THE TILT WING CONFIGURATION FOR HIGH SPEED VSTOL AIRCRAFT

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ABSTRACT

The tilt wing is definitely the most efficient, most cost effective, safest and easiest to operate powered lift concept for high speed VSTOL aircraft. It is shown that the tilt wing design has many operational and cost advantages over the tilt rotor.

Tilt wing development started with the Boeing Vertol VZ-2 in the mid-1950's. This was followed by the Hiller X-18 in the early 60's and the LTV/Hiller/Ryan XC-142A in the mid-60's. In the late 60's and early 70's the Canadair CL-84 tilt wing was successfully tested and demonstrated.

This paper discusses the unique U.S. Patent (3,029,043) by Gary B. Churchill for a tilt wing "geared flap" that simplifies the flight control system of the tilt wing in hover and in transition to and from aerodynamic flight. Recent simulation evaluations conducted by NASA Ames in their Vertical Motion Simulator (VMS) demonstrates the potential of adopting this control system design to future tilt wing aircraft.

It is shown that future tilt wing aircraft will benefit from the rapidly advancing state of the art in structures (composites where appropriate), advanced propulsion systems and power trains, advanced computerized flight control systems, advanced glass cockpits and avionics.

A clearer understanding of the major differences between the tilt wing, tilt rotor, and helicopter brings to the surface the true operational and cost advantages of the tilt wing for high speed VSTOL aircraft.

INTRODUCTION

This paper singles out several major advantages of the tilt wing design over the tilt rotor. In tilt rotor aircraft the rotor wake impinging on the upper surface of the horizontal wing, fuselage and sponsons in hover creates a vertical down force, called download. This download seriously reduces the tilt rotor aircraft's useful load and thus reduces valuable payload and/or range.

This download actually cancels what lifting advantage the large diameter rotors, with their lower disc loading, would have over the somewhat higher disc loading of smaller diameter propellers used on tilt wing aircraft. Tilt wing aircraft have no download in hover or in transition to and from level aerodynamic flight.

A weights comparison between the Canadair CL-84 tilt wing and the Bell XV-15 tilt rotor aircraft, and a similar weights comparison between the LTV/Hiller/Ryan XC-142A tilt wing and the Boeing/Bell V-22 Osprey tilt rotor, each pair having matching engine power, uncovers data that clearly reveals the lifting advantage of a tilt wing over a tilt rotor.

The higher propulsive efficiency in level cruising flight for tilt wing propellers compared to tilt rotor rotors is reviewed. These reviews and other technology comparisons, as they relate to the design process, are invaluable as we move forward with a family of high speed VSTOL tilt wing aircraft to meet future international markets.

The authors suggest a family of civil VSTOL tilt wing aircraft that are sized to carry 4, 9, 19, and 30 passengers or 4 LD-3 cargo containers. The authors predict that larger size, more than 30 passengers, vertical lift aircraft, tilt wing or tilt rotor, due to limited acceptable hovering downflow, will be more appropriate to STOL operations using a maximum of 500 foot long runways. 100 to 150 passenger tilt wing STOL aircraft using partial tilting of the wing are feasible.

A 9-passenger, 11 seat, tilt wing vehicle about the size of the Canadair CL-84 is considered the most feasible first generation high speed VSTOL aircraft for civil roles including search and rescue (SAR) missions.

The history of military aircraft that have evolved from civil aircraft development is reviewed. A prediction is made that future civil tilt wing aircraft will eventually lead to several military tilt wing derivatives.

THE BEGINNING OF VERTICAL FLIGHT

At the turn of the fifteenth century Leonardo da Vinci sketched the design of a man-carrying vertical lift vehicle, a precursor to the modern helicopter (F-1), but it wasn't until the 1800's when real attempts were made by several inventors to develop vertical rising vehicles. Several small models of these early concepts made reasonably successful hovering flights.

In 1909 Igor Sikorsky (in Russia) came close to successfully flying a man-carrying rotary wing vehicle. The earliest successful helicopter flight on record took place in 1912 when Danish engineer, Jacob C.H. Ellehammer, demonstrated a "screw plane" by lifting the vehicle a few feet off the ground. The first successful vertical rising vehicle, however, is generally conceded to be the German Focke-Achgelis Fw-61 that flew in 1936. This success was followed closely in 1939 by Sikorsky (in the United States) with his experimental VS-300 helicopter (Ref. 9).

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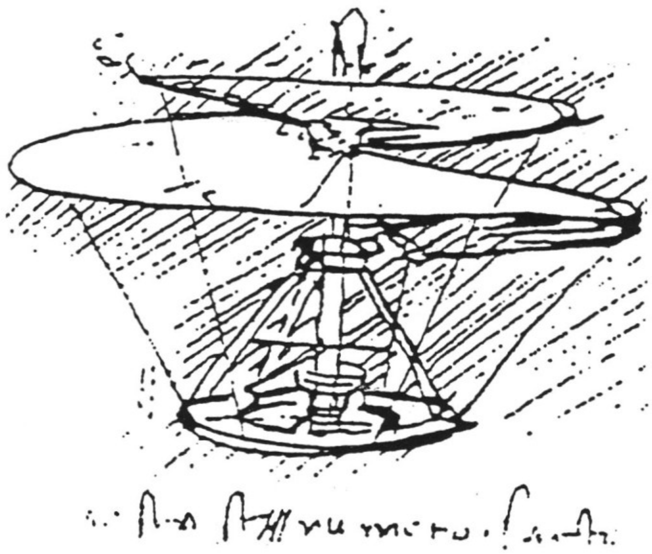
15th CENTURY VTOL CONCEPT



LEONARDO DA VINCI'S FIFTEENTH CENTURY SKETCH OF A HELIX - A PRECURSOR OF MODERN HELICOPTER DESIGN

Figure No. 1

The continuing success of the helicopter since World War II lends credence to a design that combines hovering capability with the high speed and long range cruise capability of conventional airplanes.

The helicopter enjoys high hovering efficiency produced by its large diameter low disc loading rotor (F-2). It is unlikely that the efficiency of the helicopter, in lifting heavy loads over short distances, will be challenged. Helicopters do many useful things, but they are prevented by operation and economic limitations from effectively performing many roles and missions (Ref. 17).

THE BEGINNING OF VSTOL DEVELOPMENT

Research and development in VSTOL has taken place since the mid-1950's and in the past 45 years there have been over 50 VSTOL, STOL or VTOL aircraft that reached the flying stage (Ref. 28). The Convair XFY-1 POGO was a tail sitter (tilt-airplane) concept demonstrated in the mid-50's. It was the first aircraft to make successful transitions from vertical to horizontal and back to vertical flight. The POGO was powered with a twin pack turbine engine driving counter-rotating propellers. A fan-in-wing, the Ryan XV-5A, was demonstrated in the mid-60's. A direct lift turbo-jet, the British Hawker Siddley 1127 (now known as the Harrier) was first demonstrated in the mid-60's. The Harrier has a very high disc loading with poor hovering efficiency (F-2), but it meets necessary military needs. Its high speed fighter/attack requirements take precedence over hovering efficiency.

Advanced concepts of convertiplanes, i.e., stowed rotors, compound helicopters and the stopped rotor X-Wing have been in various stages of research and development. Unlike convertiplanes, the tilt wing and tilt rotor make use of the same propulsion components for vertical lift in hovering as they do for forward thrust in level aerodynamic flight. This avoids the weight, cost and complexity of separate systems. Rotors that can change diameter in flight and rotors that tilt independently of their power plants are also concepts under study (Ref. 25).

HOVERING EFFICIENCEY

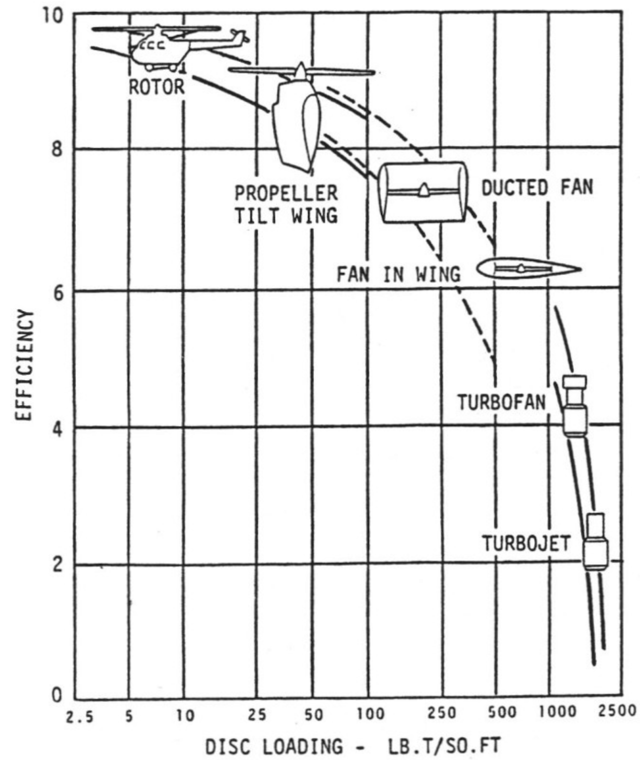


Figure No. 2

TILT WING DEVELOPMENT

The first tilt wing aircraft was the Boeing Vertol 76 VZ-2 (F-3). The VZ-2 was tested in the late 50's. This research vehicle had a single turbine engine mounted in the fuselage with shafting and gear boxes leading to propellers mounted at mid-span on the right and left wing (Ref. 12). Many successful transitions from vertical to horizontal flight and return were made.

BOEING/VERTOL VZ-2

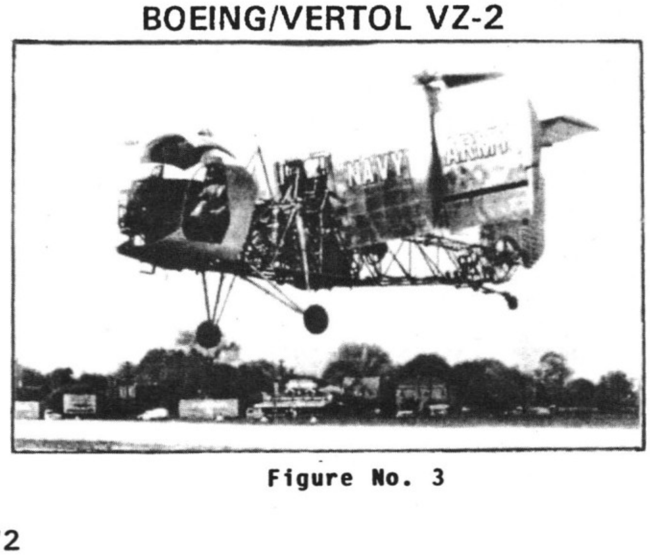


Figure No. 3

The second tilt wing aircraft was the Air Force sponsored Hiller X-18 produced in the early 60's (Ref. 13). The X-18 was a four engine, two propeller aircraft (F-4). It was powered with two twin packs identical to the one used in the Convair POGO. There was no cross shafting between the two 5,000 horsepower Allison turboprop propeller gear boxes. For safety reasons this lack of cross shafting limited testing to only partial transitions. Partial tilt STOL takeoffs and full tilt vertical takeoffs to hover close to the ground were evaluated.

HILLER X-18 TILT WING

Figure No. 4

A very large tilt wing demonstrator, the XC-142A, was developed in the mid-60's by the industry team of LTV/Hiller/Ryan in a Tri-Service sponsored program (Ref. 14). The XC-142A was a four engine, four propeller cargo transport (F-5). The XC-142A made successful demonstration flights on unprepared fields and VSTOL operations on board U.S. aircraft carriers at sea.

