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ROTOR SYSTEM RESEARCH AIRCRAFT PREDESIGN STUDY

FINAL REPORT
VOLUME I

SUMMARY AND CONCLUSIONS

BY Arthur W. Linden et al.

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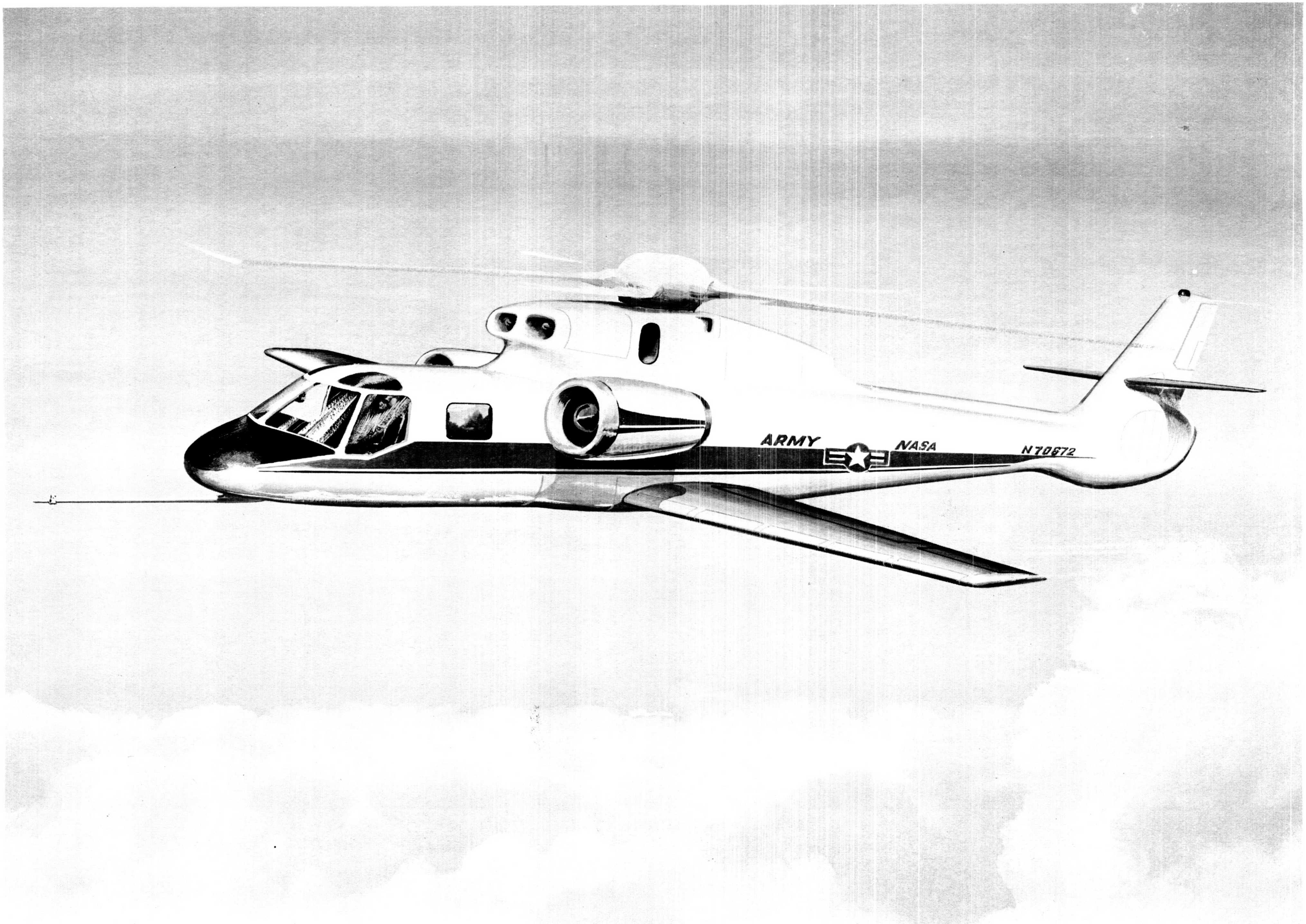

