4 VTOL CONFIGS WITH TILTING DUCTED PROPS IN TANDEM PAIRS IN LANGLEY 12-FT OCTAGONAL TEST SECTION. BLADE PITCH FIXED. DIFFUSION ANGLE NOT GIVEN. EFFECTS OF VARIOUS LAT AND VERT POSITIONS OF DUCTS, DUCT INCIDENCE, WING INCIDENCE, AND POWER ON LONG CHAR, WITH AND WITHOUT PROPS IN CRUISE AND TRANSITION. EFFECTS OF VERT TAIL, DUCT INCIDENCE, AND ANGLE OF ATTACK ON LATERAL CHARACTERISTICS.
74	66	MA	1.90	4	1.4	–	–	0 → 90°	–	–	–	–	X								MOSTLY FREE-FLIGHT TESTS OF AN .18-SCALE MODEL OF 4-DUCT TANDEM V/STOL TRANSPORT IN LANGLEY FULL-SCALE TUNNEL. DIFFUSION ANGLE NOT GIVEN. EFFECTS OF GROUND PROXIMITY ON LIFT, ROLLING AND PITCHING MOMENTS, AND AILERON YAW CONTROL EFFECTIVENESS IN HOVER AND TRANSITION. EFFECTS OF VERT-TAIL SIZE, YAW DAMPER, VORTEX GENERATORS, AND LE SLATS ON PITCHING. TUFT STUDIES OF DUCT STALL. ROLL AND YAW CONTROL BY DIFFERENTIALLY DEFLECTING AILERONS IN DUCTS. EFFECT OF DUCT INCIDENCE ON THRUST COEFF AT VARIOUS DESCENT RATES.
76	67	MA	–	4	0.5	–	–	0 → 20°	–	–	–	–	X		X						SEMISPAN WING WITH DOUBLE-SLOTTED FLAP AND DUCTED PROPELLERS IN LANGLEY FULL-SCALE AND LOW-SPEED 12-FT OCTAGONAL TEST SECTION. NO DIFFUSION. EFFECTS OF 1 OR 2 FANS, SPANWISE DUCT LOCATION, DUCT-EXIT SPLIT, FENCES, FLAP DEFLECTION, AND MOMENTUM COEFF. LIFT, DRAG, PITCHING MOMENT, AND TOTAL PRESS AT FORWARD SPEED AND STATIC THRUST CONDITIONS. LIFT INDUCED BY JET-FLAP ACTION COMPARED WITH CALC VALUES. THRUST REQUIRED IN TRANSITION. SLIPSTREAM ROTATION AND TURNING CONTROLLED BY VANES, FENCES, AND FLAPS.
77	55	TWC	1.47	2	1.50	1.48	9.6	0 → 90°	3.4/–	6.4	.213	.066 → .53					X	X			VERY LOW DISC LOADING. BLUNT CENTERBODY. 5 SMALL CIRCULAR LEADING RADII TESTED. NO DIFFUSION.
78	60	BM	2.33, 3.06		2.33	0.24	4.1	80° → 90°	8.9/–	17.4	.84	.017 → .20					X	X		X	2-, 3-, AND 4-BLADED PROPELLERS, BLADE PITCH VARIED. NO DIFFUSION. GROUND EFFECTS. ISOLATED-DUCT STATIC STAB, LE-RADIUS EFFECTS, AND INLET-GUIDE-VANE THRUST CONTROL.
79	48	MA	(a) 1.6 (b) 1.7 (c) 1.4	12	4	–	–	–	(a) 107/– (b) 119/– (c) –	–	–	–	X	X	X	X	X	X			2 HIGH-SOLIDITY PROPELLERS, ONE TESTED WITH 3 DUCTS, TESTED OUTDOORS. BLADE PITCH: 15° → 40° (UNSHROUDED PROP) 35° → 45° (DUCTED PROP) DIFFUSION ANGLE (BOTH SIDES): (a) 7°, (b) 22.4°, (c) 14.4°. RPM MEASURED, ONLY THRUST AND POWER FOR COMPONENTS AND VARIOUS BLADE ANGLES. HOVER CONDITION.
80	64	MA	2.26	3	8	–	–	75° → 105°	60/–	–	–	–			X						A FULL-SCALE HALF-MODEL OF DUAL-TANDEM DUCTED-PROP VTOL TESTED OVER SAND AND WATER IN HOVER. 31.5° BLADE PITCH AT .75R. APPROX 8° DIFFUSION (HALF-ANGLE). RPM MEASURED. EFFECTS OF GROUND PROXIMITY, DUCT INCLINATION, AFT DUCT LOCATION, DISC LOADING, AND TERRAIN TYPE ON POWER LOADING, INGESTION, AND RECIRCULATION.
81	68	MA	1.90	3	1.02	–	–	40° → 90°	–	–	.44	–	X				X				ISOLATED DUCT AND COMPLETE .145-SCALE QUAD-CONFIG, DUCTED-PROP V/STOL SIMILAR TO BELL X-22A IN PRINCETON DYNAMIC MODEL TRACK. STATIC TESTS AT FIXED BLADE ANGLE OF 19.1° (AT .75R); DYNAMIC TESTS AT BLADE ANGLES OF 25.8° → 29.2° (.75R) AND WITH DIFFERENTIAL BLADE ANGLES OF FRONT AND REAR PROPELLERS. DIFFUSION ANGLE APPROX 9° (HALF-ANGLE). RPM MEASURED. STATIC TESTS ON ISOLATED DUCT: LIFT, DRAG, AND PITCHING MOMENT COMPARED WITH FULL-SCALE DATA. TIME HISTORIES OF TRANSIENT RESPONSE CHAR IN HOVER OF COMPLETE MODEL FOR 1°, 2°, AND 3° OF FREEDOM: ROLL, YAW, SIDE VELOCITY AND VERT VELOCITY MOTIONS.
82	68	MA	1.90	3	1.02	–	–	–	–	–	–	–									.143-SCALE QUAD-CONFIG, DUCTED-PROPELLER V/STOL SIMILAR TO BELL X-22A IN PRINCETON DYNAMIC MODEL TRACK. DIFFUSION APPROX 9° (HALF-ANGLE). BLADE ANGLE VARIED 23.7° → 28° AT .75R, DIFFERENTIAL BLADE ANGLE BETWEEN FRONT AND REAR PROPS. RPM MEASURED. LONG DYNAMIC STAB CHAR AT LOW SPEED AND HIGH INCIDENCES (50° – 80°). TIME HISTORIES OF TRANSIENT RESPONSES TO 3° OF FREEDOM (PITCH, HORIZ. AND VERTICAL VELOCITY), TO 2° OF FREEDOM (PITCH AND HORIZ VELOCITY, AND PITCH AND VERT VELOCITY), AND TO 1° OF FREEDOM IN PITCH.
83	68	MA	1.90	3	1.02	–	–	–	–	–	–	–									.143-SCALE QUAD-CONFIG DUCTED-PROPELLER V/STOL SIMILAR TO BELL X-22A IN PRINCETON DYNAMIC MODEL TRACK DIFFUSION APPROX 9° (HALF-ANGLE). BLADE ANGLE VARIED FROM 24.8° → 25.6° AT .75R. LAT-DIR DYNAMIC STAB CHAR AT LOW SPEEDS AND HIGH INCIDENCES (50° – 80°). TIME HISTORIES OF TRANSIENT RESPONSES TO 3° OF FREEDOM (ROLL, YAW, LATERAL VELOCITY), TO 2° OF FREEDOM (ROLL AND YAW, AND ROLL AND LATERAL VELOCITY), AND 1° OF FREEDOM (ROLL ONLY AND YAW ONLY). RPM MEASURED.

*MA = Modified Airfoil; BM = Bellmouth; NBM = Notched Bellmouth; +D = Plus Diffuser, TWC = Thin Walled Cylinder

TABLE 9.3-A (CONTD)