LTV/HILLER/RYAN XC-142A

Figure No. 5

CANADAIR CL-84 TILT WING

Figure No. 6

In the mid-60's General Dynamics Canadair produced a medium size tilt wing aircraft, the CL-84 (Ref. 15). Tests and demonstrations continued into the early 70's. This was a twin engine, two propeller tilt wing aircraft (F-6). The propellers were 14 feet in diameter. Three CL-84 prototypes were flown in the U.S. and Canada. The CL-84 made successful test and demonstration flights at the Patuxent River Naval Air Station, from the Pentagon pad (F-7) and from two U.S. aircraft carriers at sea (F-8).

CL-84 AT THE PENTAGON

Figure No. 7

CL-84 ON THE USS GUAM

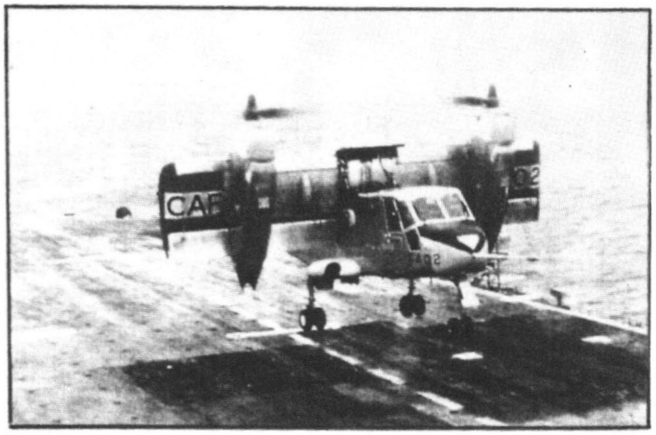


Figure No. 8

TILT ROTOR DEVELOPMENT

The Bell Helicopter Company began tilt rotor studies in the mid-1940's. Being a helicopter company, Bell is experienced in the use of large diameter low disc loading rotors for powered lift. They have been very successful in marketing helicopters in military and civil markets around the world. Their first tilt rotor aircraft was the XV-3 which was flown between the mid-50's and mid-60's. It made satisfactory transitions from vertical hover to level flight (F-9).

Bell's second generation tilt rotor was the XV-15 (F-10). Two demonstrator aircraft were built and they started flying in the late 70's. The XV-15 has two engines and two rotors. The rotors are 25 feet in diameter. Successful demonstration flights have been made including vertical takeoffs and transitions to level flight from the steps of the U.S. Capitol building in Washington, DC. One XV-15 was recently used for a rotor blade research program at the NASA Ames Research Center.

BELL XV-3 TILT ROTOR

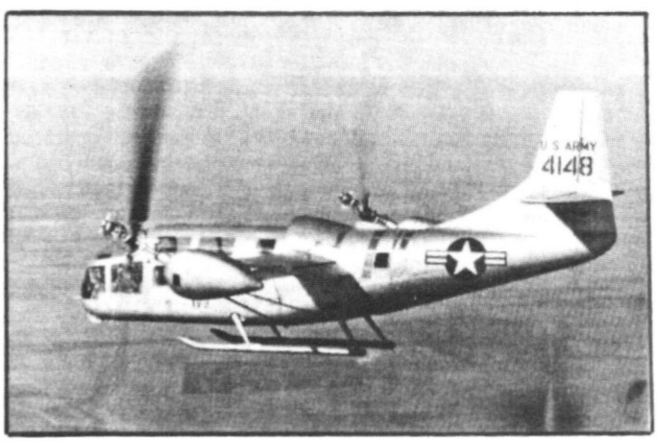


Figure No. 9

The Military Bell/Boeing V-22 Osprey is a third generation tilt rotor (F-11). Over 5.1 billion dollars have been expended or allocated for the development of this military aircraft which is years from Initial Operational Capability (IOC).Six

BELL XV-15 TILT ROTOR

Figure No. 10

BOEING/BELL V-22 TILT ROTOR

Figure No. 11

developmental aircraft were built and three are currently in a test program. Four pre-production vehicles are planned.

Requirements to meet Navy, Marine, Air Force and Army needs have made the V-22 a complex vehicle. Folding the 38 foot diameter three blade rotors and horizontally swinging the wing for carrier compatibility adds weight and complication that penalizes useful load, (range or payload) reliability, maintainability and safety. Adding to this weight and complexity are the two large diameter rotors with their helicopter cyclic/collective pitch controls.

THE CTW-409 TILT WING

The CTW-409 is a 9-passenger (11 seats) high speed VSTOL tilt wing aircraft proposed by William F. Chana Associates, Inc. in San Diego, CA (F-12, 13 & 14). This aircraft is designed to be certificated in the U.S under the FAA's "Airworthiness Criteria for Powered-Lift Normal Category Aircraft" (Ref. 32). It is a tilt wing aircraft slightly smaller than the Canadair CL-84. The CTW-409 is a twin engine aircraft with two 13 foot diameter four blade composite propellers. This aircraft will have the capability to take off and land as a conventional aircraft (CTOL), a short takeoff and landing aircraft (STOL), and a vertical takeoff and landing aircraft (VTOL).

The CTW-409 is designed to meet a civil market demand. It will serve the air taxi and commuter market, corporate/executive market, cargo/small package market, off shore resources market, search and rescue market, ambulance/police market, patrol/drug interdiction market, Navy carrier on board delivery (COD) market, and the delivery of people, cargo and mail to ships at sea.

CTW-409 TILT WING

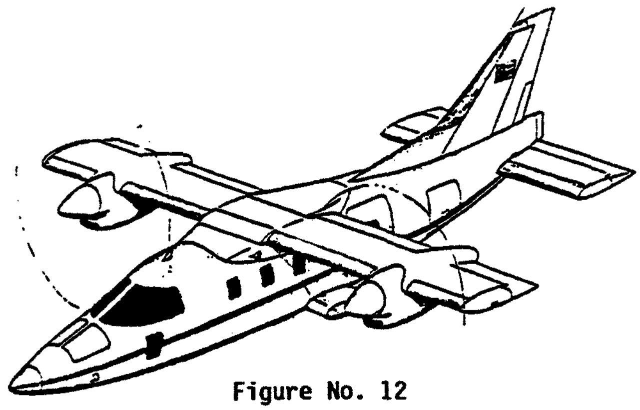


Figure No. 12

CTW-409 TWO VIEW

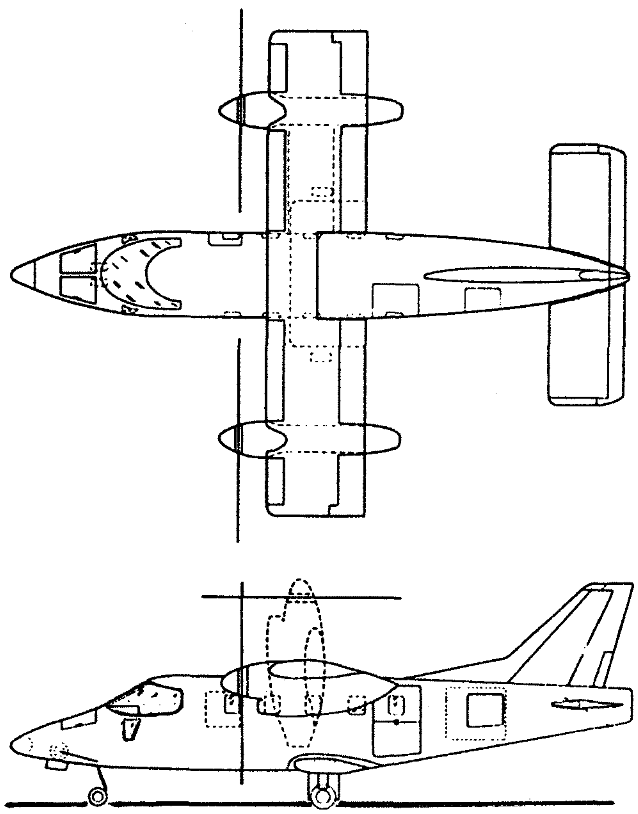


Figure No. 13

OTHER SIZES OF TILT WING AIRCRAFT

A family of tilt wing aircraft up to 30 passengers is proposed. With advancing technologies larger sizes will also be possible. However, it is prudent to start out small and then work up to the limits of feasibility and utilization. Tilt wing STOL aircraft that can operate from a maximum 500 foot long runway would be capable of carrying 100 to 150 passengers.

CTW-409 CABIN LAYOUT

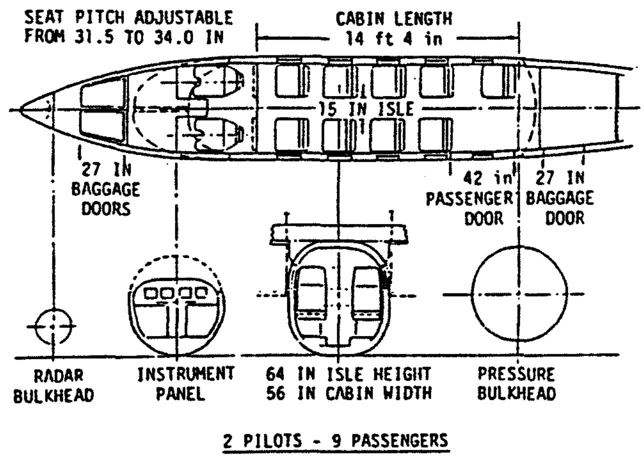


Figure No. 14

The relative size of the CL-84, CTW-409 and a 4-passenger CTW-404 is shown on (F-15). The relative size of the XC-142A, V-22, CTW-430 and CTW-419 is shown on (F-16). Besides being capable of carrying passengers the CTW-419 and CTW-430 are sized to carry standard LD-3 cargo containers.