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FOREWARD

This document was prepared by Sikorsky Aircraft, a Division of United Aircraft Corporation, Stratford, Connecticut, under Contract NAS1-11228 to the National Aeronautics and Space Administration and the U.S. Army. It is subdivided into five volumes as follows:

Volume I	Summary and Conclusions
Volume II	Conceptual Study Report
Volume III	Predesign Report
Volume IV	Preliminary Draft Detail Specification
Volume V	Development Plan Report

The report covers work conducted during the period December 1971 - July 1972.

ROTOR SYSTEMS RESEARCH AIRCRAFT

PREDESIGN STUDY *

Introduction

This report, submitted in five separate volumes, presents the results of the Rotor Systems Research Aircraft (RSRA) Predesign Study, which has been performed by Sikorsky Aircraft for the National Aeronautics and Space Administration and the U.S. Army under Contract NAS1-11228. This first volume summarizes the study results.

The Rotor Systems Research Aircraft was conceived of by NASA and the U.S. Army as a versatile research aircraft for flight testing a wide variety of advanced helicopter and compound rotor systems. The aircraft should accept these rotors with minimal changes in the basic vehicle. Rotors envisioned for testing include conventional rotors plus variable geometry, variable twist, variable diameter, coaxial, jet flap, circulation control, and slowed rotors. Various disc loadings must be accommodated. The aircraft must be configured to measure performance more accurately than past test vehicles. In addition, the aircraft should have a wing to off load the rotor while measuring performance during lightly loaded conditions. It should have variable drag and propulsive force so that the rotor can be tested while producing different values of horizontal force.

The usefulness of such a vehicle has been recognized by government and industry. To assist in further RSRA program planning, the Predesign Studies were contracted. These studies involved three basic tasks:

(1) Working closely with the NASA/Army RSRA Project Office, define the design of the aircraft to provide maximum testing capability at minimum cost.

(2) Identify and assess risk areas, particularly any subsystems that require further development prior to the development of the aircraft.

(3) Define an aircraft development plan and associated costs.

* The contract research effort which has led to the results in this report was financially supported by USAAMRDL (Langley Directorate).

Why RSRA?

The RSRA promises a number of benefits to government and industry. These include:

- More accurate testing of advanced rotor systems
- Higher speed testing with acceptable instrumentation payload and test endurance
- Lower cost than constructing test vehicles for each new rotor configuration
- Continuation of U.S. technical leadership in the rotary wing field

RSRA will perform as a "flying wind tunnel," measuring rotor performance over the full range of lifting capability and speed during actual flight conditions. The rotor, wing, auxiliary thrust engines, and anti-torque systems are mounted through load cells to provide inflight measurement of forces and moments with excellent accuracy.

The RSRA is being designed for 300-knot speeds with 15 minutes of endurance at the 300-knot test point. An allowance for 2000 pounds of instrumentation payload is included. This greatly expands the test capability of RSRA over past high speed compound aircraft, all of which had minimal endurance and payload capabilities. At 300 knots, the RSRA will be able to test rotor and wing lift sharing, rotor loads and stability, and the various control system concepts proposed for high speed compounds.

Because RSRA is a single design configured to test many advanced rotor systems, it will be less costly than the alternative approach of developing a separate vehicle to test each new rotor concept. It should also reduce the development times for these new concepts, since the test aircraft need only be developed once.

RSRA will continue to advance the technical leadership of the United States in the rotary wing field. The basic aircraft itself will have capabilities beyond those of present vehicles. In addition, RSRA will ease the development of the advanced rotor systems, reducing their development time.

RSRA can be used to test advanced aircraft subsystems other than rotors. For example, it will include a practical helicopter ejection system. It could also be used to test integrated propulsion systems that use the same engines to power the rotor system and the auxiliary propulsion system.

RSRA promises many benefits for advanced VTOL transportation systems. It will demonstrate safe, efficient, high speed rotary wing flight, with a vehicle sized for good payload and endurance. It can also be used to demonstrate the low noise and environmental characteristics of advanced helicopters and compounds.