REFERENCE NO.	YEAR OF PUBLICATION	GEOMETRY: DUCT SHAPE*	GEOMETRY: DUCT ASPECT RATIO	GEOMETRY: TOTAL NO. PROP. BLADES PER DUCT	GEOMETRY: NOMINAL PROP. DIAM. (FT)	TUNNEL DATA: PROP. DISK AREA / TUNNEL AREA (%)	TUNNEL DATA: MAX. $\bar{q}$ / MIN. $\bar{q}_{TUNNEL}$ (%)	TEST CONDITIONS: α_0 RANGE	TEST CONDITIONS: MAX. TESTED &/OR DESIGN DISK LOADING (LB/FT^2)	TEST CONDITIONS: MAX. V_0/V_∞	TEST CONDITIONS: MAX. ADVANCE RATIO	TEST CONDITIONS: R_l RANGE × 10^{-6}	DUCT FORCE, MOMENTS	PROP. FORCES, MOMENTS	DUCT PRESS. DISTRIBUTION	VELOCITY SURVEY	STATIC DATA	PROP.-REMOVED DATA	EXIT-VANE TESTS	INLET GUIDE VANE TEST	COMMENTS
84	59	–	–	–	–	–	–	–	–	–	–	–									124 REPORTS LISTED PERTAINING TO DUCTED PROPELLERS. A TABLE OF 29 REPORTS CONTAINING EXPERIMENTAL DATA IN HOVER, CRUISE, AND TRANSITION FLIGHT SHOW THE PARAMETERS VARIED, WITH ADDITIONAL COMMENTS, SIMILAR TO THE ANALYSIS IN THIS TABLE.
86	63	MA	1.90	3	1.02	–	–	–	–	1.52	–	–	X								1/31.27-SCALE MODEL OF X-22A. DIFFUSION ANGLE APPROX 9° (HALF-ANGLE). EFFECT OF GROUND AND ANGLE OF ATTACK ON LIFT, PITCHING MOMENT, AND ROLLING MOMENT IN HOVERING.
87	65	MA	1.9	3	1.40	–	–	$-5° \rightarrow 90°$	–	–	–	.066 → .48	X	X					X		1/5-SCALE VTOL MODEL WITH 4 DUCTED PROPELLERS IN 17-FT TEST SECTION OF LANGLEY 300-MPH, 7- x 10-FT TUNNEL. DIFFUSION ANGLE NOT GIVEN. HOVER, CRUISE, AND TRANSITION FLIGHT. EFFECTS OF ANGLE OF ATTACK, POWER, VERT-TAIL SIZE AND ASPECT RATIO, AND VERT. FINS ON SIDE-FORCE, YAWING AND ROLLING MOMENTS. PROPELLER THRUST COEFFICIENTS. YAW AND ROLL CONTROL BY EXIT VANES.
88	66	MA	1.9	3	1.40	–	–	$-5° \rightarrow 90°$	–	–	–	.066 → .48	X						X		1/5-SCALE VTOL MODEL WITH 4 DUCTED PROPELLERS IN 17-FT TEST SECTION OF LANGLEY 300-MPH, 7- x 10-FT TUNNEL. DIFFUSION ANGLE NOT GIVEN. HOVER, CRUISE, AND TRANSITION FLIGHT. EFFECT OF GROUND ON LIFT, DRAG, AND PITCHING MOMENT.
																					EFFECTS OF HORIZ TAIL, DUCT FAIRINGS, DUCT LOCATION, DUCT DEFLECTION, DUCT LIP, DIFFERENTIAL DUCT DEFLECTION, PROPELLER, PROP ROTATION DIRECTION, NACELLES, VANE DEFLECTION, AND POWER ON LIFT, DRAG, AND PITCHING MOMENT OF MODEL; ALSO ISOLATED DUCTED PROP DATA. DUCT STALL. TUFT STUDIES AT VARIOUS THRUST COEFF., DUCT DEFLECTION ANGLES, AND ANGLES OF ATTACK.
90	60	–	–	8	4	–	–	$0 \rightarrow 90°$	–	–	–	–	X							X	VTOL CONFIG WITH TILTING DUCTED FANS ON EACH WING-TIP (DOAK 16) IN FLIGHT TEST. TIME HISTORIES OF AIRCRAFT MOTIONS IN ROLL, PITCH, AND YAW, CONTROL POSITIONS, AND DUCT PITCHING-MOMENT VARIATIONS IN HOVER AND TRANSITION.
92	60	–	–	–	–	–	–	–	–	–	–	–	X					X			84 REF. LISTED CONTAINING TEST DATA ON DUCTED PROPS. 17 REF. ANALYZED, INCLUDING 19, 27, 40 THROUGH 45, 56, 63, 70, AND 79, AND PRESENTED ON PLOTS OF STATIC EFFICIENCY AND SHROUD THRUST IN HOVER; THRUST COEFFICIENT AS A FUNCTION OF ADVANCE RATIO AND BLADE ANGLE, PROPULSIVE EFFICIENCY, AND SHROUD THRUST IN CRUISE; AND LIFT, DRAG, AND POWER COEFF. AND PITCHING AND ROLLING MOMENTS IN TRANSITION.
93	66	MA	2.48	3	2.21	–	–	–	–	–	–	–	X		X						SHROUDED PROPELLER IN HOVER, REARWARD MOTION, AND FORWARD MOTION. BLADE PITCH VARIED FROM 5° TO 25°, BLADE TWIST ZERO. DIFFUSION APPROX 15° (HALF-ANGLE). RPM MEASURED. SHROUD PRESS. DISTRIBUTION, STAGNATION-LINE LOCATION, AND SHROUD THRUST FOR 3 CASES OF MOTION AT SEVERAL PROP PITCH ANGLES, PROP ROTATIONAL SPEEDS, AND VEHICLE LINEAR SPEEDS. TUFT STUDIES OUTSIDE OF DUCT.
95	58																				PROGRAM SUMMARY OF UNIV. OF WICHITA DUCTED PROPELLER RESEARCH. NO DATA BUT SOME MODEL GEOMETRIC CHARACTERISTICS GIVEN.
96	61	MA	–	–	4	–	–	$0 \rightarrow 90°$	250/–	–	–	–	X						X		SEMISPAN WING WITH DOAK DUCTED FAN MOUNTED ON WING TIP IN AMES 40- x 80-FT TUNNEL. DIFFUSION ANGLE NOT GIVEN. EFFECT OF WING ANGLE OF ATTACK ON DOWNWASH. EFFECTS OF EXIT VANE DEFLECTION, AIRPLANE WEIGHT AND DISC LOADING, AND LIP STALL ON DUCT PITCHING MOMENT FROM HOVER TO CRUISE. LIFT AND PITCHING MOMENT FOR DUCT AND DUCT PLUS WING.
97	61	MA	1.64	8	4.0	0.39	2.64	$0 \rightarrow 90°$	125/100	6.75	0.91	.59 → 4.06				X			X	X	VZ4 SEMISPAN WING PLUS DUCT (PROTOTYPE COMPONENTS). NO BLADE PITCH VARIATION. TRANSITION CONDITIONS. WING-ALONE DATA. DOWNWASH INVESTIGATION AT HORIZ. LOCATION. EXIT-VANE PITCHING-MOMENT CONTROL INVESTIGATED. 11° DIFFUSION (HALF-ANGLE).

*MA = Modified Airfoil; BM = Bellmouth; NBM = Notched Bellmouth; +D = Plus Diffuser; TWC = Thin Walled Cylinder

9.3.1 DUCTED-PROPELLER LIFT VARIATION WITH POWER AND ANGLE OF ATTACK

The primary purpose of enclosing a propeller in a duct is to increase the thrust-generating capability in the static and low subsonic speed regimes for a given propeller diameter and power input. Because of strong mutual interference effects, the ducted-propeller aerodynamic characteristics are vastly different from those of a free propeller and an annular airfoil. The forces and moments acting on a ducted propeller may be considered as arising from the propeller forces, the duct forces, and the mutual interference of the duct and propeller.

As a consequence of the input of mechanical energy to a propeller delivering positive thrust, there is a pressure rise at the propeller disk, which is subsequently transformed into kinetic energy in the slipstream. If the propeller is enclosed within a fairing, a further velocity increment is produced at the propeller, which must be superimposed on the propeller flow. If this velocity increment is positive, the mass flow and consequently the total thrust are increased. This increase in force acts on the duct, and its magnitude depends upon the velocity increment due to the duct and the propeller loading. In addition, the mutual interference of the duct and propeller and other bodies which may be present results in an induced circulation, which may either increase or decrease the internal mass flow.

The Datcom methods presented for estimating forces and moments on ducted-propeller configurations require knowledge of only the total internal axial thrust rather than the thrust due to the propeller and to the duct at angle of attack. However, the fundamental phenomenon of ducted-propeller aerodynamics may be clarified somewhat by an analysis of the division of loads between the duct and the propeller.

The results of an investigation of the division of the forces and moments between a duct and a propeller of a ducted propeller are reported in reference 6. The investigation covered an angle-of-attack range and an advance-ratio range typical of the transition of a tilt-duct VTOL aircraft.

Figures 9.3.1-10a and 9.3.1-10b, reproduced from reference 6, present a comparison of the normal force, thrust force, and pitching moment on the propeller with the total model forces and moments, for an unstalled and a stalled duct, respectively. The unstalled configuration is the basic symmetrical duct shape modified by the addition of leading-edge fairings. These results show that the normal force and pitching moment acting on the propeller and spinner are relatively small in comparison with the total normal force and pitching moment of either the stalled or unstalled unit and that the duct is the primary source of normal force and pitching moment.

Figure 9.3.1-12, reproduced from reference 6, presents the variation of propeller thrust relative to total thrust with angle of attack for both the unstalled and the stalled duct configurations. In hovering ($V/nd_p = 0$), the propeller carries approximately 40 percent of the total thrust. At the highest value of the advance ratio tested, the propeller carries approximately 70 percent of the total thrust when α is near 0°. For the unstalled operation, the propeller thrust ratio generally decreases with increasing angle of attack at a constant advance ratio. Beyond the stall the propeller thrust ratio increases with increasing angle of attack at a constant advance ratio. The increase can be attributed to the reduction in duct thrust caused by the lip stall.

Unpowered conditions correspond to a duct exit-velocity ratio of approximately 1.0. The exact value depends on the circulation about the duct. Annular wing reports, such as reference 2, may be used to estimate the forces and moments on an unpowered ducted propeller at angle of attack.

For convenience, the methods presented in subsequent Sections provide wind-axis aerodynamic force coefficients: conventional lift and drag coefficients normal and parallel to the free stream. The aerodynamic force and moment coefficients are referred to free-stream dynamic pressure.

Ducted propeller forces and moments are compared with those predicted by the Datcom methods in this and the following Sections. The experimental data represent a wide variation of duct and propeller variables over angle-of-attack and advance-ratio ranges typical of the transition range of a tilting duct VTOL aircraft. Experimental axial-thrust values have been used in the Datcom method calculations. A comparison of some of the pertinent geometric and aerodynamic parameter variations of the test configurations can be made by referring to the reference list of this Section and the reference list and table 9.3-A of Section 9.3. The Datcom methods are based on modifications to simple momentum theory and do not account for the possible wide variation in design parameters.

The lift predicted by the Datcom method of this Section compares favorably with test results throughout the range of the investigation. On the other hand, the pitching moment and drag predicted by the Datcom methods of Sections 9.3.2 and 9.3.3, respectively, vary noticeably from experimental results.

The method presented in this Section for the estimation of the lift of a ducted propeller is expressed as the sum of the lift components resulting from the internal and external mass flows. The internal-mass-flow component is estimated on the basis of simple momentum theory with empirical flow-turning corrections as a function of the duct aspect ratio and the duct exit-velocity ratio. The external-mass-flow component is estimated on the basis of empirical modifications of the data of references 1 and 2.