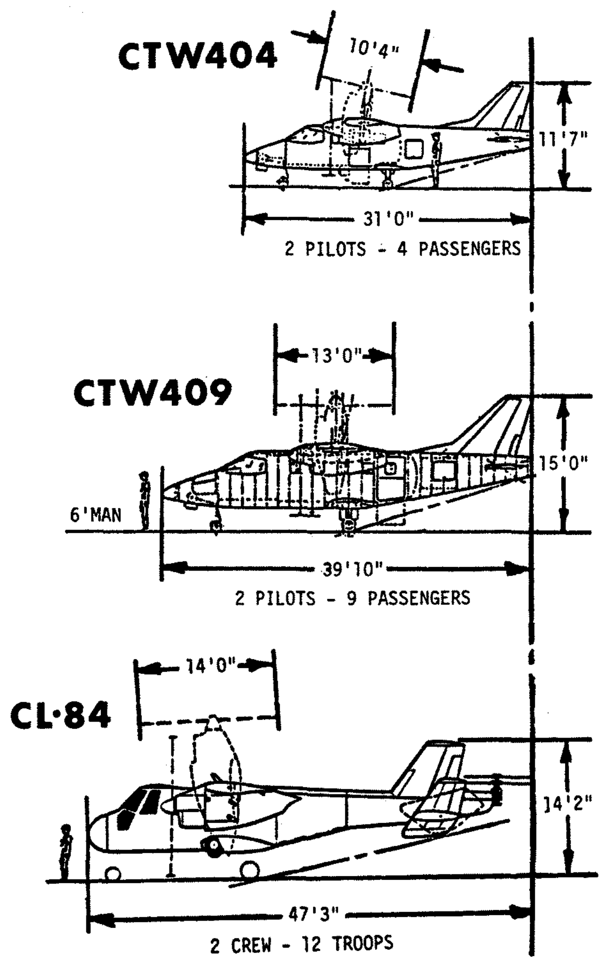


Figure No. 15

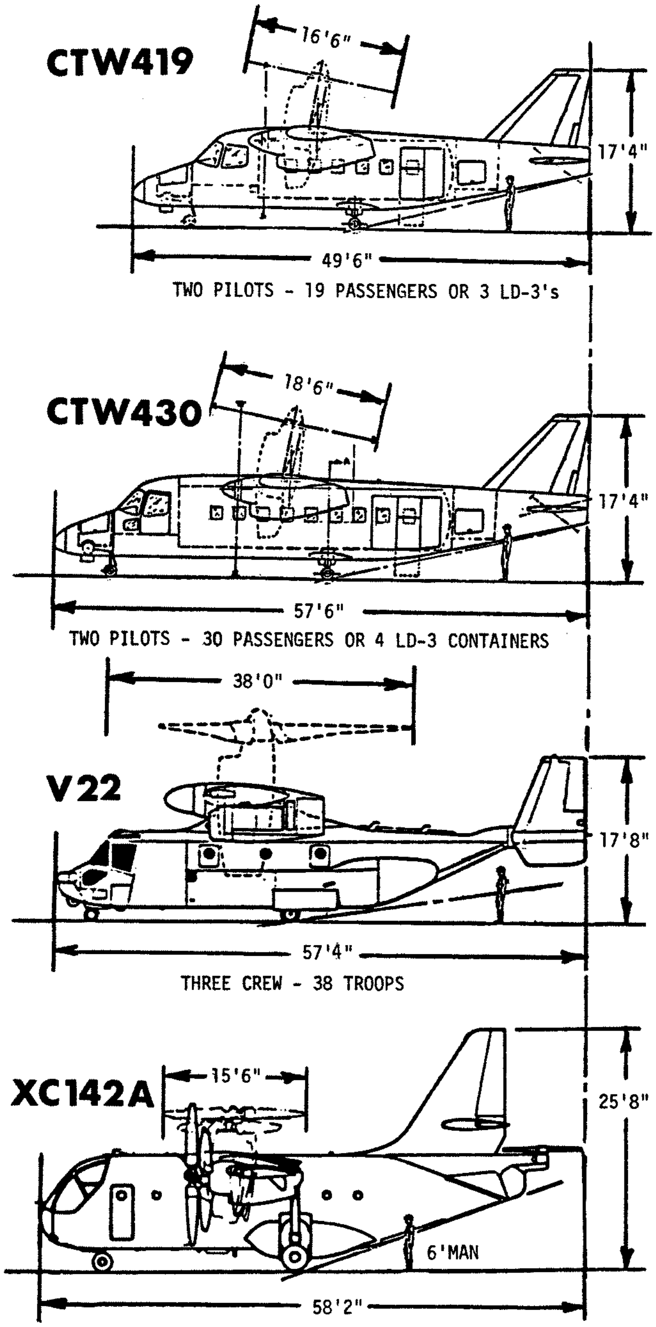


Figure No. 16

A TILT WING INNOVATION

The NASA Ames Research Center conducted flying quality studies of a tilt wing aircraft with an innovative geared flap that has the potential of providing aircraft pitch control in hover and transition. This concept would eliminate the need for the horizontal tail rotor that was used on the VZ-2, CL-84 and XC-142A.

The geared flap was patented by Gary B. Churchill (U.S. Patent #3,029,043). Recent simulation evaluations of this "Churchill flap" have been conducted by NASA Ames in their Vertical Motion Simulator (Ref. 30). The geared flap (F-17) without a tail rotor was evaluated against a conventional flap (F-18) with a tail rotor. Pilots that participated in the VMS tests reported that the flying qualities of the geared flap concept showed little difference to the conventional system.

Co-author, T.M. Sullivan, flew the simulator briefly and felt comfortable with the geared flap control in hover, vertical takeoffs and landings, and in transition to and from horizontal flight. Mr. Sullivan has had prior test pilot experience.

GEARED FLAP CONTROL CONCEPT

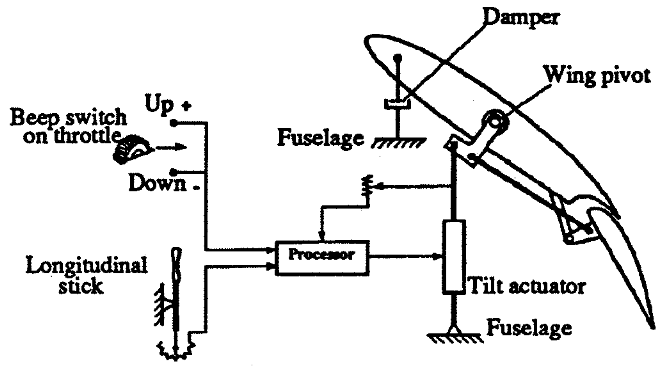


Figure No. 17

CL-84 TILT WING CONTROL

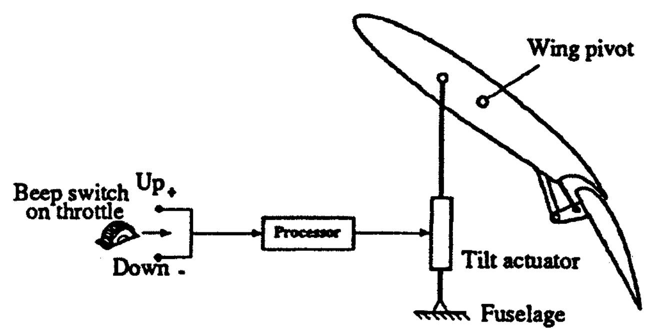


Figure No. 18

TILT WING AND HELICOPTER OUTFLOWS

Canadair conducted comparison tests of the outflow velocities from the CL-84 and an equivalent weight helicopter (Ref. 6). The objective of the flight test was to assess the suitability of the CL-84 as a hover rescue vehicle compared to helicopters.

The data revealed that, near the downwash impingement area, the vertical variation of the outflow velocity is appreciably different for the two vehicles. While the helicopter velocity-height profile is nearly uniform (F-19), the higher disc loading of the CL-84 shows higher velocities near the ground and lower velocities at head height (F-20). The horizontal high speed layer near the ground for the CL-84 gave ground observers the feeling of moving about in a flow field similar to

HELICOPTER VELOCITY-HEIGHT

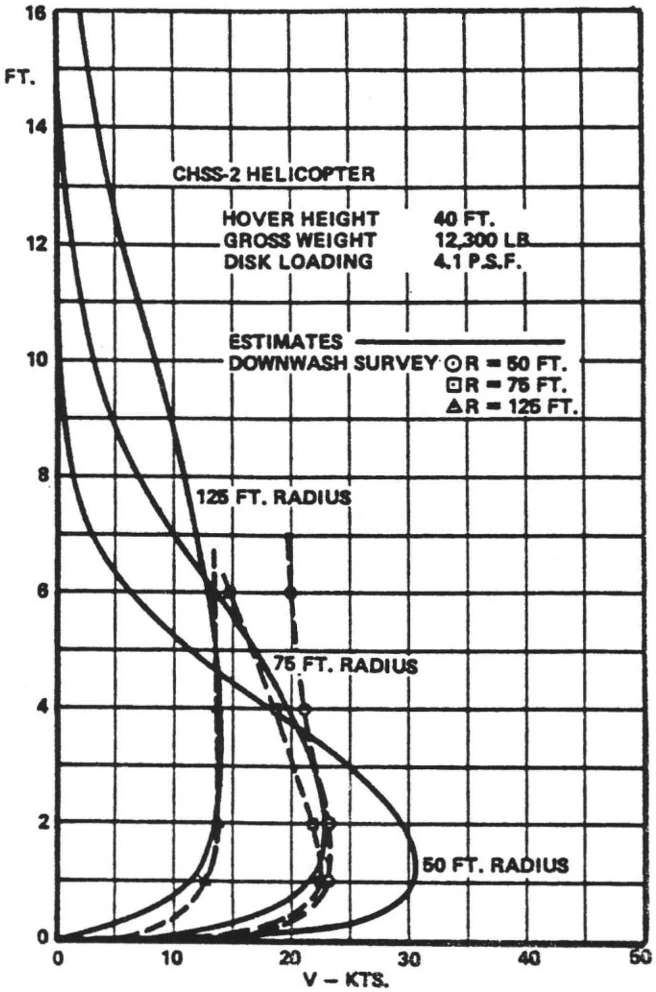


Figure No. 19

CL-84 VELOCITY-HEIGHT

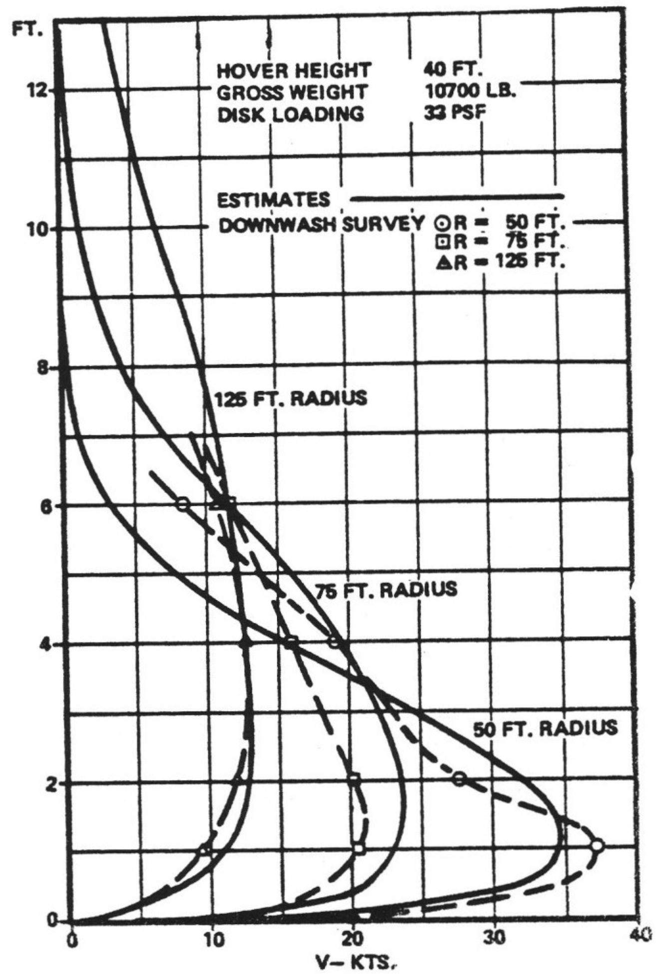


Figure No. 20

that of wading in shallow water. The CL-84 outflow velocity dissipated appreciably faster with radial distance than that from the helicopter.

During demonstration flights of the CL-84, live simulated rescues from a 40-foot hover position were made from both land and sea (F-21). The rescuee reported that at no time during the operation was there enough turbulence to cause concern, in fact the area directly beneath the aircraft was relatively calm.

THE CANADAIR CL-84

The Canadair CL-84 tilt wing was a successful research vehicle and demonstrator (F-6, 7 & 8). The prototype made its first free hovering flight on 7 May 1965. The first transition from hovering to conventional flight was made on 17 January 1966. This aircraft was powered by two 1,500 shp Lycoming T-53 (LTC1S-2A) turboprops each driving a four bladed propeller 14 feet in diameter (F-22). These propellers had fiberglass blades. The engines and propellers were mounted at the mid-span of the right and left wing which placed the total wing in the propeller slipstream. Cross shafting between the two propeller gear boxes permitted single engine operation with both propellers developing equal thrust.