The Aircraft Design

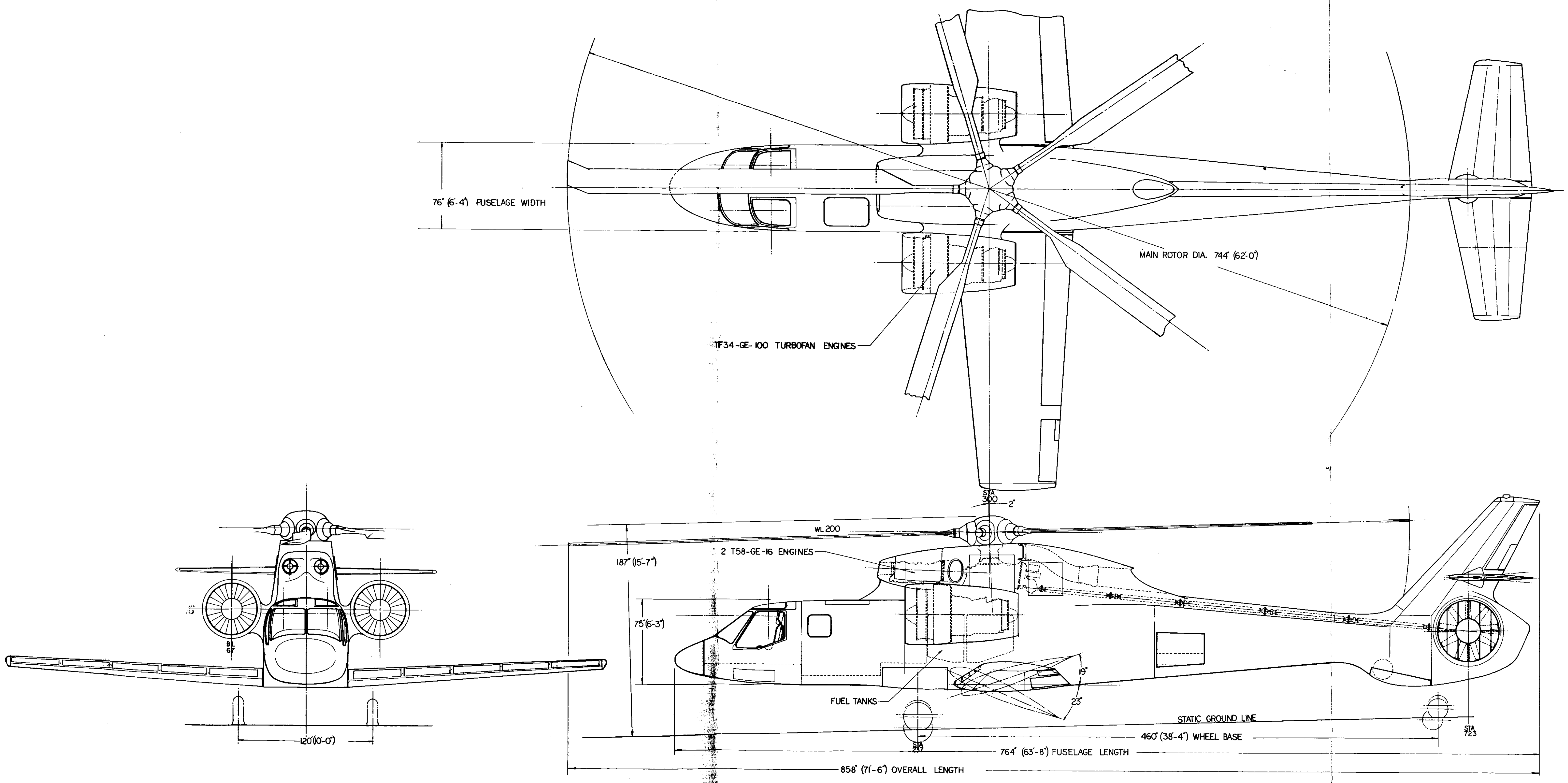
The RSRA aircraft is a 300-knot single rotor compound helicopter that uses existing dynamic components combined with a new airframe. The airframe is designed to offer the special features required for RSRA. The rotor is from Sikorsky's S-67 Blackhawk$_{TM}$. The transmission is a 3700-horsepower roller gearbox now under a U.S. Army Development Program. Two General Electric T-58-16 engines provide rotor propulsion. Two General Electric TF-34-100 turbofan engines provide auxiliary propulsion. A side-by-side seating arrangement was chosen for human factors considerations.