DATCOM METHOD

The method presented for the estimation of ducted-propeller lift coefficient is expressed as the sum of the components resulting from the internal and external mass flows. This approach is summarized by

$$C_L = \frac{L}{q_\infty S_D} = C_{L_i} + C_{L_e}$$

$$= \frac{\pi A_D}{2}\left[1 - \left(\frac{d_{CB}}{d_e}\right)^2\right]\left(\frac{V_e}{V_\infty}\right)^2 \sin \delta_{i_f} + C_{L_e} \qquad \text{9.3.1-a}$$

where

C_{L_i} is the lift coefficient resulting from the internal mass flow

C_{L_e} is the lift coefficient resulting from the external mass flow. It is obtained from figure 9.3.1-13 as a function of duct aspect ratio and angle of attack. Figure 9.3.1-13 is based on empirical modifications of the data of references 1 and 2.

δ_{i_f} is the net turning angle of the internal flow including power effects.

The basic approach to the solution of equation 9.3.1-a is as follows:

1. Determine the turning angle of the internal flow neglecting the effects of power.

2. Determine the exit-velocity ratio V_e/V_∞.

3. Determine the net turning angle of the internal flow including power effects.

4. Evaluate the internal-flow lift contribution using the terms obtained in steps 2 and 3 above.

The results of reference 2 indicate that the lift-curve slope of annular wings is twice that of plane unswept wings of the same aspect ratio. Based on simple momentum theory, the usual small-angle approximation, and the assumption of no lip separation, the turning angle of the internal flow, neglecting power effects, is

$$\delta_{i_o} \approx \sin^{-1}\left(\frac{C_{L_\alpha}\,\alpha}{\pi\, A_D}\right) \qquad 9.3.1\text{-b}$$

The unpowered, internal-flow turning angle relative to duct angle of attack is presented in figure 9.3.1-14 as a function of duct aspect ratio. Figure 9.3.1-14 is based on the unstalled test data of reference 2 and equation 9.3.1-b.

Addition of power causes further turning of the internal flow. This turning occurs forward of the propeller plane because of the closed boundaries of the duct. The flow is assumed to pass through the duct normal to the propeller plane, and the total velocity increase imparted to the internal flow (V_i) is assumed to be the difference between the duct exit velocity and the free-stream velocity. This results in the following expression for the net turning angle of the internal flow, including power effects (see figure 9.3-11b).

$$\delta_{i_f} \approx \sin^{-1}\left[\frac{V_\infty \sin\delta_{i_o} + (V_e - V_\infty)\sin\alpha_D}{V_e}\right] \qquad 9.3.1\text{-c}$$

The total lift contribution of a ducted propeller is obtained from the procedure outlined in the following steps:

Step 1. Determine the turning angle of the internal flow, neglecting power effects, by

$$\delta_{i_o} = \alpha_D\left(\frac{\Delta\delta_{i_o}}{\Delta\alpha_D}\right) \qquad 9.3.1\text{-d}$$

where $\frac{\Delta\delta_{i_o}}{\Delta\alpha_D}$ is obtained from figure 9.3.1-14 as a function of duct aspect ratio.

Step 2. Determine the exit-velocity ratio $\frac{V_e}{V_\infty}$ using

$$\frac{V_e}{V_\infty} = \frac{1 + \sqrt{1 + \frac{2T_i}{q_\infty S_e}}}{2} \qquad 9.3.1\text{-e}$$

where

S_e is the flow area at the duct exit plane $= \frac{\pi d_e^2}{4}\left[1 - \left(\frac{d_{CB}}{d_e}\right)^2\right]$

T_i is the total internal axial thrust ($\alpha_D = 0$), obtained as the sum of the net axial thrust T_{net} and the external duct drag.

$$T_i = T_{net} + C_{D_e} q_\infty S_D \qquad 9.3.1\text{-f}$$

Estimation of the net axial thrust is a ducted-propeller performance problem and is consequently outside the scope of the Datcom. A propulsion engineer should be consulted for this parameter.

The external duct drag C_{D_e} is obtained from figure 9.3.3-4 at $\alpha_D = 0^\circ$, where $C_{D_e} = -C_{F_{x_e}}$

Step 3. Using equation 9.3.1-c, obtain δ_{i_f} with the δ_{i_o} and $\frac{V_e}{V_\infty}$ values from Steps 1 and 2 above.

Step 4. Determine the internal-mass-flow lift-coefficient contribution by

$$C_{L_i} = \frac{\pi A_D}{2}\left[1 - \left(\frac{d_{CB}}{d_e}\right)^2\right]\left(\frac{V_e}{V_\infty}\right)^2 \sin\delta_{i_f} \qquad 9.3.1\text{-g}$$

Step 5. Obtain the lift coefficient C_{L_e} from figure 9.3.1-13 as a function of the duct aspect ratio and angle of attack.

Step 6. The total lift coefficient is given by equation 9.3.1-a

$$C_L = C_{L_i} + C_{L_e}$$

A comparison of test data with ducted-propeller lift coefficients computed by this method is shown in Table 9.3.1-A.

Sample Problem

Given: The ducted propeller configuration of reference 1

$d_e = 4.525$ ft $\quad d_{CB} = 1.208$ ft $\quad c = 2.75$ ft $\quad S_D = 12.45$ sq ft

Additional Characteristics

$V_\infty = 93.5$ ft/sec $\quad \alpha_D = 30^\circ \quad T_{net} = 635$ lb $\quad$ Sea level $\quad q_\infty = 10.4$ lb/sq ft

Compute:

Step 1. Determine the turning angle of the internal mass flow without power effects.

$$A_D = \frac{d_e}{c} = \frac{4.525}{2.75} = 1.645$$

$$\frac{\Delta \delta_{i_o}}{\Delta \alpha_D} = 0.830 \quad \text{(figure 9.3.1-14)}$$

$$\delta i_o = \alpha_D \left(\frac{\Delta \delta_{i_o}}{\Delta \alpha_D}\right) \quad \text{(equation 9.3.1-d)}$$

$$= (30)(0.830)$$

$$= 24.9 \text{ deg}$$

Step 2. Determine the exit-velocity ratio

$$C_{D_e} = -C_{F_{X_e}} = 0.022 \quad \text{(figure 9.3.3-4, at } \alpha_D = 0)$$

$$T_i = T_{net} + C_{D_e} q_\infty S_D \quad \text{(equation 9.3.1-f)}$$

$$= 635 + (0.022)(10.4)(12.45)$$

$$= 637.7 \text{ lb}$$

$$S_e = \frac{\pi d_e^2}{4}\left[1 - \left(\frac{d_{CB}}{d_e}\right)^2\right] = \frac{\pi (4.525)^2}{4}\left[1 - \left(\frac{1.208}{4.525}\right)^2\right]$$

$$= 16.10 \quad (0.9295)$$

$$= 14.97 \text{ sq ft}$$

$$\frac{V_e}{V_\infty} = \frac{1 + \sqrt{1 + \dfrac{2T_i}{q_\infty \quad S_e}}}{2} \quad \text{(equation 9.3.1-e)}$$

$$= \frac{1 + \sqrt{1 + (2)\frac{637.7}{(10.4)(14.97)}}}{2}$$

$$= \frac{1 + \sqrt{1 + 8.19}}{2}$$

$$\frac{V_e}{V_\infty} = 2.02$$

Step 3. **Determine the net turning angle of the internal mass flow, including power effects.**

$$\delta_{i_f} \approx \sin^{-1}\left[\frac{V_\infty \sin \delta_{i_o} + (V_e - V_\infty) \sin \alpha_D}{V_e}\right] \text{(equation 9.3.1-c)}$$

$$= \sin^{-1}\left[\frac{(93.5)(0.421) + (189 - 93.5)(0.50)}{189}\right]$$

$$= \sin^{-1} (0.4609)$$

$$= 27.45 \text{ deg}$$

Step 4. **Determine the lift-coefficient contribution of the internal mass flow.**

$$C_{L_i} = \frac{\pi A_D}{2}\left[1 - \left(\frac{d_{CB}}{d_e}\right)^2\right]\left(\frac{V_e}{V_\infty}\right)^2 \sin \delta_{i_f} \quad \text{(equation 9.3.1-g)}$$

$$= \frac{\pi(1.645)}{2} (0.9295)(2.02)^2(0.4604)$$

$$= 4.53$$

Step 5. **Determine the lift-coefficient contribution of the external mass flow.**

$C_{L_e} = 0.69$ (figure 9.3.1-13)

Solution:

$C_L = C_{L_i} + C_{L_e}$ (equation 9.3.1-a)

$= 4.53 + 0.69$

$= 5.22$

This corresponds to an experimental value of 5.40 obtained from reference 1.