CL-84 LIVE SIMULATED RESCUE

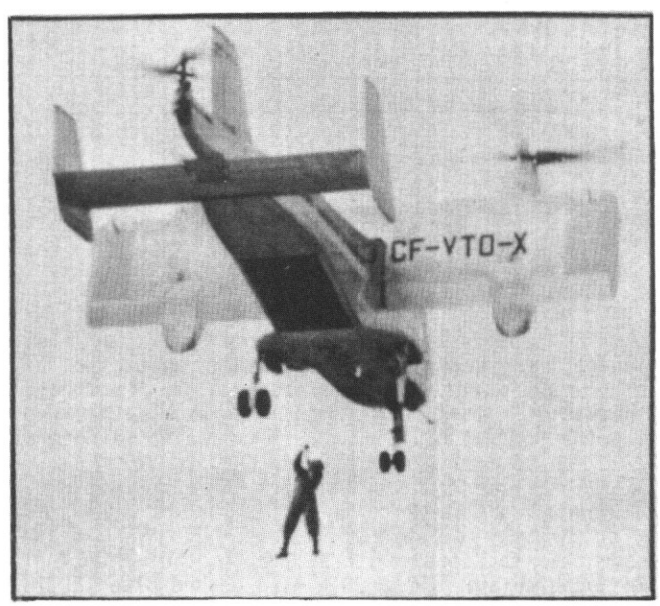


Figure No. 21

The CL-84's design takeoff gross weight for VTOL operations was 12,600 lb and 14,500 lb for STOL. The useful load for VTOL operations was 3,018 lb and 4,918 lb for STOL. The CL-84 had a relatively boxy fuselage utilizing a retractable tri-cycle landing gear and a retractable rear cargo ramp and door for hover rescue retrieval. Its maximum permissible structural diving speed was 360 knots (414 mph). The aircraft's empty weight was 9,023 lb. Internal fuel capacity was 247 U.S. Gallons (Ref. 38).

Three CL-84 prototypes were flown in Canada and the United States. They were flown 476 hours by 40 pilots on 709 flights. The CL-84 is credited with having made the first full blind flight transition to hover. Routine operational demonstrations were made from the Pentagon helicopter pad and from two U.S. aircraft carriers at sea (Ref. 8). A Tri-Service Team conducted test and evaluation flights at Patuxent River NAS over a period of two years. The team concluded "The CL-84 aircraft was suitable (as demonstrated) for search and rescue, surveillance, light transport and utility type missions..."

The CL-84 aircraft incorporated airplane type cockpit controls. There was no inherent instability or stall buffet involved in the transition from high horizontal speeds to vertical hover. Steep VSTOL approaches to beyond 30° glide slope were tested (Ref. 15). Fixed wing airplane pilots found it easy to hover and easy to transition requiring only a minimum amount of flight time to check out. The CL-84 was designed, tested and demonstrated by people whose experience was primarily in conventional fixed wing airplanes.

THE BELL XV-15

The Bell XV-15 tilt rotor was a successful research vehicle and demonstrator (F-10). The prototype made its first free hovering flight on May 3, 1977. The first in-flight conversion to airplane mode was made on 24 July 1979. This aircraft was powered by two 1,550 shp Lycoming T-53 (LTC1K-4K) turboprops driving three bladed rotors that are 25 feet in diameter (F-22). The original rotor blades were made of stainless steel; however, rotor blades made of carbon fibre, glass fibre, and Nomex honey comb were tested on the XV-15 at NASA Ames. The two engines and two rotors are wing tip mounted on a stationary horizontal wing. Cross shafting between the two rotor gear boxes permits single engine operation with both rotors developing equal thrust.

The XV-15's design takeoff gross weight for VTOL operation is 13,000 lb and 15,000 lb for STOL. The useful load for VTOL operations is 2,871 lb and 4,871 lb for STOL. The XV-15 has a relatively small and well streamlined fuselage. Its maximum permissible structural diving speed is 364 knots (419 mph). The aircraft's empty weight is 9,570 lb. Internal fuel capacity is 229 U.S. Gallons (Ref. 38).

CL-84 & XV-15 PHYSICAL COMPARISON

A physical comparison between the Canadair CL-84 tilt wing and the Bell XV-15 tilt rotor is shown in (F-22). It should be noted that both aircraft have two identical turboshaft engines of about 1,500 horsepower each. The CL-84 had propellers that were 14 feet in diameter, and the XV-15 had rotors 25 feet in diameter. The disc loading in hover for the CL-84 was 44.5 and for the XV-15 it is 15.2. The two aircraft were essentially the same physical size with the exception of their propeller and rotor diameters (F-23).

CL-84 & XV-15 COMPARISON

DIMENSIONAL COMPARISON	Units	Tilt Wing Canadair CL-84-1	Tilt Rotor Bell XV-15
Wing Span	ft-in	33-4	35-2
Wing Chord	ft-in	7-0	5-3
Wing Aspect Ratio	b/c	4.76	6.12
Wing Area	ft^2	233.3	169.0
Wing Airfoil Section	NACA	63_3-418	64A223
Span over Prop/Rotors	ft-in	34-8	57-2
VTOL Max. Wing Loading	lb/ft^2	54.0	76.9
STOL Max. Wing Loading	lb/ft^2	62.2	88.7
Prop/Rotor Tip Ground Clearance(0° Nac.Pos.)	ft-in	0-2½	- 5-0
Overall Length	ft-in	47-3½	42-1½
Overall Height	ft-in	14-2½	15-4
Tail Span	ft-in	16-8	12-10
Wheel Base	ft-in	14-0½	15-9
Wheel Track	ft-in	10-2	8-8
Cabin Length	ft-in	10-0	14-10
Cabin Width	ft-in	4-8	5-0
Cabin Height	ft-in	4-4	5-0
Cabin Volume	ft^3	200	300

PROPULSION COMPARISON			
Power Plant	model	LTC1S-2A	LTC1K-4K
Horsepower per Engine	shp	1,500	1,550
Emergency HP per Engine	shp	1,500	1,800
Prop/Rotor Diameter	ft-in	14-0	25-0
Prop/Rotor Disc Area (ea)	ft^2	153.9	490.9
Prop/Rotor Blades	number	4	3
Disc Loading(in hover)	lb T/ft^2	44.5	15.2
VTOL Power Loading	lb/shp	4.20	4.19
STOL Power Loading	lb/shp	4.82	4.83
Maximum Fuel Capacity	US gal	247.0	229.0
Unusable Fuel	US gal	8.2	9.5
Oil Capacity	US gal	16.3	20.8

Figure No. 22

CL-84 & XV-15 WEIGHTS COMPARISON

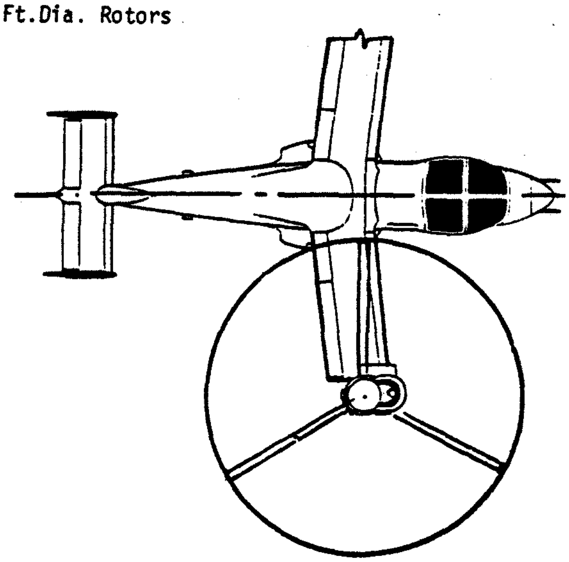
A weights comparison between the Canadair CL-84 tilt wing and the Bell XV-15 tilt rotor is shown in (F-24). The manufacturing weight empty of the XV-15 is 547 pounds more than for the CL-84. The VTOL and STOL design takeoff gross weights of the XV-15 are 400 and 500 pound more than the CL-84 respectively.

Since the two aircraft are very close to the same physical size and they have about the same total horsepower, it is significant to note that the useful load of the CL-84 tilt wing is greater than the XV-15 tilt rotor for both VTOL and STOL. This represents a positive payload advantage for the tilt wing. Download, which is fundamental to the tilt rotor, seriously takes away from the XV-15's useful load making it less payload efficient than the CL-84 tilt wing.

Therefore, it seems hardly realistic to use 25 foot diameter rotors with their associated cyclic pitch complexity, historically high maintenance, and limited level flight speed when 14 foot diameter conventional turboprop propellers on a tilt wing can do a better job.

XV-15 TILT ROTOR

25 Ft.Dia. Rotors



CL-84 TILT WING

14 Ft.Dia. Propellers

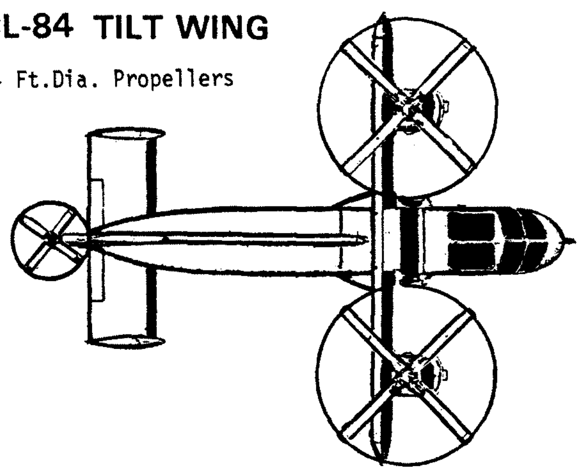


Figure No. 23

WEIGHTS COMPARISON

WEIGHTS COMPARISON (lb)		Tilt Wing Canadair CL-84-1	Tilt Rotor Bell XV-15
A.	Mfg. Weight Empty	9,023(1)(6)	9,570(2)(7)
B.	Pilot and Copilot	360	360
C.	Miscel. Equipment	199	199
VTOL Operations			
D. (A+B+C)	Operating Weight Empty	9,582	10,129
E.	Usable Fuel(6.7 lb/US gal)	1,600(1)	1,471(1)
F.	VTOL Payload	2,135(4)	2,135(5)
G. (D+E+F)	VTOL Overload T.O.G.W.	13,317	13,735
H.	VTOL Design T.O.G.W.	12,600(3)	13,000(2)
I. (G-H)	Fuel Off Load	717	735
J. (E-I)	VTOL Usable Fuel with Full Payload	883	736
K. (J÷E)	Percent of Usable Fuel	55.1	50.0
L. (H-D-E)	VTOL Payload with Full Fuel	1,418	1,400
M (F+J)	VTOL Useful Load	3,018	2,871
STOL Operations			
N. (D)	Operating Weight Empty	9,582	10,129
O. (E)	Usable Fuel(6.7 lb/US gal)	1,600	1,471
P.	STOL Payload	4,035(4)	3,400(2)
Q. (N+O+P)	STOL Overload T.O.G.W.	15,217	15,000
R.	STOL Design T.O.G.W.	14,500(3)	15,000(2)
S. (Q-R)	Payload Off Load	717	- 0 -
T. (P-S)	STOL Payload With Usable Fuel	3,318	3,400
U. (O+T)	STOL Useful Load	4,918	4,871

NOTES:
(1) Weight and Balance Data
(2) 1980-81 JANE'S All The World's Aircraft
(3) 1969-70 JANE'S All The World's Aircraft
(4) 1969-70 JANE'S(Adjusted downward 2nd pilot)
(5) No published "VTOL Payload" for the XV-15 Assumed same "VTOL Payload" as CL-84. Any greater "VTOL Payload" requires more "Fuel Off Load" to meet the"VTOL Design T.O.G.W."
(6) Includes 187 lb Oil and Unusable Fuel
(7) Includes 173 lb Oil and Unusable Fuel

Figure No. 24

THE LTV/HILLER/RYAN XC-142A

The LTV/Hiller/Ryan XC-142A was a successful test and demonstration vehicle (F-5). Five prototypes were built. The first conventional flight was made on 29 September 1964 and the first hovering flight followed on 29 December. On 11 January 1965 the aircraft performed its first two conversions, from hover to horizontal flight and return. By 4 February 1967 the five XC-142A's had logged 350 hours in the air, in 420 flights (Ref. 38). This aircraft was powered by four 3,080 shp General Electric T64-G.E.-1 Turboprop engines each driving a four bladed propeller 15 feet 6 inches in diameter (F-25). The propellers had glass-fibre blades with a steel core. The total wing was in the propeller slipstream. Cross shafting between the four propeller gear boxes permitted hovering flight with one engine inoperative.