Unique features of this aircraft include:

- A wing capable of supporting full aircraft design gross weight at speeds as low as 120 knots
- A variable wing incidence mechanism to vary wing angle of attack in flight
- Load cell instrumentation systems to measure all rotor and wing forces as well as auxiliary propulsion and anti-torque thrust
- An electrical/mechanical control system to provide testing versatility with low cost and risk
- A crew escape system, including a mechanism to sever rotor blades before extraction of the crew
- A ballast system to vary aircraft center of gravity and inertia
- Drag brakes to vary aircraft parasite drag
- A fixed-wing type landing gear and braking system to permit fixed-wing landings at speeds up to 120 knots
- A fan-in-fin anti-torque/yaw control system

Basic parameters of the aircraft are as follows:

Design Gross Weight	26,392 lbs
Compound Mission Gross Weight	26,392 lbs
Compound Mission Empty Weight	20,559 lbs
"Helicopter Simulation" Gross Weight	26,392 lbs
"Helicopter Simulation" Empty Weight	21,925 lbs
Hover Mission Gross Weight	20,276 lbs
Hover Mission Empty Weight	15,599 lbs
Design Limit Load Factor	4.0
Ultimate Load Factor	6.0
Main Rotor, Diameter	62 ft.
Number of Blades	5
Tip Speed, Hover	686 ft/sec
Rotor Engines	Two GE-T58-16
Cruise Engines	Two GE-TF-34-100



MAIN ROTOR	
DIAM.	62'
BLADES	5
CHORD	1.52
AIRFOIL	NACA 0012
TIP SWEEP	30°
TWIST	-3°

FAN DATA	
DIAM.	4'-8"
NO BLADES	7
A.F.	950

WING DATA	LARGE	SMALL
AREA	348	184
SPAN	45'-8"	33'-3"
AR	6	6
FLAP AREA	42.8	40
C_T	5'-6"	3'-10"
C_R	9'-3"	6'-5"
AIRFOIL	NACA 23015	
DIHEDRAL	3°	3°

The Aircraft Design (Cont'd)

Rotor engines mount forward of the transmission, above the fuselage. The anti-torque system uses the fan-in-fin concept presently being investigated by Sikorsky under a U.S. Army funded program. The auxiliary propulsion engines mount high on each side of the fuselage center section.

The wing structure is carried uninterrupted through the lower portion of the fuselage. The wing mounts on two hinges near the forward spar. Three hydraulic actuators near the aft wing spar provide for inflight variation of the wing incidence angle. The hinges include two-axis load cells to measure vertical and horizontal forces. Each actuator has a load cell in series with it. With this arrangement, the complete load path between the wing and the fuselage is carried through load cells.

Two wings have been designed for this aircraft. The large wing is sized to unload the rotor at speeds between 100 and 200 knots. The smaller wing is designed for the 300 knot compound mission. These wings are interchangeable, and they can be left off for lower speed testing as a conventional helicopter.

The load cell mounting system for the main gearbox measures rotor forces and moments. It consists of four vertical and three horizontal load cells. Like the wing system, these cover the complete load path between the force producing element and the fuselage. Load cells are also provided to measure thrust of the auxiliary propulsion engines and anti-torque system.