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TABLE 9.3.1-A

DATA SUMMARY AND SUBSTANTIATION

DUCTED PROPELLER LIFT COEFFICIENT

Reference	α_D deg	J	V_∞ fps	T_i lb	$\frac{V_e}{V_\infty}$	δ_{i_o} deg	δ_{i_f} deg	C_L Calc	C_L Test	% Error
1*	15	0.62	165.5	251.6	1.21	12.4	12.85	1.31	1.3	.8
c = 2.75 ft		0.48	128.0	456.3	1.52		13.28	1.79	1.8	-.6
d_e = 4.525 ft	30	0.62	165.5	251.6	1.21	24.9	25.78	2.23	2.6	-14.2
A_D = 1.645		0.48	128.0	456.3	1.52		26.61	3.16	3.6	-12.2
d_{CB} = 1.208 ft		0.35	93.5	637.7	2.02		27.45	5.22	5.4	-3.3
		0.28	74.8	743.9	2.49		27.93	7.69	8.3	-7.3
	45	0.48	128.0	456.3	1.52	37.3	39.82	4.17	5.3	-21.3
		0.35	93.5	637.7	2.02		41.10	7.07	8.0	-11.6
		0.28	74.8	743.9	2.49		41.80	10.59	12.4	-14.6
		0.22	58.8	820.0	3.13		42.44	16.52	18.0	-8.2
	60	0.42	112.0	535.1	1.70	49.7	53.65	6.06	8.0	-24.2
		0.28	74.8	743.9	2.49		55.54	12.77	14.8	-13.7
		0.22	58.8	820.0	3.13		56.41	20.06	23.4	-14.3
		0.17	45.4	894.0	4.03	62.2	57.18	33.26	32.0	3.9
	75	0.35	93.5	637.7	2.02		67.77	9.28	11.2	-17.1
		0.22	58.8	743.9	3.13		70.03	22.34	25.4	-12.0
	90	0.22	58.8	743.9	3.13	74.6	81.30	23.28	27.5	-15.3
3										
c = 0.794 ft	30	0.35	75.0	88.2	3.18	25.6	28.60	10.77	11.56	-6.8
d_e = 1.16 ft		0.35	100.0	256.0	3.85		28.84	15.60	16.24	-3.9
A_D = 1.46		0.70		53.2	2.11		27.90	5.01	5.26	-4.8
d_{CB} = 0.348 ft										
4	30	0.35	100.0	262.5	3.93	26.25	29.03	14.49	15.49	-6.5
c = 0.895 ft		0.50		115.4	2.80		28.65	7.59	8.20	-7.4
d_e = 1.16 ft		0.70		45.0	1.99		28.10	4.09	4.78	-14.4
A_D = 1.296	45	0.25	75.0	323.9	5.55	39.38	43.95	40.11	40.27	-.4
d_{CB} = 0.348 ft		0.35		147.6	3.93		43.52	20.26	21.59	-6.2
		0.50		64.9	2.80		42.93	10.47	11.55	-9.4
	60	0.20	50.0	146.4	5.59	52.5	58.54	49.68	50.46	-1.5
		0.30		57.7	3.72		57.8	22.12	23.04	-4.0
		0.40		28.8	2.80		57.15	12.39	13.18	-6.0
	75	0.20	40.0	93.7	5.59	65.63	72.96	55.40	49.00	13.1
		0.30		36.8	3.72		71.73	24.39	25.39	-3.9
		0.40		18.5	2.80		71.14	13.90	14.55	-4.5
	90	0.20	30.0	52.7	5.59	78.75	85.30	57.35	55.99	2.4
		0.30		20.7	3.72		84.00	25.4	26.18	-3.0
		0.40		10.4	2.80		83.25	14.39	14.77	-2.6
5	20	0.39	100.0	75.53	2.26	15.10	17.81	5.53	5.73	-3.5
c = 0.58 ft		0.292		141.20	2.86		18.27	8.62	9.31	-7.4
d_e = 1.246 ft		0.25		194.86	3.25		18.48	11.08	12.48	-11.2
A_D = 2.15	30	0.39		75.53	2.26	22.65	26.69	7.85	7.59	3.4
d_{CB} = 0.348 ft		0.292		141.20	2.86		27.38	12.39	12.99	-4.6
		0.25		194.86	3.25		27.69	15.99	17.60	-9.1

*Test results include wing-duct interference effects.

TABLE 9.3.1-A (CONTD)

Reference	α_D deg	J	V_∞ fps	T_i lb	$\frac{V_e}{V_\infty}$	δ_{i_o} deg	δ_{i_f} deg	C_L Calc	C_L Test	e % Error
5 (con't)	20	0.39	100.0	73.89	2.37	15.56	18.11	5.64	5.21	8.3
c = 0.58 ft		0.292		132.35	2.96		18.49	8.59	8.61	-.2
		0.25		177.20	3.33		18.65	10.79	10.80	-.1
d_e = 1.160 ft	30	0.39		73.89	2.37	23.34	27.14	8.02	7.22	11.1
A_D = 2.0		0.292		132.35	2.96		27.71	12.34	12.29	.4
d_{CB} = 0.348 ft		0.25		177.20	3.33		27.96	15.56	15.92	-2.3
	40	0.39		73.89	2.37	31.12	36.13	10.12	8.66	16.9
		0.292		132.35	2.96		36.89	15.69	14.52	8.1
		0.25		177.20	3.33		37.23	19.84	18.60	6.7
6	10	0.595	100.0	18.8	1.39	8.30	8.80	1.08	1.06	1.7
c = 0.859 ft	15					12.50	13.18	1.59	1.59	0
d_e = 1.41 ft	20					16.60	17.56	2.03	1.95	4.1
A_D = 1.64	30					24.90	26.30	2.75	2.75	0
d_{CB} = 0.358 ft	40					33.20	35.00	3.32	3.39	-2.1
	45					37.40	39.37	3.58	3.59	-.3

$$\text{Average error} = \frac{\sum |e|}{n} = 7.1\%$$

(a) UNSTALLED CONFIGURATION

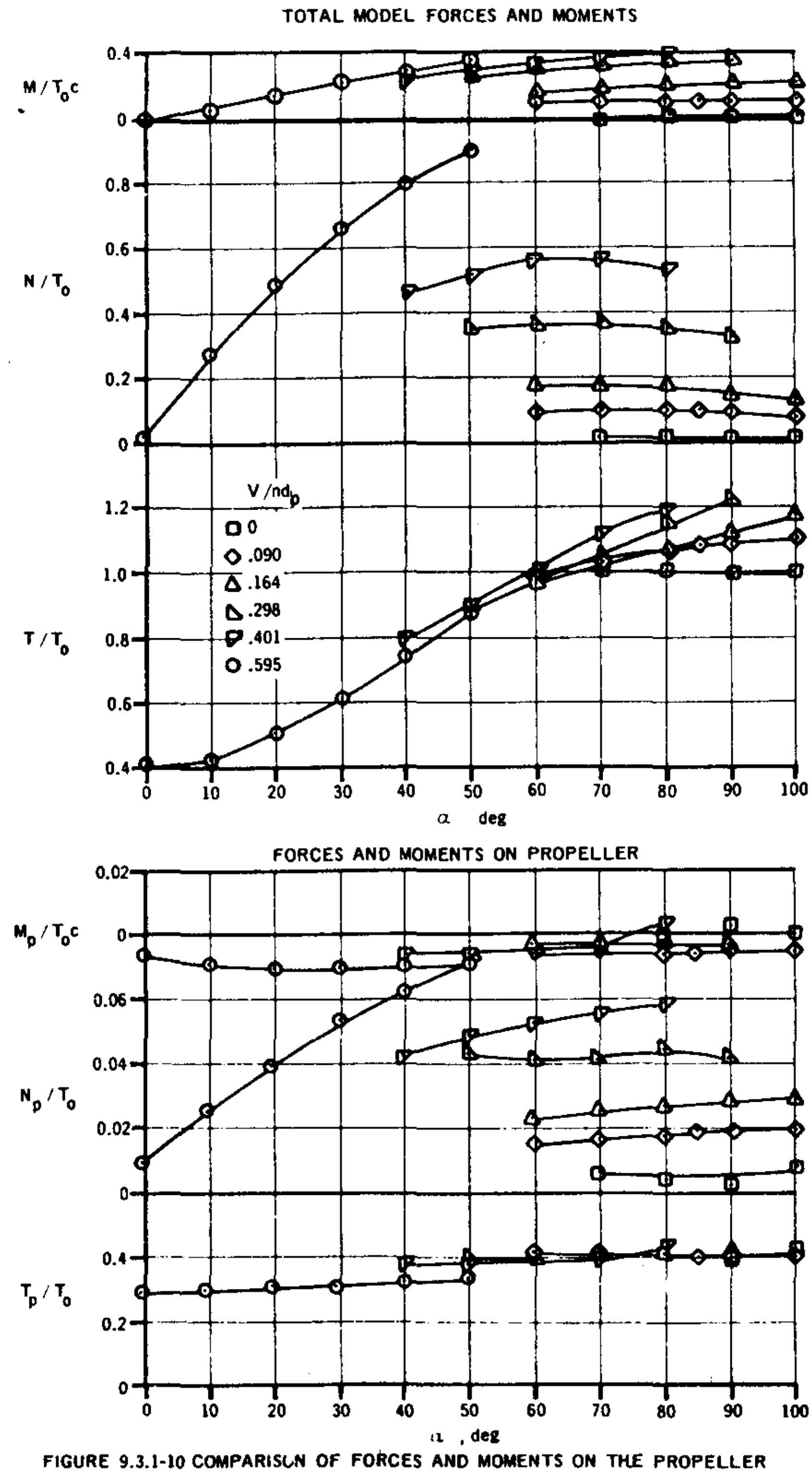

FIGURE 9.3.1-10 COMPARISON OF FORCES AND MOMENTS ON THE PROPELLER WITH TOTAL FORCES AND MOMENTS FOR THE DUCTED PROPELLER CONFIGURATION OF REFERENCE 6