The XC-142A's design takeoff gross weight for VTOL operations was 37,474 lb and 44,500 lb for STOL. The useful load for VTOL operations was 14,174 lb and 21,200 lb for STOL. The XC-142A had a very large fuselage cross section yet it had a maximum level design speed of 356 knots (409 mph) at sea level. The aircraft's empty weight was 22,595 lb. Internal fuel capacity was 1,400 U.S. Gallons. Provisions were provided for ferry tanks in the cargo compartment (Ref. 38).

THE BELL/BOEING V-22

The Bell/Boeing V-22 Osprey was developed to meet the U.S. Defense Department's Joint Services Advanced Vertical Lift Aircraft Requirement (F-11). Prototypes No. 1, 3 and 6 were built by Bell and No. 2, 4 and 5 were built by Boeing. The first prototype built by Bell made its first hover flight on 19 March 1989. The first in-flight transition from helicopter to airplane mode was achieved by No. 1 on 14 September 1989. This aircraft is

XC-142A & V-22 COMPARISON

DIMENSIONAL COMPARISON	Units	Tilt Wing LTV/H/R XC-142A	Tilt Rotor Bell/B V-22
Wing Span	ft-in	67-6	46-0
Wing Chord	ft-in	7-11	8-4
Wing Aspect Ratio	b/c	8.6	5.5
Wing Area	ft^2	534.3	381.8
Span over Prop/Rotors	ft-in	70-7.5	98.9
VTOL Max. Wing Loading	lb/ft^2	70.1	124.4
STOL Max. Wing Loading	lb/ft^2	83.3	144.0
Prop/Rotor Tip Ground Clearance(0^o Nac.Pos.)	ft-in	2-6	- 3-11
Overall Length	ft-in	58-2	57-4
Overall Height	ft-in	25-8	17-8
Tail Span	ft-in	26-8	18-5
Wheel Base	ft-in	21-9	21-6
Wheel Track	ft-in	17-9	15-2
Cabin Length	ft-in	30-0	24-2
Cabin Width	ft-in	7-6	5-11
Cabin Height	ft-in	7-0	6-0
Cabin Volume	ft^3	1575	858
Cabin Floor Area	ft^2	225	143
Max. No. of Troops	number	48	38
Floor area per soldier	ft^2	4.68	3.76

PROPULSION COMPARISON			
Number of Engines	number	4	2
Engine Manufacturer	name	G.E.	Allison
Engine Model	number	T64-GE-1	T406-AD-400
Horsepower per Engine	shp	3,080	6,000
Total Horsepower	shp	12,320	12,000
Prop/Rotor Diameter	ft-in	15-6	38-0
Prop/Rotor Disc Area (ea)	ft^2	188.6	1133.5
Prop/Rotor Blades	number	4	3
Disc Loading(in hover)	lb T/ft^2	49.7	20.9
VTOL Power Loading	lb/shp	3.04	3.95
STOL Power Loading	lb/shp	3.61	4.58
Maximum Fuel Capacity	US gal	1,400	2,008
Unusable Fuel	US gal	n/a	95

Figure No. 25

WEIGHTS COMPARISON

WEIGHT COMPARISON (lb)			Tilt Wing L/H/R XC-142A	Tilt Rotor B/B V-22
A.		Mfg. Weight Empty	22,595(5)(6)	31,886(5)(6)
B.		Crew	380	570
C.		Miscel. Equipment	325(est)	344(est)
VTOL Operations				
D.	(A+B+C)	Operating Weight Empty	23,300	32,800
E.		Usable Fuel	9,170(1)(6)	13,050(6)(8)
F.		VTOL Design Payload	8,000(6)	12,000(6)
G.	(D+E+F)	VTOL Overload T.O.G.W.	40,470	57,850
H.		VTOL Design T.O.G.W.	37,474(2)(6)	47,500 (6)
I.	(G-H)	Fuel Off Load	2,996	10,350
J.	(E-I)	VTOL Usable Fuel with Full Payload	6,174	2,700
K.	(J÷E)	Percent of usable fuel	67.3%	20.7%
L.	(H-D-E)	VTOL Payload with Full Fuel	5,004(3)	1,650(7)
M.	(F+J)	VTOL Useful Load	14,174	14,700
STOL OPERATIONS				
N.	(D)	Operating Weight Empty	23,300	32,800
O.	(E)	Usable Fuel	9,170	13,050
P.		STOL Capable Payload	12,030	20,000
Q.	(N+O+P)	STOL Overload T.O.G.W.	44,500	65,850
R.		STOL Design T.O.G.W.	44,500(6)	55,000(6)
S.	(Q-R)	Payload Off Load	- 0 -	10,850
T.	(P-S)	STOL Payload with Usable Fuel	12,030(4)	9,150(9)(6)
U.	(O+T)	STOL Useful Load	21,200	22,200

Notes
(1) 1,400 gal. JP-4 (6.55 lb/US gal)
(2) With 230 mile radius mission
(3) 20 Troops at 240 lb each
(4) Based on STOL Capable Payload 50 Troops at 240 lb each
(5) Assumes all systems fluids, Full Oil & Unusable Fuel
(6) JANE'S All The World's Aircraft
(7) 7 Troops at 240 lb each
(8) 1,913 gal. JP-5 (6.82 lb/US gal)
(9) 38 Troops at 240 lb each

Figure No. 26

powered with two Allison T406-AD-401 turboshafts, each with a takeoff and intermediate rating of 6,150 shp driving three bladed 38 foot diameter rotors (F-25). These rotors have graphite/glass-fibre, tapered blades. Cross shafting between the two rotor gear boxes permits symmetrical thrust with one engine inoperative.

The V-22's design takeoff gross weight for VTOL operations is 47,500 lb and 55,000 lb for STOL. The useful load for VTOL operations is 14,700 lb and 22,000 lb for STOL. The maximum design level speed at maximum STOL takeoff weight is 340 knots (391 mph). The aircraft's empty weight is 31,886 lbs. Internal fuel capacity is 2,009 U.S. Gallons. Provisions are provided for ferry tanks in the cargo compartment (Ref. 38).

XC-142A & V-22 PHYSICAL COMPARISON

A physical comparison between the LTV/Hiller/Ryan XC-142A tilt wing and the Boeing Bell V-22 tilt rotor is shown in (F-25). It should be noted that both aircraft have essentially the same total horsepower, i.e., 12,300 shp. The XC-142A had propellers that were 15 feet 6 inches in diameter and the V-22 rotors are 38 feet in diameter. The disc loading in hover for the XC-142A is 39.7 and for the V-22 it is 20.9.

Although the aircraft have the same amount of available horsepower, they are considerably different in physical size. The XC-142A cabin (cargo hold) volume is almost double that of the V-22. The XC-142A's cargo hold length, width and height are all greater than the V-22. Both aircraft use a rear loading ramp for access to the cargo hold (Ref. 38).

XC-142A & V-22 WEIGHTS COMPARISON

Since the XC-142A and V-22 have essentially the same available horsepower (12,000 shp), a weights comparison was made between them (F-26). Here we see that the manufacturer's weight empty of the V-22 is 10,205 pounds or 41% more than the XC-142A. The V-22 design TOGW for VTOL operations is 27% more and the TOGW for STOL operations is 23% more than the XC-142A. The useful load, however, of these aircraft in both the VTOL and STOL mode is, for all practical purposes, the same. Based on STOL capable payloads, the V-22 can carry 38 fully equipped troops and the XC-142A can carry 48. The cabin floor area of the V-22 allows 3.76 sq. ft. per soldier and the XC-142A allows 4.68 sq. ft. per soldier.

The V-22 payload (F-26) with full fuel for VTOL operations is only 1,650 pounds compared to 5,004 pounds for the XC-142A. The high inherent download has a large negative effect on the tilt rotor aircraft's payload and operating efficiency.

As in the case of the CL-84 and XV-15 it seems hardly realistic to use 38 foot diameter tilt rotors with their complexity when 15'6" diameter conventional propellers on a tilt wing can do the job. With its nacelles in a horizontal position the V-22's rotor tips extend 6'4" below ground level. With its wings and nacelles in their horizontal position the XC-142A's propeller tips cleared the ground by 2'6" making it capable of conventional takeoffs and landings.

VERTICAL LIFT, DOWNWASH AND DOWNLOAD

In tilt wing aircraft the engines and propellers are mounted at mid span on the left and right wing to provide slipstream over the total wing including its leading edge and trailing edge flaps. The total propeller slipstream flowing smoothly over the wing eliminates the possibility of conventional wing stall (F-29).

In tilt rotor aircraft the wing stays horizontal while the nacelles and rotors tilt at the wing tips. In vertical flight (hover) the tilt rotor's wing is, in effect, a flat plate immersed in the rotor downwash (F-30).

This downwash flow on the wing and on a substantial part of the fuselage, including sponsons, creates a vertical down force called download. This download reduces the effective net lift of the system. A NASA funded study prepared by Boeing/Bell indicates that the download on the V-22 Osprey expressed as a percentage of rotor thrust, is in the 9% range (Ref. 22). Since the gross lift from the V-22 rotors is approximately 60,000 pounds, 5,400 pounds of available lift (or payload) is lost due to the downwash flow. The tilt wing concept has no such download.

A recent study conducted by the U.S.A.F. Directorate of Design Analysis at Wright-Patterson Air Force Base indicates that for a tilt rotor transport the loss due to download on the wing can be in the order of 12% of the available lift. The study further states that this loss in lift translates to a 24% increase in engine power required with corresponding increases in weight and engine fuel flow (Ref. 31).

Wind tunnel tests conducted in the 40 x 80 foot wind tunnel at the NASA Ames Research Center on a 0.658 scale V-22 rotor and wing substantiates that the download can be as high as 10% of the rotor thrust in hover and the resulting reduction in payload can be as large as 40%. The economic viability of a VSTOL aircraft is determined by its payload capability (Ref. 33).

A study conducted by Ishida Aerospace Research indicates that for a 200 nm mission the XC-142A would be capable of carrying a 23% greater payload than the V-22 (Ref. 29).

PUBLIC ACCEPTANCE

Studies sponsored by the FAA have been completed in California, New York, Hawaii, Puerto Rico and other strategic areas to determine the feasibility and acceptability of high speed VSTOL type aircraft. It was found that community residents accept helicopters in their air ambulance or police roles, but are adamant in complaining about helicopters otherwise flying over their neighborhood. They say that if new high speed VSTOL aircraft look like and sound like helicopters, then they don't want them in their community.

According to one marketing professional in the field, "Perception is reality.". He points out that "Whether we think that helicopters are noisy or not, safe or unsafe, if the neighbors living near a proposed heliport thinks they are, then they are." Community education is imperative (Ref. 23).

Fortunately the CTW-409 high speed VSTOL tilt wing looks like an airplane and far from a helicopter (F-27). The CTW-409 can operate like a conventional airplane from airport runways, it can operate as a STOL airplane from short 500 foot strips, and it can take off and land vertically (F-28) from vertiports or heliports strategically located around city centers or equally well at major hub airports. Tilt wing aircraft can use steep departure and arrival flight paths which reduces their noise foot print. The perceived noise levels of tilt wing aircraft over typical residential areas will be far below that of commercial jets or the disturbing thump-thump-thump of the helicopter rotor.