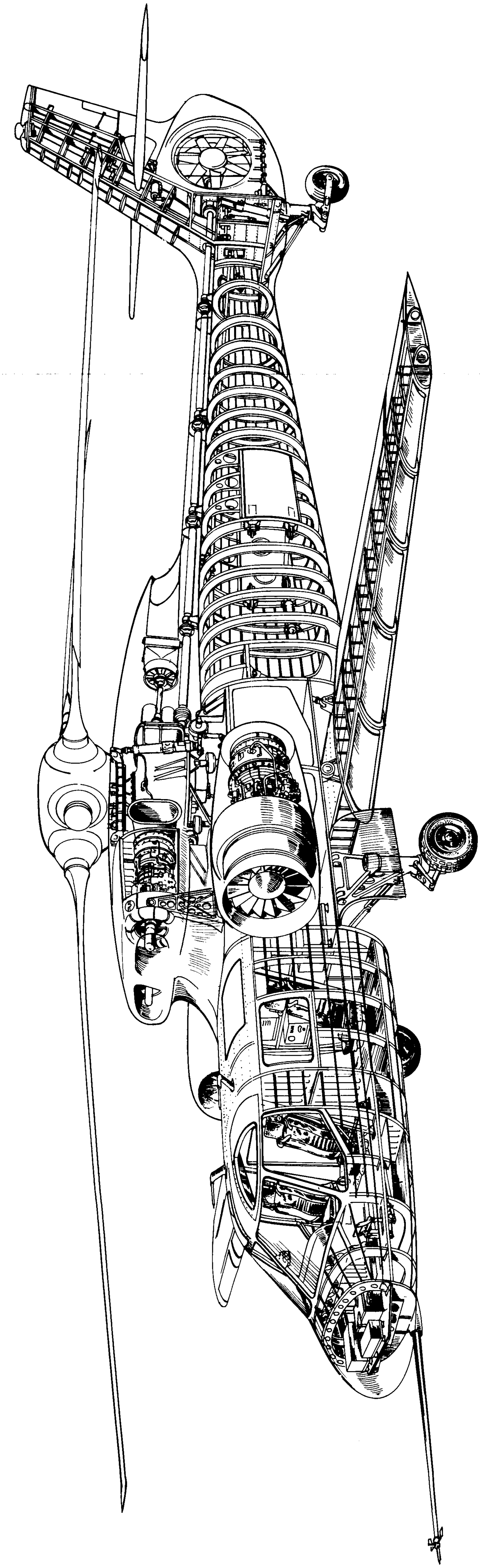
A generous cabin aft of the cockpit accommodates an optional third crewman and test instrumentation.

The drag brakes, at the forward end of the tailcone, can be deployed in flight to increase aircraft parasite drag when simulating other fuselages.

Ballast compartments are located under the cockpit and within the tailcone. High density ballast can be installed in these compartments to effectively control aircraft c.g. position for a variety of rotor configurations.

A full set of fixed wing control surfaces is provided. These include wing ailerons and high lift devices, full floating horizontal stabilator, and a vertical fin with a rudder. These surfaces and the rotor itself are controlled by a combined electrical/mechanical control system chosen for versatility and low risk.