(b) STALLED CONFIGURATION

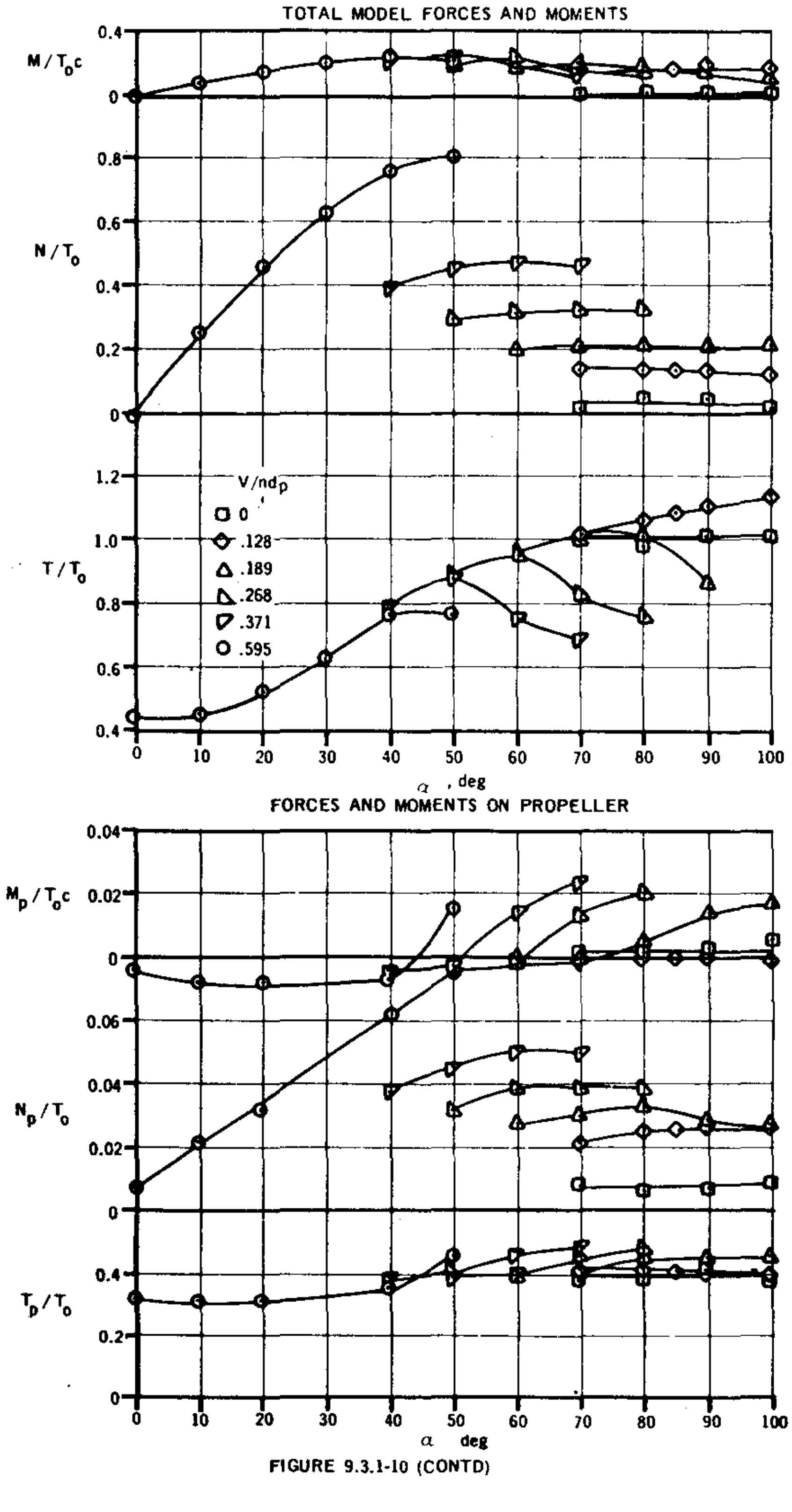

FIGURE 9.3.1-10 (CONTD)

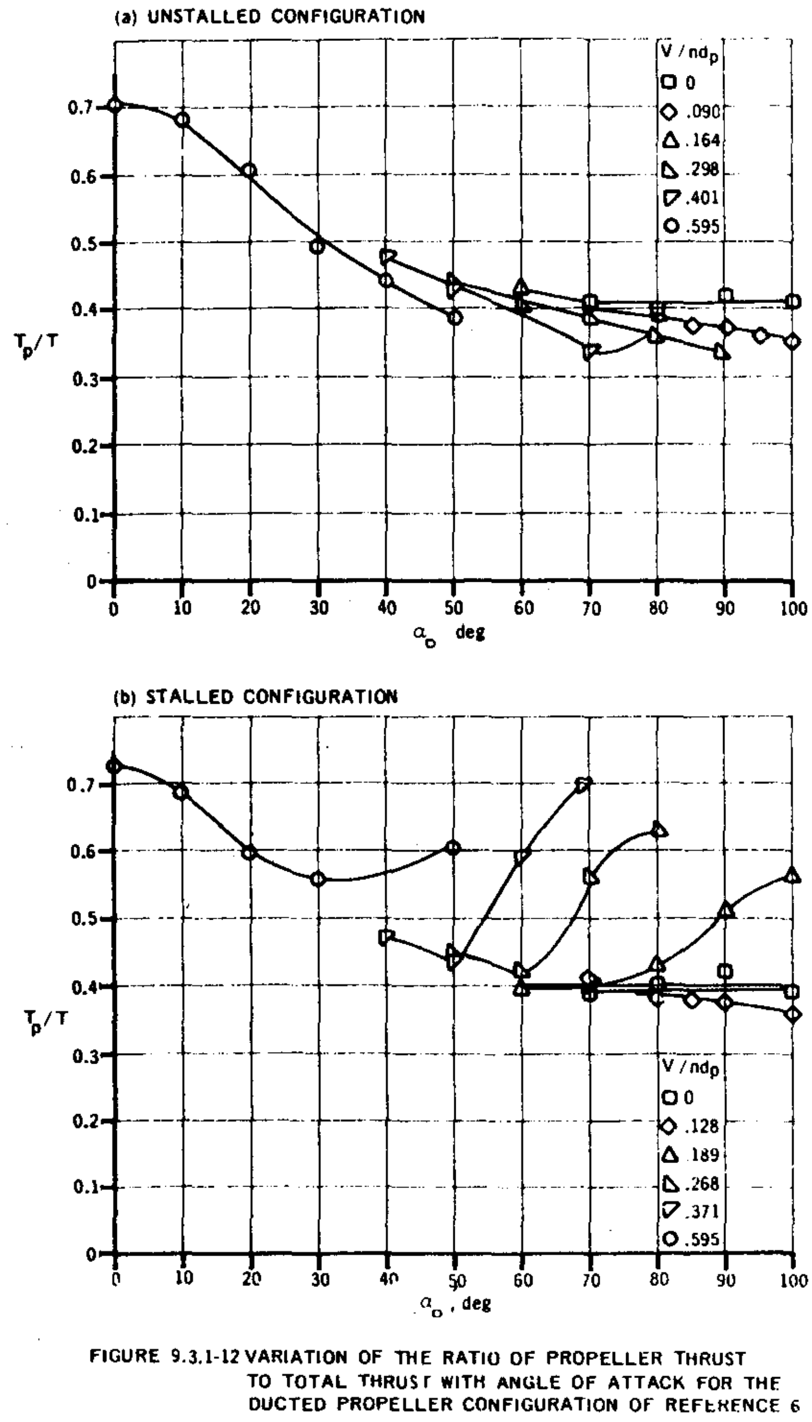

FIGURE 9.3.1-12 VARIATION OF THE RATIO OF PROPELLER THRUST TO TOTAL THRUST WITH ANGLE OF ATTACK FOR THE DUCTED PROPELLER CONFIGURATION OF REFERENCE 6