CTW-409 CRUISE CONFIGURATION

Figure No. 27

CTW-409 VTOL CONFIGURATION

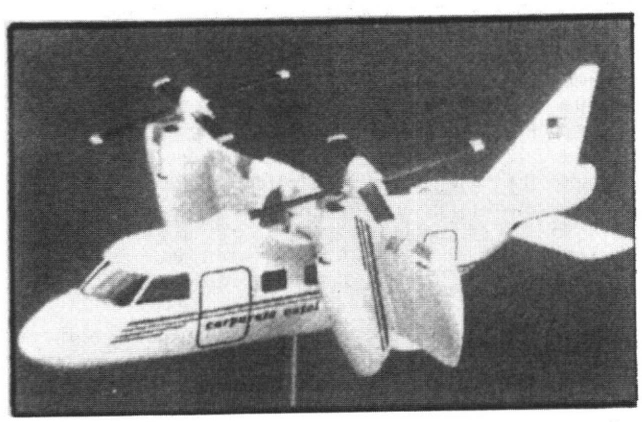
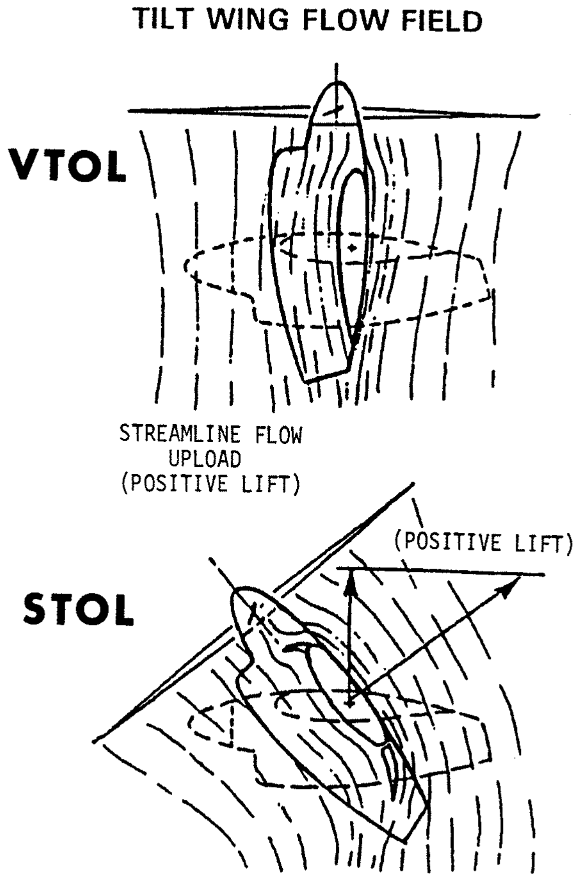


Figure No. 28



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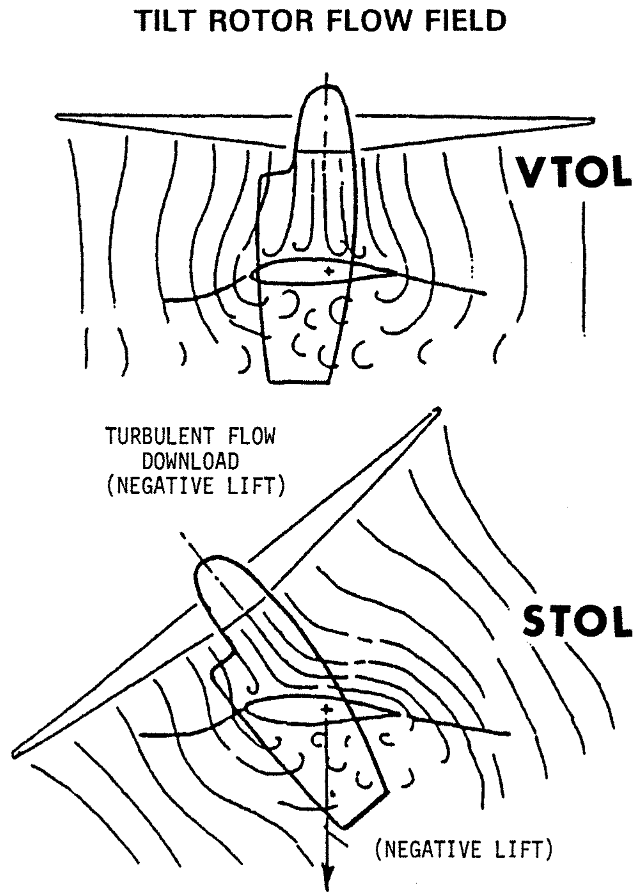


Figure No. 30

CRUISE SPEED

Tilt wing aircraft can fly at speeds far in excess of the helicopter and greater than tilt rotor aircraft (F-31). Helicopters are in the lower range of 100 to 175 knots. Compound helicopters can increase this speed up to about 250 knots.

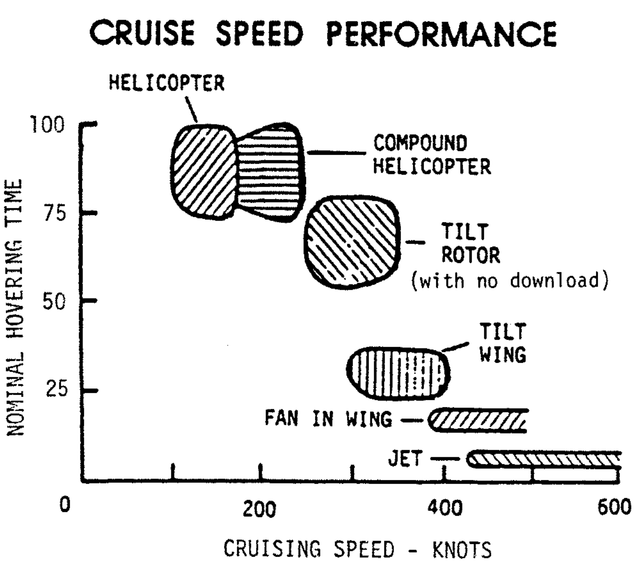


Figure No. 31

Tilt rotor aircraft can have maximum cruising speeds between 250 and 350 knots. Tilt wing aircraft can cruise from 300 to 400 knots. Good cruise performance over a wide range of speeds up to 400 knots is realized by using small diameter propellers rather than large diameter rotors. Very high speed tilt wing aircraft will use advanced technology propellers with sweep to penetrate into higher tip speed Mach numbers and to further reduce noise.

BLOCK TIME

A preliminary analysis of block time vs stage distance for a helicopter, conventional twin engine turboprop, and twin engine high speed VSTOL tilt wing aircraft shows a block time advantage for the tilt wing (F-32). At stage distances up to 50 miles the block times are essentially the same for the three types of aircraft. Greater than 50 miles the gap widens between the helicopter and the tilt wing and at 300 miles the block time is half that of the helicopter. The block time for a tilt rotor aircraft will be more than a tilt wing.

DIRECT OPERATING COST

A preliminary analysis of Direct Operating Cost (DOC) vs stage distance for a helicopter, a conventional twin engine turboprop, and a twin engine high speed VSTOL tilt wing aircraft shows a sizeable reduction in DOC for the tilt wing even at

COMPARATIVE BLOCK TIMES

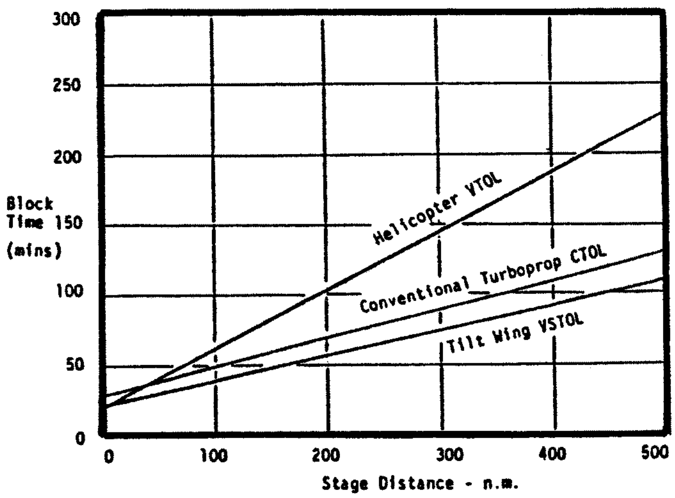


Figure No. 32

COMPARATIVE COST PER MILE

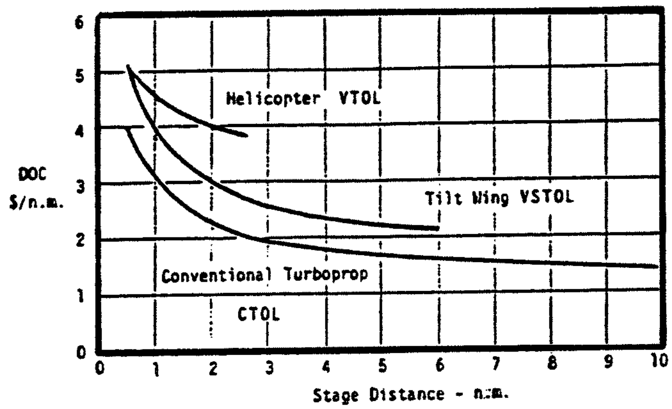


Figure No. 33

a stage distance of 50 miles (F-33). At 300 miles the tilt wing's DOC is about two-thirds that of the helicopter. The DOC of a tilt rotor will be more than a tilt wing and less than a helicopter.

PROPULSIVE EFFICIENCY

To keep rotor tip Mach number in a range for best efficiency with acceptable noise levels, the large diameter rotors on tilt rotor aircraft must turn at a much lower rpm than the relatively small diameter propellers on tilt wing aircraft. For efficient high speed level flight operations a high rpm propeller is better than a low rpm rotor (Ref. 15).

With a large disc, i.e., a low disc loading, in cruising flight, drag is a major issue, not gross weight. Consequently, the parasitic drag of the rotor blades tends to be relatively high and induced losses are very low. These conditions tend to offer low propulsive efficiency.

A preliminary study indicates a tilt rotor propulsive efficiency in cruise flight of 69% even with the rotor speed reduced in cruise relative to that used in hover. The Canadair CL-84 propulsive efficiency in cruise flight was 82%.

Parasite losses in lightly loaded rotors results in lower efficiency and thus there is a very substantial benefit for the tilt wing due to basic propeller and rotor characteristics.

PILOT TRANSITION

Fixed wing pilots that flew the Canadair CL-84 and the XC-142A tilt wing aircraft found them easy to hover and easy to transition requiring only a minimum amount of flight time for familiarization. Helicopter trained pilots also found them easy to fly. The Canadair pilot that first demonstrated the CL-84 on a U.S. aircraft carrier at sea had no previous deck operations experience.

The CL-84 was designed, built, flight tested, and demonstrated primarily by people who had experience only with conventional fixed wing aircraft.

The CL-84 incorporated airplane type cockpit controls. Conventional operation of the pilot's stick and rudder pedals produced normal movement about the various axes for all wing tilt positions in the VTOL, STOL, CTOL, or level flight modes. A single throttle lever was used and the wing tilt angle was selected by a rocker switch on the top of the throttle. The conventional airplane pilot was "at home" in the CL-84 cockpit.