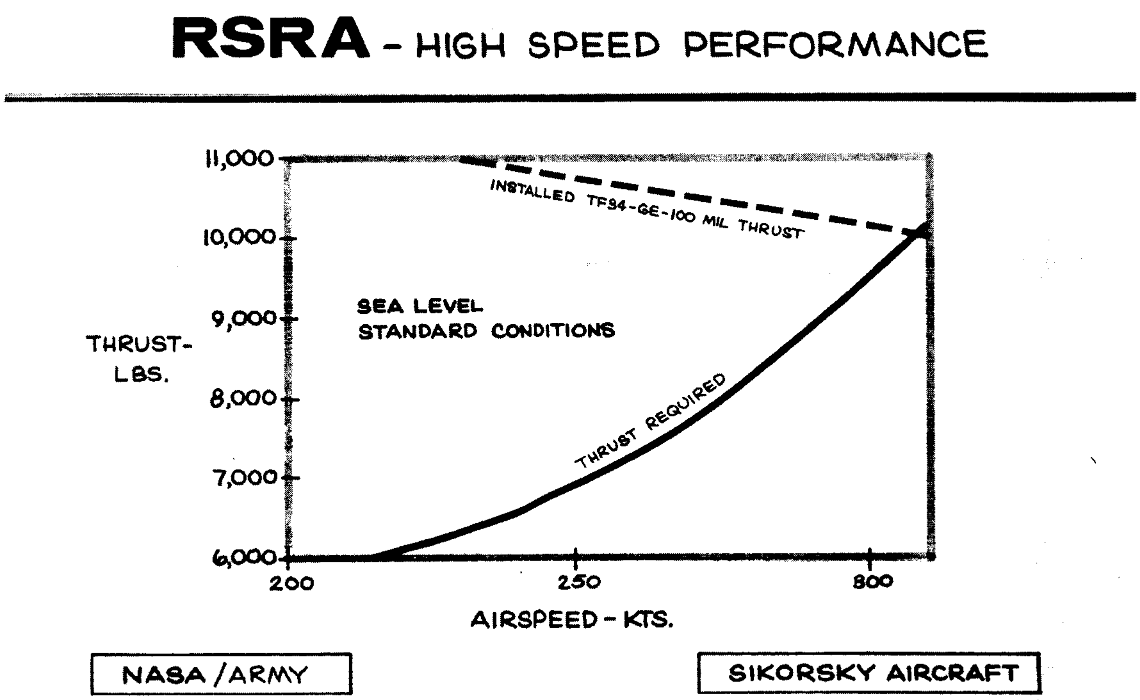
The RSRA aircraft also has a crew escape system. This system has a rotor blade severance system and canopy ejection, combined with a "YANKEE" crew escape package.



RSRA Performance

High Speed

The equivalent parasite area for the aircraft in the high speed configuration (which includes zero lift wing drag for the small wing) was calculated using government approved methods. This was found to be 23.6 square feet. With this equivalent area, high speed thrust requirements were determined. Thrust required includes basic aircraft fuselage drag, wing induced and parasite drag, and rotor induced drag and H forces. The high speed end of the thrust required curve is shown below with the TF34-GE-100 installed available thrust. At design gross weight, the aircraft can exceed the 300-knot RSRA speed requirement at both sea level standard and 9500-feet standard atmospheric conditions.



Hover

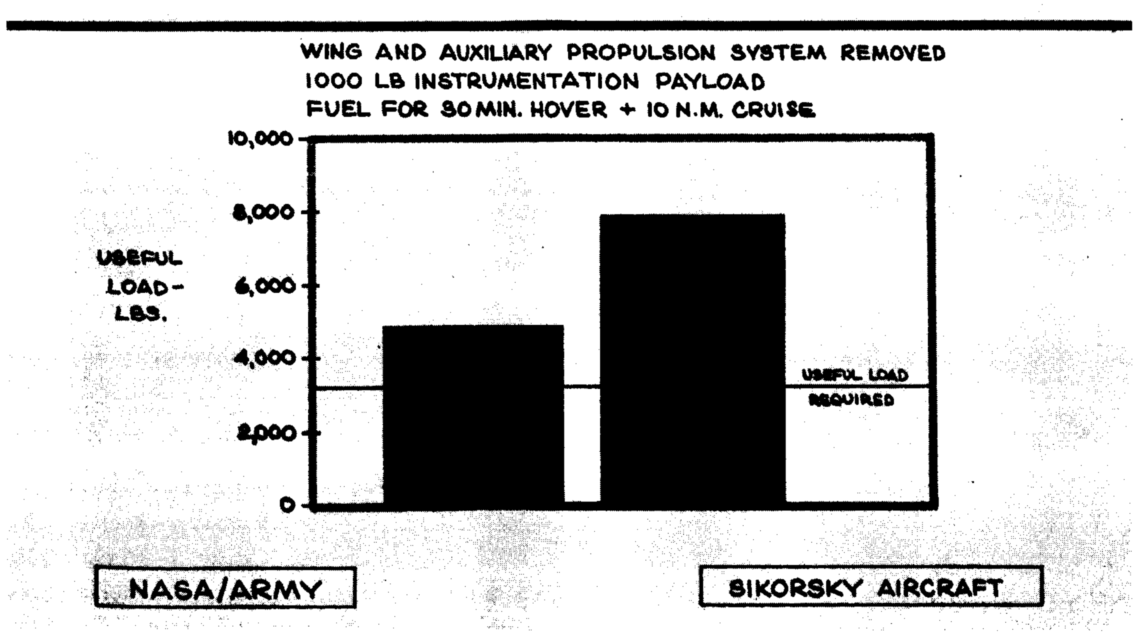
Aircraft hovering performance was calculated for compliance with the RSRA requirements.