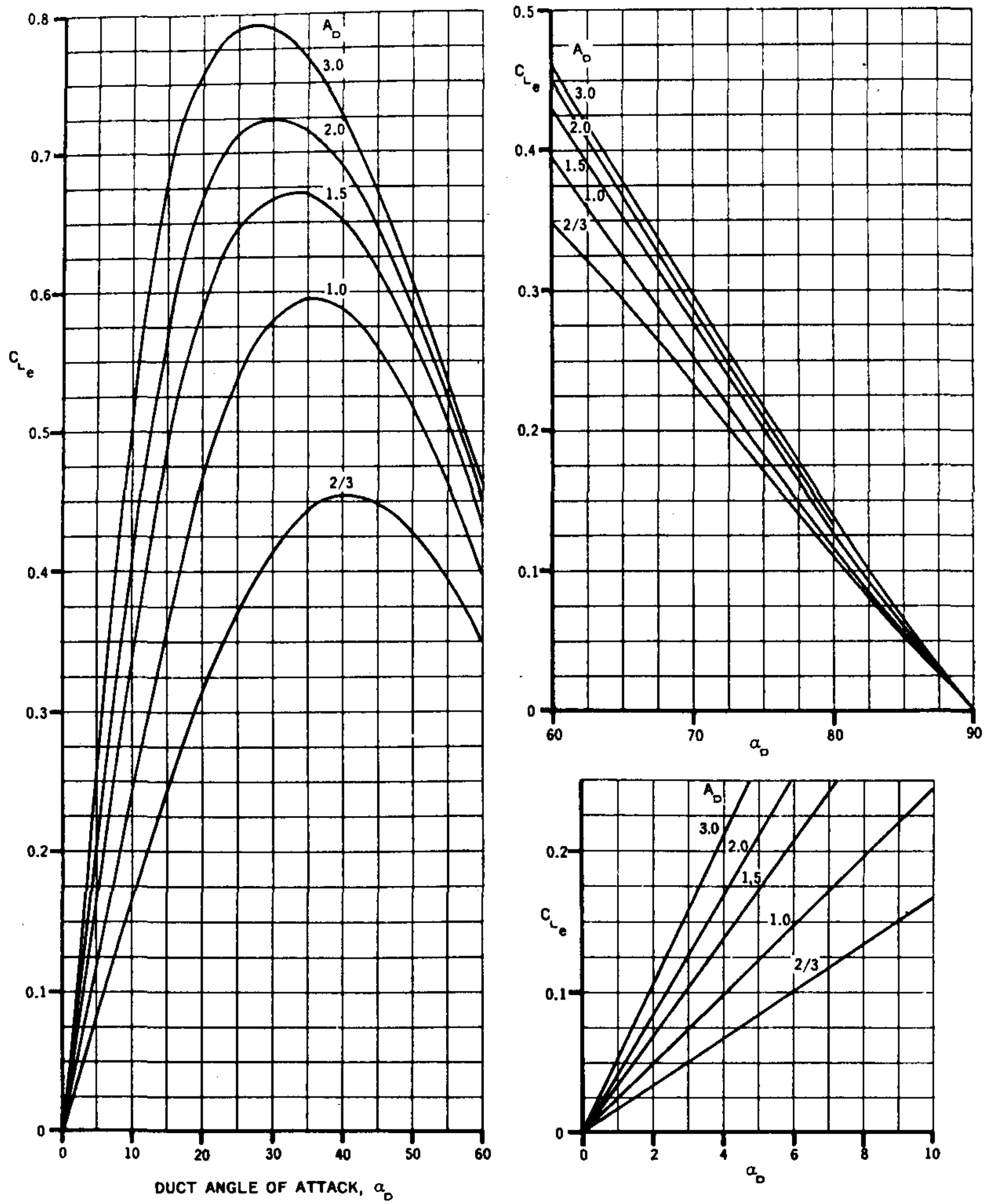

FIGURE 9.3.1-13 EXTERNAL MASS FLOW LIFT COEFFICIENT

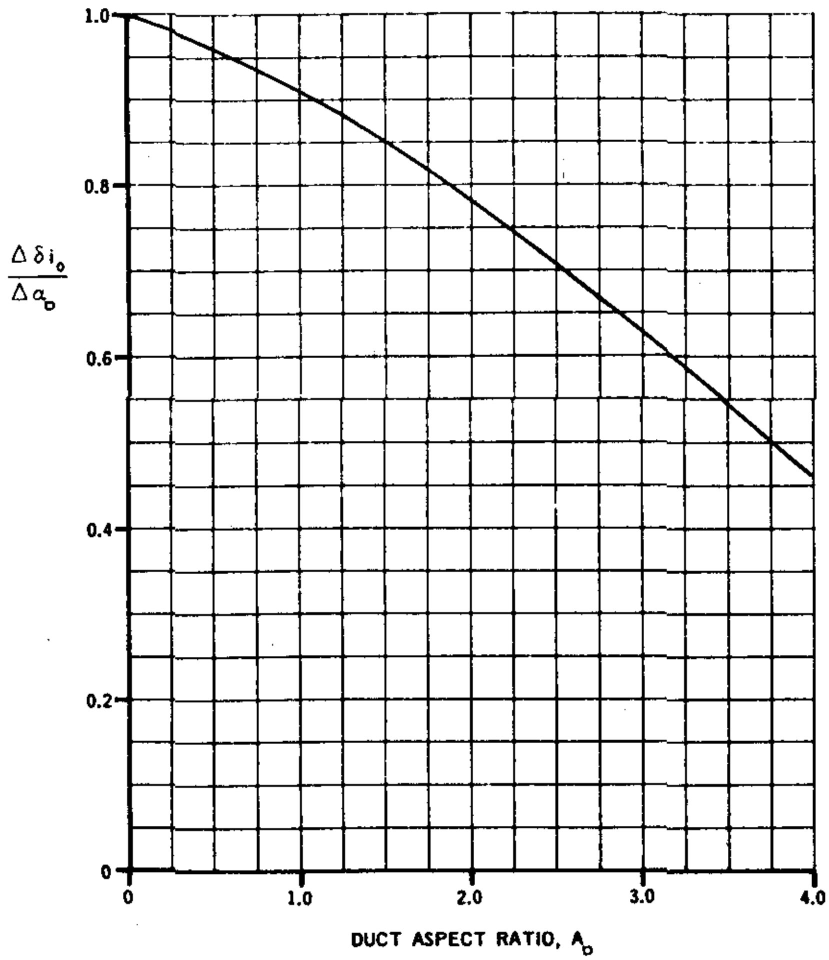

FIGURE 9.3.1-14 RATIO OF UNPOWERED DUCT INTERNAL MASS FLOW TURNING ANGLE TO DUCT ANGLE OF ATTACK

9.3.2 DUCTED-PROPELLER PITCHING-MOMENT VARIATION WITH POWER AND ANGLE OF ATTACK

This Section presents a method for estimating ducted-propeller pitching moments as functions of power and angle of attack. The basic discussion in Section 9.3.1 is directly applicable to this Section, and the reader is referred to that discussion for a general description of the fundamental phenomenon.

DATCOM METHOD

The method presented for estimating ducted-propeller pitching moments is based on ring vortex and simple momentum theories with empirical modifications.

The pitching moment consists of three component parts:

(1) A circulation-induced moment which in effect causes a shift in axial duct forces (essentially a shift in thrust axis.)
(2) A moment due to the lift component
(3) A moment due to the negative drag component

The circulation-induced moment is always positive (nose-up) and increases with increasing power. The last two components also increase in magnitude with power but may be positive or negative depending upon the location of the ducted-propeller center of pressure. This method assumes the center-of-pressure location to be independent of power and angle of attack and to be on the duct axis at the unstalled center-of-pressure location of the undiffused annular wings of reference 2.

The pitching-moment contribution of a ducted-propeller configuration, based on the duct planform area and duct chord and referred to an arbitrary moment center, is given by

$$C_m = \frac{\pi A_D}{2}\left(\frac{V_e}{V_\infty} - \cos\ \delta_{i_f}\right) \sin \alpha_D + \frac{\bar{x}}{c}\left(C_L \cos \alpha_D - C_{F_x} \sin \alpha_D\right) \qquad 9.3.2\text{-a}$$

where the first term on the right-hand side is the circulation-induced moment as derived by Sacks in reference 1, modified by the empirical relation for the net turning angle of the internal flow, discussed in Section 9.3.1. The last two terms are the components due to lift and drag.

$\frac{V_e}{V_\infty}$ is the exit-velocity ratio, obtained from equation 9.3.1-e

δ_{i_f} is the internal-flow turning angle, including the effects of power, obtained from equation 9.3.1-c

C_L is the total lift coefficient of the ducted propeller, obtained from Section 9.3.1

C_{F_x} is the total negative drag coefficient of the ducted propeller, obtained from Section 9.3.3

$\frac{\bar{x}}{c} = \left(\frac{x_m}{c} - \frac{x_{cp}}{c}\right)$, the chordwise distance, in duct chords, from the reference center to the unstalled duct center of pressure, positive for the center of pressure ahead of the reference center

$\frac{x_m}{c}$ is the chordwise distance, in duct chords, from the duct leading edge to the reference center, positive aft of the duct leading edge

$\frac{x_{cp}}{c}$ is the chordwise distance, in duct chords, from the duct leading edge to the center of pressure of the unstalled duct, positive aft of the duct leading edge. It is obtained as a function of duct aspect ratio from figure 9.3.2-6.

A comparison of test data with ducted propeller pitching-moment coefficients computed by this method is shown in table 9.3.2-A.

Because of the number of variables involved in the ducted propeller problem and the design parameters not considered in the Datcom method, the comparison between theory and experiment cannot be analyzed by examining the isolated effect of one variable. However, it is felt that one important factor pertaining to the test conditions of the available data, namely scale effect, should be considered before assessing the accuracy of this method. The data presented in reference 1 of table 9.3.2-A are the only available test results of a large-scale ducted propeller in the non-axial flow regime. Although experimental data on similar models of different scale are needed for the proper evaluation of the scale effect, it is felt that the low Reynolds numbers of small scale tests will appreciably affect the stalling characteristics of the duct. Therefore, comparison of calculated and large-scale experimental results of reference 1 in table 9.3.2-A is more indicative of the accuracy of the method than comparison with the other reference data.

Sample Problem

Given: Same ducted propeller configuration as sample problem of Section 9.3.1. Some of the characteristics are repeated below.

$d_e = 4.525$ ft $\qquad d_{CB} = 1.208$ ft $\qquad c = 2.75$ ft

$A_D = 1.645 \qquad S_D = 12.45$ sq ft

Additional Characteristics

$V_\infty = 93.5$ ft/sec $\qquad \alpha_D = 30^\circ \qquad$ Sea level

Moment reference center at 0.49c $\qquad q_\infty = 10.4$ lb/sq ft

Compute:

$$\left.\begin{aligned} \frac{V_e}{V_\infty} &= 2.02 \\ \delta_{i_f} &= 27.45^\circ \\ C_L &= C_{L_i} + C_{L_e} = 5.22 \end{aligned}\right\} \quad \text{(sample problem Section 9.3.1)}$$

$C_{F_x} = 3.455$ (sample problem Section 9.3.3)

$\frac{x_{cp}}{c} = 0.266$ (figure 9.3.2-6)

$$\frac{\bar{x}}{c} = \frac{x_m}{c} - \frac{x_{cp}}{c}$$

$$= (0.49 - 0.266)$$

$$= 0.224$$

Solution:

$$C_m = \frac{\pi A_D}{2}\left(\frac{V_e}{V_\infty} - \cos \delta_{i_f}\right) \sin \alpha_D + \frac{\bar{x}}{c}\left(C_L \cos \alpha_D - C_{F_x} \sin \alpha_D\right) \quad \text{(equation 9.3.2-a)}$$

$$= \frac{\pi(1.645)}{2}(2.02 - 0.8874)(0.50) + 0.224\left[(5.22)(0.866) - (3.455)(0.50)\right]$$

$$= (2.58)(1.1326)(0.50) + 0.224\,(2.792)$$

$$= 2.085$$

This corresponds to an experimental value of 1.899 obtained from reference 1.