There was no inherent instability or wing stall involved in the transition from high speed horizontal flight to vertical descent and landing. Steep VSTOL approaches to 30 degrees glide slope and higher were tested (Ref. 15). As demonstrated by the CL-84, taking off vertically and then accelerating from zero airspeed to 100 knots took about eight seconds. Transition from vertical hover to horizontal aerodynamic flight begins as soon as the wing starts to tilt down from the vertical. As the wing is tilted, propeller lift begins to decrease, but forward speed increases immediately and so does wing lift because the wing is also in smooth air flow from the propeller slip stream. The result is a safe balance making the tilt wing an easy aircraft to fly while transitioning.

RELIABILITY/MAINTAINABILITY AND SAFETY

It is fairly well known that helicopters with their large diameter rotors, cyclic pitch and collective pitch combination require considerably more maintenance than normal controllable pitch propellers commonly used on fixed wing aircraft.

Tilt wing aircraft use standard controllable pitch propellers. For aircraft roll control in hover, the propellers use differential pitch. Propellers have a proven track record for high reliability, low maintenance and safety.

In tilt rotor aircraft the wing tip mounted nacelles and rotors must be synchronized to ensure that they tilt up and down together. An emergency system must automatically stop the tilting process if the nacelle positions become unsynchronized.

Both tilt wing and tilt rotor aircraft incorporate cross shafting between the propeller gear boxes (F-34) to ensure that symmetrical thrust remains if engine power is unequal.

CTOL/VTOL/STOL AND STOVL

Tilt wing aircraft can be designed so that their propellers in cruise wing position clear the

POWER TRANSMISSION SYSTEM

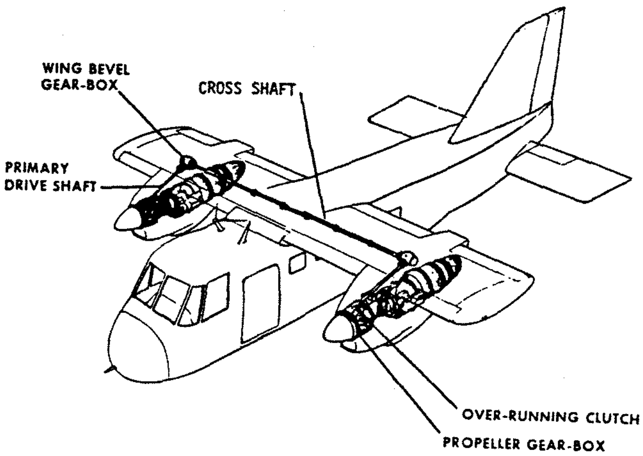


Figure No. 34

ground; the tilt rotor cannot (Ref. 21). A tilt rotor design must ensure that the nacelle rotation actuation system will not fail with the nacelles in the horizontal cruise position. An emergency mechanical override system must be considered, perhaps similar to emergency landing gear extension systems employed on conventional aircraft. This emergency system, which adds complexity, must drive the nacelles upward to a point where the rotor tips can clear the ground for a safe, no damage STOL landing.

It is not necessary to have a similar emergency mechanical override for actuation of a tilt wing because tilt wing aircraft can take off or land with the wing in any position.

Since VSTOL aircraft have the capability of carrying a greater payload when operating in the short takeoff and landing mode (STOL) the tilt wing and tilt rotor offer operational flexibility with a maximum payload. Takeoffs can be made in the STOL mode. The landing, following fuel burn off, can often be made in the VTOL mode.

STRUCTURAL DYNAMICS

With the tilt rotor's low disc loading and low rpm there can be a low rpm coupling with the fundamental modes of the fuselage and wing, i.e., the large components. The once per rev excitation of the rotor (which is low frequency) tends to excite these large components. This means that the tilt rotor aircraft's wing and fuselage have to be designed with high stiffness in mind. Even after structural dynamics requirements are met, a lot of weight is required to provide the necessary stiffness (Ref. 32).

SEARCH AND RESCUE (SAR)

The helicopter has been used successfully for many years as a search and rescue vehicle. In the case of the helicopter, the open door or hatch for personnel retrieval is near the axis of rotation of the rotor, therefore, there is little, if any, turbulence in this area to complicate a transfer of the rescuee into the fuselage.

In tilt wing and in tilt rotor aircraft the maximum downwash velocity takes place in the area immediately to the left and right of the fuselage. The CL-84 demonstrated live simulated rescues from both land and sea with the aircraft hovering 40 feet above the surface. The rescuee reported no undesirable turbulence during the winch retrieval operation. Retrieval was made through an on centerline cargo opening at the rear of the fuselage cargo bay (F-21). The XC-142A also demonstrated live simulated rescues from land and sea with the aircraft hovering 120 feet above the surface. A centerline opening was used.

The mission range of search and rescue aircraft is important and the time required to reach the person to be rescued is usually critical (Ref. 1). Also, returning the rescuee to a main base or hospital in the shortest possible time can make the difference between life or death.

The larger (heavier) the rescue vehicle, the greater the downwash. In this regard the CTW-409 is an ideal size for a rescue aircraft.

DEVELOPMENT AND PRODUCTION COST

The greater complexity of the tilt rotor means higher costs. In 1984 a technical and management risk assessment of the V-22 tilt rotor program was conducted for the Marine Corps. It was found that the complex rotor and wing folding mechanisms were a potential source of troublesome vibration and structural instability that would prove costly in development time, overall weight, and program costs (Ref. 21). Ten years later this is proving to be true.

If we can assume that a tilt rotor aircraft,like the V-22, can be fully developed and ready for delivery to the military services by 1996 and that a total of $5.5 billion will be expended to reach this goal, historical data indicates that the cost of this development comes about to $100,000 per pound of Takeoff Gross Weight (Ref. 37). The same historical data indicates that conventional high technology commercial or military aircraft can be developed by "Typical Industry" for about $20,000 per pound.

A small company using a "Skunk Works" approach can develop a basic 9-passenger tilt wing aircraft for about $17,000 per pound. The development cost of the CTW-409 would be about $270 million not counting propeller gear box development and certification. This assumes that FAA Certification will take place in 1999.

MILITARY DERIVATIVES FROM CIVIL AIRCRAFT

"We must not overlook the possibility of fall-out from civil developments which could be useful to the military." The Air Force "wants faster, longer endurance search and rescue aircraft which can also be used for special forces missions". The Navy "needs a vehicle which can fly long distances at high speed and then hover for its ASW mission". The Army and Marines "need an aircraft which can transport large numbers of troops long distances at high speed and deposit them silently in combat zones or behind enemy positions" (Ref. 17).

Examples of military derivatives are the C-47 troop transports that developed from the Douglas DC-3, the T-29 navigational trainer that came from the Convair 240, the C-131 D&E's that were mirror images of the Convair 340, the KC-135 tanker that developed from Boeing's Model 80 private venture and the B707 commercial transport, and the KC-10 that followed the Douglas DC-10.

During development of the CL-84, Canadair and Convair,which were both part of the General Dynamics Corporation, made innumerable studies and

NAVY ASW TILT WING CONCEPT

Figure No. 35

NAVY AEW TILT WING CONCEPT

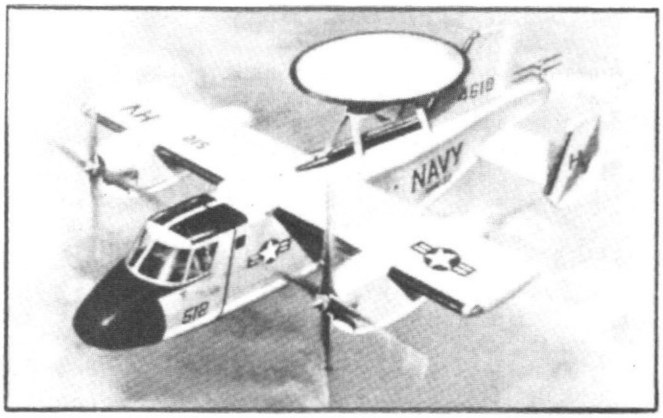


Figure No. 36

USAF CLOSE SUPPORT TILT WING

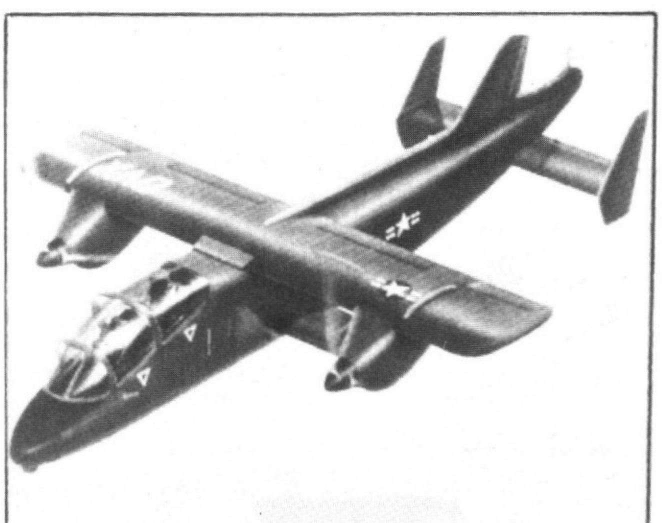


Figure No. 37

wind tunnel tests of tilt wing aircraft (Ref. 5) to meet the Navy's Sea Control Ship (SCS) requirement, the Air Force's strike and reconnaissance mission, and the Army's observation and close support task. Tilt wing aircraft had the capacity to extend the Navy ASW (F-35) and the AEW (F-36) defense perimeter of the SCS system well beyond that attainable with helicopters. Catapults and arresting gear are unnecessary. Launch and recovery of SCS aircraft depend on VSTOL performance (Ref. 7). Canadair conducted an extensive study of a tilt wing attack VSTOL aircraft that was provided with tandem seating, a bubble canopy and zero-zero ejection seats (F-37). Its maximum speed at sea level would be over 400 knots.

INTERNATIONAL COOPERATION

There are three major benefits from international cooperation in research and development: (1) stimulates innovation, (2) fosters mutual respect and trust, and (3) accelerates technology readiness (Ref. 26).

Aircraft development requires capital investments which can be far in excess of a corporation's net worth. Risk sharing participating partners are being used today to accomplish major civil aircraft programs. Historical data (Ref. 37) projected to the year 2000 indicates that over $30 billion will be needed to develop a 700-passenger "Ultra High Capacity Aircraft" (UHCA) currently being studied independently by three major aircraft manufacturers. And further into the future, a supersonic or hypersonic transport may require risk sharing with participating governments. International cooperation is a "now and forever" requirement.

Developing a 9-passenger high speed VSTOL tilt wing aircraft (CTW-409) requires a capital investment of about $270 million. Finding an innovative financial partner in and/or outside the U.S. is a big challenge.

TECHNOLOGY TRANSFER

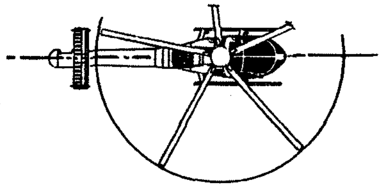
It has been said that knowing where we have been helps us understand where we are going. Orville and Wilbur Wright studied their predecessors, i.e., Cayley, Lilienthal, Maxim, and Langley and then applied their self taught knowledge to accomplish the world's first power-driven, heavier-than-air, and controlled sustained flight with their "Wright Flyer" on December 17, 1903.

It has been said that "One of the greatest tools of scientific men is the record of past discoveries, experiments and inventions. Just think of the number of hours, effort and money that are saved in knowing what has been done in the past in a particular field. Not only can an experimenter start were others have left off, but he can also co-relate facts of many researchers and by applying his own experience discover new ideas that will benefit mankind" (Ref. 27).