In the figure below, useful load is the sum of the crew, trapped fluids, mission fuel, and payload weights. The wing and the auxiliary propulsion system have been removed to reduce aircraft empty weight. An instrumentation payload of 1000 pounds is assumed. Fuel, calculated on the basis of the design hovering mission, includes fuel for 32 minutes of hover, 10 nautical miles of cruising, and the required fuel reserves.

As shown, 3200 pounds of total useful load is required to perform this mission. At sea level, 95°F conditions, the aircraft can lift 4850 pounds of useful load. At sea level standard conditions, the aircraft can lift almost 8000 pounds of useful load.

The margins between what the aircraft can do and the basic RSRA requirements illustrate the fact that this aircraft has sufficient installed power to hover other rotors that may have higher disc loadings or not be as efficient as the baseline (S-67) rotor. These rotors can be installed on the aircraft and still have excellent hover endurance times.

RSRA - HOVER PERFORMANCE



RSRA Helicopter Simulation

One primary function of the RSRA is to test helicopter rotor systems in the speed range of 100 to 200 knots. It is desired that the aircraft be capable of reacting large ranges of vertical and horizontal rotor forces so that complete rotor performance maps can be generated for the rotors under test. The large wing has been sized to support full aircraft gross weight at speeds as low as 120 knots, so that rotor operation can be investigated at zero lift conditions. The drag devices have been added so that operation at high horizontal propulsion forces can be investigated. With auxiliary propulsion engines, rotor performance can be investigated during autorotation.

The figures on the opposite page illustrate the capability of the aircraft to react rotor forces in the 100 to 200 knot speed range. The maximum vertical load the airframe can put on the rotor is the sum of aircraft weight plus maximum negative lift that can be generated by the wing. At 100 knots, this amounts to 37,000 pounds. Maximum negative lift increases as wing download increases with speed. This is more than sufficient for any rotor considered for testing on the RSRA.

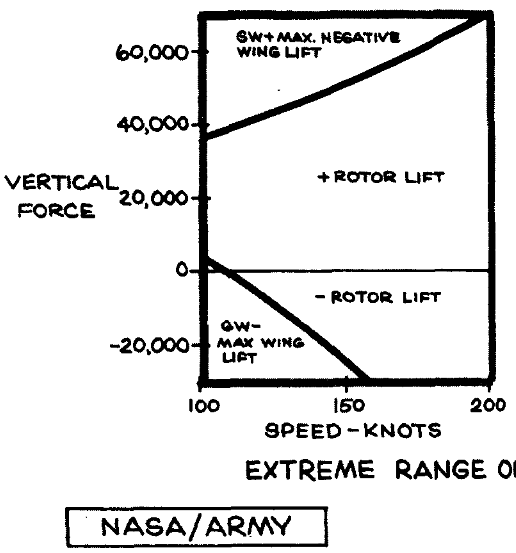
At the other end of the vertical force spectrum, the minimum vertical load (or maximum negative load) that the airframe can put on the rotor is determined by aircraft weight minus maximum lift of the wing. The wing can fully unload the rotor down to almost 100 knots. With a reasonable stall margin, full unloading down to 120 knots is still practicable. Above 100 knots, the wing theoretically can put the rotor into a negative lift condition, although steady state operation and testing in this regime would be of questionable value.