REFERENCES

1. Sacks, A. H.: The Flying Platform as a Research Vehicle for Ducted Propellers. Institute of Aeronautical Sciences Preprint No. 832, 1958. (U)

2. Fletcher, H. S.: Experimental Investigation of Lift, Drag, and Pitching Moment of Five Annular Airfoils. NACA TN 4117, 1957. (U)

TABLE 9.3.2-A[a]

DATA SUMMARY AND SUBSTANTIATION

DUCTED PROPELLER PITCHING-MOMENT COEFFICIENT

Ref[b]	α_D deg	J	$\frac{V_e}{V_\infty}$	C_L Table 9.3.1-A	C_{F_x} Table 9.3.3-A	$\frac{\bar{x}}{c}$	C_m Calc	C_m Test	e % Error
1[c]	15	0.62	1.21	1.31	0.38	0.224	0.42	0.50	-16.0
		0.48	1.52	1.79	1.61		0.67	0.70	-4.3
	30	0.62	1.21	2.23	-0.135		0.84	1.00	-16.0
		0.48	1.52	3.16	0.915		1.32	1.10	20.0
		0.35	2.02	5.22	3.46		2.035	1.90	9.5
		0.28	2.49	7.69	6.79		2.81	2.60	8.1
	45	0.48	1.52	4.17	-0.010		2.02	2.10	-3.8
		0.35	2.02	7.07	1.91		3.12	2.85	9.5
		0.28	2.49	10.59	4.49		4.15	4.35	-4.6
		0.22	3.13	16.52	9.22		5.52	5.20	6.2
	60	0.42	1.70	6.06	-0.724		3.29	3.30	-0.3
		0.28	2.49	12.77	1.69		5.41	5.10	6.1
		0.22	3.13	20.06	4.75		7.08	6.50	8.9
		0.17	4.03	33.26	10.72		9.44	7.80	21.0
	75	0.35	2.02	9.28	-1.90		5.03	4.45[s]	13.0
		0.22	3.13	22.34	-0.237		8.29	7.90	4.9
	90	0.22	3.13	23.28	-4.60		8.72	8.50[s]	2.5
3	30	0.35	3.18	10.77	12.70	0.283	3.40	2.94	15.6
		0.35	3.85	15.60	20.60		4.29	3.24	32.4
		0.70	2.11	5.01	3.80		2.02	1.71	18.1
4	30	0.35	3.93	14.49	17.33	0.353	4.48	3.86	16.1
		0.50	2.80	7.59	7.18		3.01	2.52	19.4
		0.70	1.99	4.09	2.42		1.95	1.68	16.1
	45	0.25	5.55	40.11	30.2		9.43	7.93[s]	18.9
		0.35	3.93	20.26	12.86		6.45	5.71	13.0
		0.50	2.80	10.47	4.84		4.38	3.76	16.5
	60	0.20	5.59	49.68	19.14		11.83	9.74[s]	21.5
		0.30	3.72	22.12	6.04		7.69	6.55[s]	17.4
		0.40	2.80	12.39	1.98		5.55	4.94[s]	12.3
	75	0.20	5.59	55.40	5.89		13.45	10.08[s]	33.4
		0.30	3.72	24.39	0.435		8.79	7.15[s]	22.9
		0.40	2.80	13.90	-1.205		6.53	5.54[s]	17.9
	90	0.20	5.59	57.35	-6.22	0.353	13.38	13.26	0.9
		0.30	3.72	25.40	-4.82		9.08	8.40	8.1
		0.40	2.80	14.39	-4.08		6.89	6.31	9.2

a Refer to Table 9.3.1-A for additional characteristics
b These references are found in Section 9.3.1
c Test results include wing-duct interference effects
s Stalled

TABLE 9.3.2-A[a] (CONTD)

Ref[b]	α_D deg	J	$\frac{V_e}{V_\infty}$	C_L Table 9.3.1-A	C_{F_x} Table 9.3.3-A	$\frac{\bar{x}}{c}$	C_m Calc	C_m Test	e % Error
5	20	0.39	2.26	5.53	7.79	0.208	2.01	1.59	26.4
		0.292	2.86	8.62	15.17		2.79	1.91	46.1
		0.25	3.25	11.08	20.76		3.32	1.99	66.8
	30	0.39	2.26	7.85	6.69		2.99	2.20	35.9
		0.292	2.86	12.39	13.19		4.15	2.90	43.1
		0.25	3.25	15.99	18.53		4.91	3.31	48.3
	20	0.39	2.37	5.64	8.20		2.05	1.33	54.1
		0.292	2.96	8.59	15.01		2.78	1.82	52.7
		0.25	3.33	10.79	20.23		3.24	2.19	47.9
	30	0.39	2.37	8.02	7.05		3.04	1.81	68.0
		0.292	2.96	12.34	13.25		4.11	2.54	61.8
		0.25	3.33	15.56	18.02		4.78	2.79	71.3
	40	0.39	2.37	10.12	5.58		4.02	2.34	71.8
		0.292	2.96	15.69	10.96		5.40	3.31	61.3
		0.25	3.33	19.84	15.11		6.27	5.72	65.5
6	10	0.595	1.39	1.08	1.19	0.174	0.403	0.219	84.0
	15			1.59	1.05		0.593	0.359	65.2
	20			2.03	0.87		0.77	0.47	63.8
	30			2.75	0.43		1.09	0.72	51.4
	40			3.32	-0.90		1.41	0.94	50.0
	45			3.58	-0.37		1.52	1.064	42.9

$$\text{Average error} = \frac{\sum |e|}{n} = 29.5\%$$

a Refer to Table 9.3.1-A for additional characteristics
b These references are found in Section 9.3.1

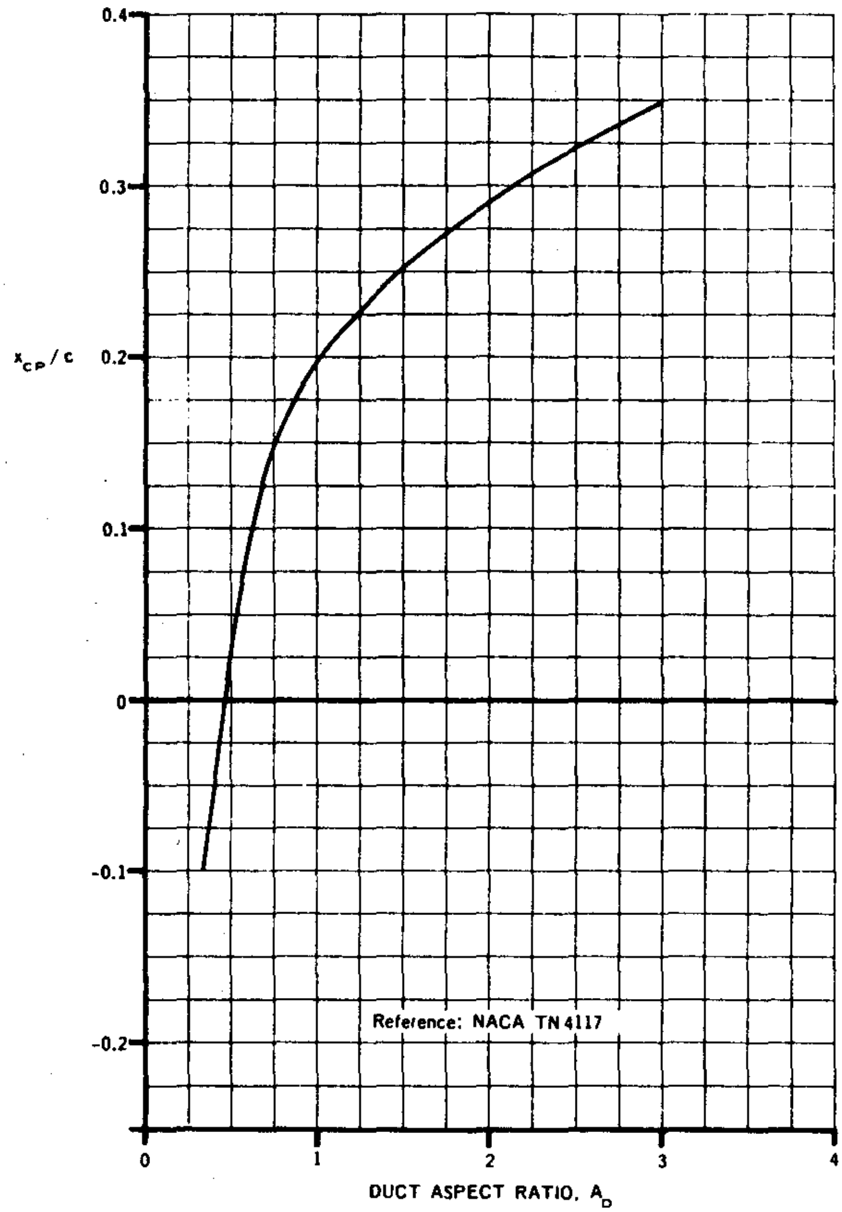

FIGURE 9.3.2-6 DUCT CENTER OF PRESSURE LOCATION

9.3.3 DUCTED-PROPELLER DRAG VARIATION WITH POWER AND ANGLE OF ATTACK

This Section presents a method for estimating ducted-propeller drag as a function of power and angle of attack. The basic discussion in Section 9.3.1 is directly applicable to this Section, and the reader is referred to that discussion for a general description of the fundamental phenomenon.

DATCOM METHOD

The method presented for estimating ducted-propeller drag is expressed as the sum of the components resulting from the internal and external mass flows. The theoretical basis of this method is the same as that of the Datcom lift-estimation method of Section 9.3.1.

The negative drag coefficient of a ducted propeller is given by

$$C_{F_x} = \frac{\pi A_D}{2}\left[1 - \left(\frac{d_{CB}}{d_e}\right)^2\right]\left[\left(\frac{V_e}{V_\infty}\right)^2 \cos\delta_{i_f} - \left(\frac{V_e}{V_\infty}\right)\right] + C_{F_{x_e}} \qquad 9.3.3\text{-a}$$

where the first term on the right-hand side is due to internal flow and is estimated on the basis of simple momentum theory modified by the empirical relation for the net internal-flow turning angle, discussed in Section 9.3.1.

$\frac{V_e}{V_\infty}$ is the exit-velocity ratio, obtained from equation 9.3.1-e

δ_{i_f} is the net turning angle of the internal flow, obtained from equation 9.3.1-c

$C_{F_{x_e}}$ is the external negative drag coefficient, resulting from the external flow, obtained from figure 9.3.3-4 as a function of duct aspect ratio and angle of attack. Figure 9.3.3-4 is based on empirical modifications of the data of references 1 and 2.

A comparison of test data with ducted-propeller drag coefficients computed by this method is shown in table 9.3.3-A. The measurement of drag involves the difference between the components of the thrust force and the normal force and is inherently less accurate than the measurement of the lift force. At a tunnel velocity near that for steady level flight ($C_{F_x} = 0$), slight errors in drag measurement can result in test values with an opposite sign than that predicted by theory; and percent error becomes incalculable, although the actual magnitude of the difference may be less than that for lift. Consequently, a comparison of theory and experiment in this area may be misleading when presented in terms of percent error. Therefore, a summary of the results presented in table 9.3.3-A is presented as a weighted error.