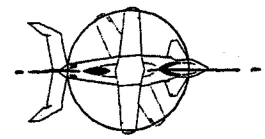
SUMMARY

If there are no airflow obstructions below a rotor or propeller disc (as is the case of the tilt wing) there is no slipstream download. A plan view of the V-22 indicates that the area of the wing (with wing flaps down in an optimum position to reduce download) under the disc is 9.9% of the

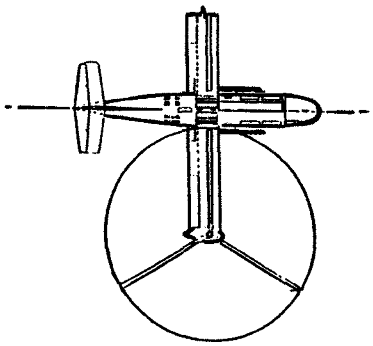
McDonnell
Douglas H.
MD-520N
Helicopter
R.Dia.27.3'
Obs. 10.6%
(Ref. 38)



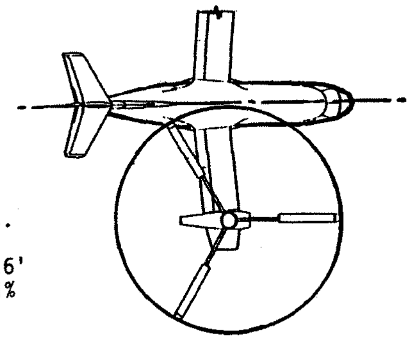
McDonnell
Douglas H.
Canard RW
UAV Concept
R.Dia.10.25'
Obs. 31.5%
(Ref. 34)



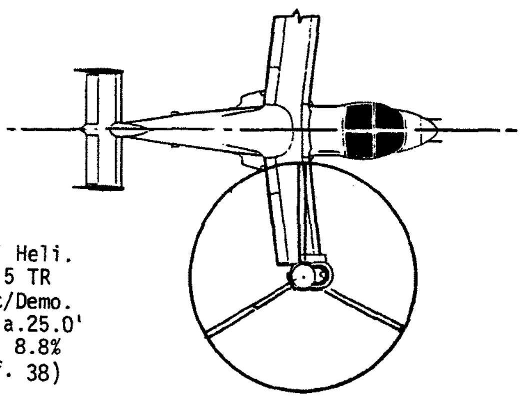
Bell Heli.
XV-3 TR
Research
R.Dia.23.0'
Obs. 9.8%
(Ref. 38)



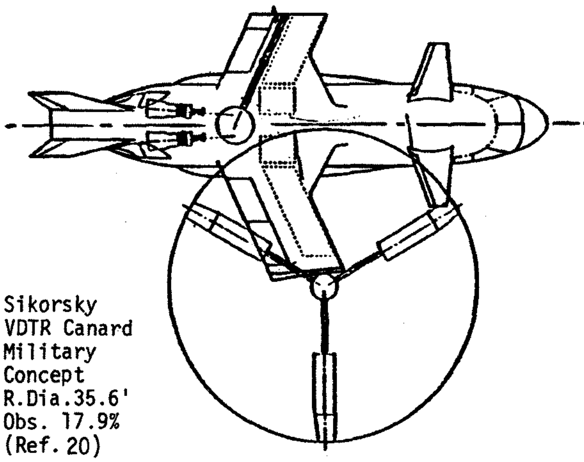
Sikorsky
VDR Trans.
Concept
R.Dia.24.6'
Obs. 10.1%
(Ref. 18)



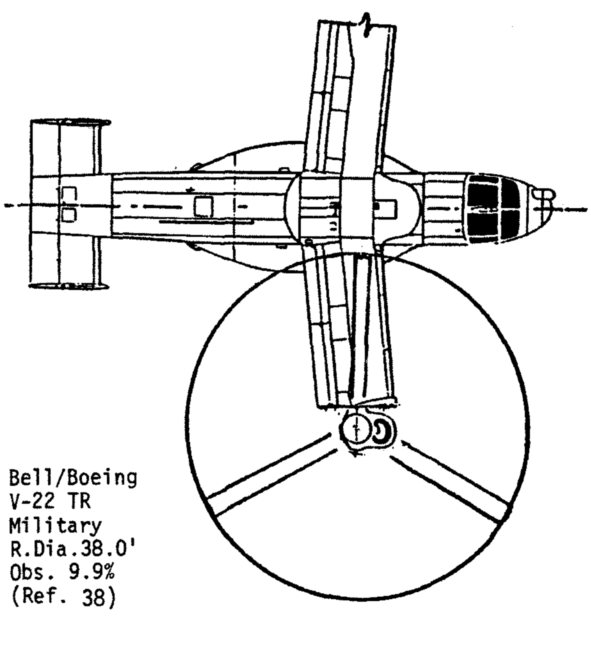
Bell Heli.
XV-15 TR
Test/Demo.
R.Dia.25.0'
Obs. 8.8%
(Ref. 38)



Sikorsky
VDTR Canard
Military
Concept
R.Dia.35.6'
Obs. 17.9%
(Ref. 20)



Bell/Boeing
V-22 TR
Military
R.Dia.38.0'
Obs. 9.9%
(Ref. 38)



Aerospatiale
Eurofar TR
Transport
Concept
R.Dia.36.75'
Obs. 9.6%
(Ref. 19)

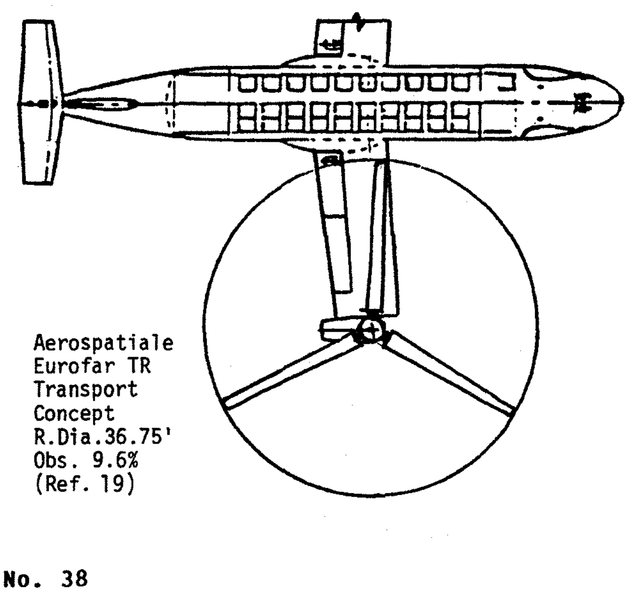


Figure No. 38

rotor disc area (F-38). This percentage correlates closely with the NASA wind tunnel tests and the NASA funded study conducted by Boeing/Bell.

The amount of lift lost in tilt rotor aircraft is directly related to the area of the flat plate projected obstruction below the rotor disc. A plan view of one helicopter, one rotor-wing, and several tilt rotor type aircraft is shown in (F-38) along with the approximate percentage of obstruction (Obs.) under the rotor disc.

CONCLUSIONS

1. There is a need for a first generation 9-passenger high subsonic speed VSTOL civil aircraft that uses conventional controllable pitch propellers. Advancements since the 1970's in propulsion, computerized flight controls, avionics, and structures will make the CTW-409 an efficient aircraft to serve markets throughout the world.

2. Markets will develop for a second generation 19-passenger high subsonic speed VSTOL commuter/regional airliner. A third generation 30-passenger high speed VSTOL aircraft will follow. Consideration must be given to the strong downwash created by larger heavier VSTOL aircraft and to the structural dynamics, vibration and noise problems which greatly multiply as high speed VSTOL aircraft get bigger.

3. There is a need for both small and medium size high speed VSTOL aircraft in the U.S., China, Japan, the Philippines, Indonesia, Great Britain, Spain, Russia and many other countries that have unique geography and congested major airports.

4. The biggest challenge in the total process from design to civil certification and production is arranging for short and long term investment capital so that a high speed VSTOL tilt wing aircraft can move smoothly through the various development and certification phases on schedule, on budget and without work stoppages (Ref. 11). To make this happen, it will take innovative financial partners with long term goals, a skunkworks approach for development and competent "can do" men and women.

5. The tilt wing concept has many design features superior to the tilt rotor making it a more efficient, cost effective, safer and easier aircraft to operate. The development costs, productions costs, and operating costs of a tilt wing are much less than for a tilt rotor.

6. Tilt rotor download seriously reduces the aircraft's useful load and thus its payload and/or range. The tilt wing has no slipstream download in hover. It has an increment of wing lift both in hover and during transition from hover to level aerodynamic flight.

7. Tilt rotor download actually cancels most of the lifting advantage large diameter low disc loading rotors might offer. The economic viability of a VSTOL powered lift aircraft is determined by its payload capability.

8. Developers and potential users of powered lift VSTOL aircraft must consider the negative effect that tilt rotor download has on payload and operating efficiency.

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ABOUT THE AUTHORS

William F. Chana began his aerospace career in 1941 with Consolidated Aircraft Corporation in San Diego, California and played an active roll in flight testing the XB-24 Liberator Bomber, the XF-92A first delta wing airplane, the POGO XFY-1, the first VTOL airplane, Sea Dart XF2Y-1 supersonic seaplane, the 240/340 commercial airliners and other Convair aircraft.

In the 1950's he was a partner in building and flight testing three small aircraft. The first of these was known as the "WEE BEE" which the news reels and the media called "The World's Smallest Airplane". The Guinness Book of World Records for many years identified the Wee Bee as "The World's Lightest Airplane".

In the early 1960's he shifted from airplanes to missiles when he was assigned as Convair's Base Manager for the installation and checkout of operational ATLAS missiles at Fairchild Air Force Base in Spokane, Washington. After later assignments as the Base Manager at Convair's test site for hot firing the ATLAS and Centaur launch vehicles, Manager of Missile Updating, Marketing Manager, Long Range Planning Manager and 32 years with Convair, Mr. Chana moved to Rohr Industries as Deputy Program Director on a proprietary triphibian airplane program. In 1976 he started his own consulting company specializing in aviation design and marketing. He is President of William F. Chana Associates, Inc.

Mr. Chana has been an active member of the San Diego Aerospace Museum's Board of Directors since 1963. He holds a commercial pilots license for single engine land planes and gliders. In 1973 he earned a Masters Degree from National University in San Diego. He is an AIAA FELLOW and a SAE, AHS, OX-5, EAA, and Silver Wings member.

T.M. Sullivan began his aeronautical career following graduation from the University of Detroit in 1935 where he earned a Bachelor Degree in Aeronautical Engineering. Prior to WWII he taught aeronautical engineering at the Indiana Institute of Technology followed by several years as a design engineer with the Glenn L. Martin Company. During and following WWII through 1960 he was employed by the Fairchild Engine and Airplane Corporation. He was Manager of Flight Test Operations and Experimental Test Pilot at the Engine Division of Fairchild. He then moved to Field Engineering where he managed all out of plant engineering test programs. In 1952 he opened and managed the Fairchild West Coast Office in Los Angeles.

Between 1964 and 1980 he was employed by the General Dynamics Corporation. Initially he was responsible for international marketing of the Canadair CL-41, a turbojet trainer produced by GD Canadair. He was Director of International Marketing for the Canadair CL-84 high speed VSTOL tilt wing aircraft. This included evaluations by the USAF and by the Navy and Marine Corps at Patuxent River Naval Air Station and aboard two aircraft carriers. This responsibility involved trips to Viet Nam during the conflict and trips to other Far East areas and Europe. From 1975 he was Manager and then Director of the General Dynamics Corporate Middle East Office based in Iran, Israel and Greece.

He is a member of Tau Beta Pi, an Associate FELLOW of AIAA and a member of OX-5 and Silver Wings. He is a commercial pilot and flight instructor, airplanes and gliders.

He is a Vice President of William F. Chana Associates, Inc.

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