Sample Problem

Given: Same ducted-propeller configuration as sample problem of Section 9.3.1. Some of the characteristics are repeated below.

$d_e = 4.525$ ft $\qquad d_{CB} = 1.208$ ft $\qquad c = 2.75$ ft

$A_D = 1.645$ $\qquad S_D = 12.45$ sq ft

Additional Characteristics

$V_\infty = 93.5$ ft/sec — Sea level

$\alpha_D = 30^\circ$ — $q_\infty = 10.4$ lb/sq ft

Compute:

$$\left.\begin{aligned}\frac{V_e}{V_\infty} &= 2.02\\ \delta_{1_f} &= 27.45^\circ\end{aligned}\right\}\quad \text{(sample problem Section 9.3.1)}$$

$$\left[1 - \left(\frac{d_{CB}}{d_e}\right)^2\right] = 0.9295$$

$$C_{F_{x_e}} = -0.395 \quad \text{(figure 9.3.3-4)}$$

Solution:

$$C_{F_x} = \frac{\pi A_D}{2}\left[1-\left(\frac{d_{CB}}{d_e}\right)^2\right]\left[\left(\frac{V_e}{V_\infty}\right)^2 \cos\delta_{1_f} - \left(\frac{V_e}{V_\infty}\right)\right] + C_{F_{x_e}} \quad \text{(equation 9.3.3-a)}$$

$$= \frac{\pi(1.645)}{2}(0.9295)\left[(2.02)^2(0.8874)-(2.02)\right] + (-0.395)$$

$$= (2.41)(1.60) - 0.395$$

$$= (3.455)$$

This corresponds to an experimental value of 3.785 obtained from reference 1.

REFERENCES

1. Mort, K. W., and Yaggy, P. F.: Aerodynamic Characteristics of a Four-Foot Diameter Ducted Fan Mounted on the Tip of a Semi-Span Wing. NASA TN D-1301, 1962. (U)

2. Fletcher, H. S.: Experimental Investigation of Lift, Drag, and Pitching Moment of Five Annular Airfoils. NACA TN 4117, 1957. (U)

TABLE 9.3.3-A[a]

DATA SUMMARY AND SUBSTANTIATION

DUCTED-PROPELLER DRAG COEFFICIENT

Ref[b]	α_D deg	J	$\frac{V_e}{V_\infty}$	C_{F_x} Calc	C_{F_x} Test	e % Error
1[c]	15	0.62	1.21	0.38	0.40	-5.0
		0.48	1.52	1.61	1.70	-5.3
	30	0.62	1.21	-0.135	0.10	-
		0.48	1.52	0.915	1.30	-29.6
		0.35	2.02	3.46	3.80	-9.1
		0.28	2.49	6.79	7.50	-10.6
	45	0.48	1.52	-0.01	0.20	-
		0.35	2.02	1.91	2.10	-9.0
		0.28	2.49	4.49	5.30	-15.3
		0.22	3.13	9.22	11.20	-17.7
	60	0.42	1.70	-0.724	-0.50	44.8
		0.28	2.49	1.69	1.40	20.7
		0.22	3.13	4.75	5.90	-19.5
		0.17	4.03	10.72	10.40	3.1
	75	0.35	2.02	-1.90	-2.40	-20.8
		0.22	3.13	-0.237	-0.60	-60.5
	90	0.22	3.13	-4.60	-7.30	-37.0
3	30	0.35	3.18	12.70	10.90	16.5
		0.50	3.85	20.60	16.90	21.9
		0.70	2.11	3.80	2.69	41.3
4	30	0.35	3.93	17.33	17.39	-0.3
		0.50	2.80	7.18	6.94	3.5
		0.70	1.99	2.42	2.63	-8.0
	45	0.25	5.55	30.2	28.65	5.4
		0.35	3.93	12.86	12.50	2.9
		0.50	2.80	4.84	4.58	5.7
	60	0.20	5.59	19.14	18.36	4.2
		0.30	3.72	6.04	5.19	16.4
4	60	0.40	2.80	1.98	1.02	94.1
	75	0.20	5.59	5.89	2.40	145.4
		0.30	3.72	0.435	-0.63	-
		0.40	2.80	-1.205	-2.22	-45.7
	90	0.20	5.57	-6.22	-12.34	-49.6
		0.30	3.72	-4.82	-7.91	-29.1
		0.40	2.80	-4.08	-6.35	-35.7
5	20	0.39	2.26	7.79	6.70	16.3
		0.292	2.86	15.17	13.50	12.4
		0.25	3.25	20.76	19.09	8.7
	30	0.39	2.26	6.69	4.66	43.6
		0.292	2.86	13.19	10.80	22.1
		0.25	3.25	18.53	15.30	21.1
	20	0.39	2.37	8.20	5.87	39.7
		0.292	2.96	15.01	12.10	24.0
		0.25	3.33	20.23	16.94	19.4
	30	0.39	2.37	7.05	4.38	61.0
		0.292	2.96	13.25	9.73	36.2
		0.25	3.33	18.02	13.73	31.2
	40	0.39	2.37	5.58	2.70	106.7
		0.242	2.96	10.96	7.03	55.9
		0.25	3.33	15.11	8.66	74.5
6	10	0.595	1.39	1.19	1.204	-1.2
	15			1.05	1.126	-6.7
	20			0.87	1.00	-13.0
	30			0.43	0.704	39.8
	40			-0.90	0.188	-
	45			-0.37	-0.303	18.2

$$\text{Weighted error} = \frac{\sum\left(|e|\ \left|C_{F_{x_{Test}}}\right|\right)}{\sum\left|C_{F_{x_{Test}}}\right|} = 21.8\%$$

a Refer to Table 9.3.1-A for additional characteristics

b These references are found in Section 9.3.1

c Test results contain wing-duct interference effects

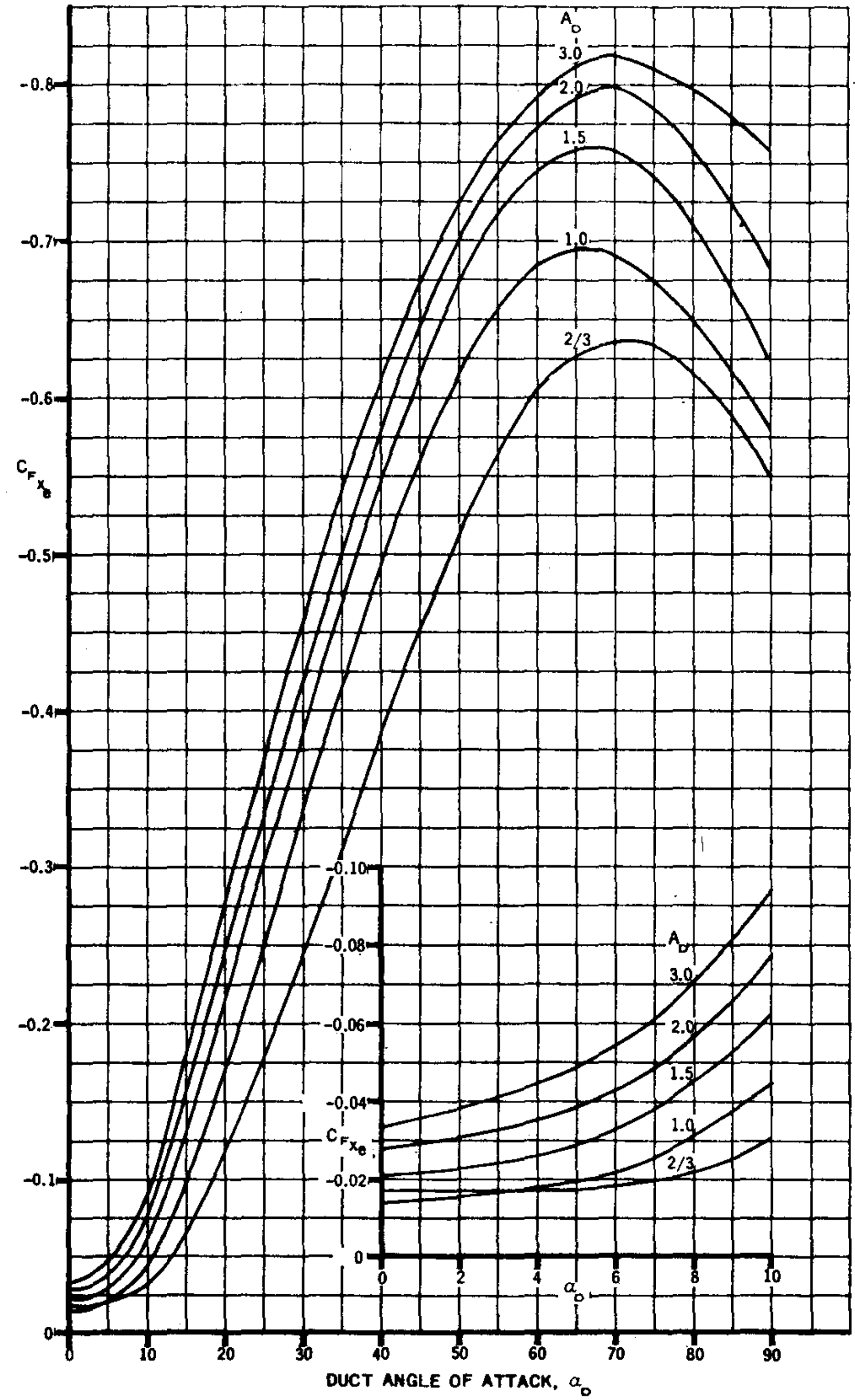

FIGURE 9.3.3-4 EXTERNAL MASS FLOW NEGATIVE DRAG COEFFICIENT

* U.S. GOVERNMENT PRINTING OFFICE: 1983 -659-062/688