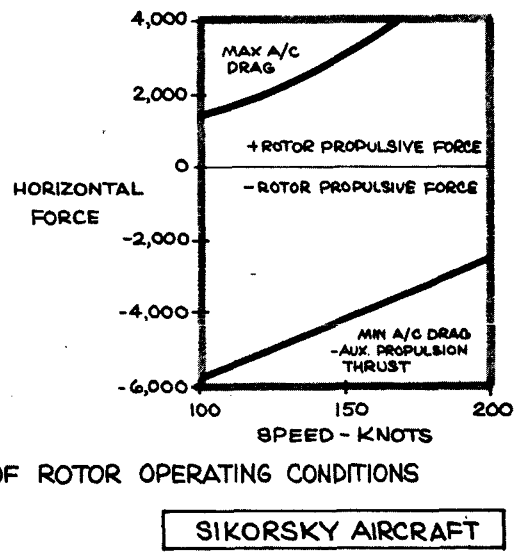
Maximum horizontal rotor propulsive force is reacted by the airframe in its high drag configuration (with drag brakes fully deployed). This will provide over 1300 pounds of reactive force at 100 knots. Higher values are achievable at higher speeds as parasite drag increases.

Minimum rotor propulsive force for testing rotors in autorotation is determined by the minimum aircraft drag minus the propulsive force capability of the auxiliary propulsion engines. Minimum aircraft drag is achieved by not deploying the drag brakes. This capability to react minimum rotor propulsive force varies with speed as the aircraft parasite drag increases and the thrust of the engines decreases with increasing speed.

This analysis illustrates how the RSRA airframe can generate a complete range of reactive forces for testing rotors over a large operating spectrum. Rotors can be tested from close to zero rotor lift to their stall limit, and from maximum propulsive force to full autorotation.

RSRA-"HELICOPTER SIMULATION" PERFORMANCE





EXTREME RANGE OF ROTOR OPERATING CONDITIONS

Modifications to Accommodate Other Rotors

The aircraft modifications required to accommodate certain types of test rotors are listed opposite. The analysis considers drive system modifications, engine modifications, control system modifications, and whether an RPM variation of greater than 30 percent is required.

All single rotor, shaft-driven concepts can use the same main gearbox and engine installation. The rigid counterrotating coaxial rotor would require a new gearbox, but can use the same engine installation if the gearbox were designed to be compatible with it. The non-shaft driven jet flap rotor would require a new engine installation, with the shaft engines being replaced by gas generators. The mechanical drive system would not be needed, but a structure would have to be designed to support the rotor and provide for the required gas flow.

All the concepts will require some modification of the rotor control system. The variable geometry rotor requires modifications to the rotating swashplate to provide variable blade azimuth position, and various length push-rods to provide variable vertical positioning of the upper rotor hub. The rigid coaxial requires major modifications of the control system to provide control for two rotors. The variable diameter rotor, variable twist rotor, and slowed rotor all can use the baseline system with minor modifications. With the variable diameter rotor, a separate control must be provided for the rotor diameter. For the variable twist rotor, separate control of twist is required; this may include a second swashplate assembly or other similar device. The jet flap rotor will require a completely new control system, the details of which will depend upon the specific control concepts being considered.

The final item on the chart considers whether an RPM variation of over 30 percent is required in the operation of the rotors being considered. If such an RPM variation is required, some type of active vibration suppression system will be needed to avoid airframe resonant frequencies.

ADAPTABILITY TO NEW ROTORS

ROTOR CONFIGURATION	AIRCRAFT MODIFICATIONS REQUIRED: NEW MAIN GEARBOX	NEW ENGINE INSTALLATION	CONTROL SYSTEM MODIFICATION	RPM VARIATION GREATER THAN 20%
VARIABLE GEOMETRY ROTOR	NO	NO	MINOR	NO
RIGID COUNTERROTATING COAXIAL ROTOR	YES	NO	MAJOR	NO
VARIABLE DIAMETER ROTOR	NO	NO	MINOR	NO
JET FLAP ROTOR	YES	YES	MAJOR	NO
VARIABLE TWIST ROTOR	NO	NO	MINOR	NO
SLOWED ROTOR	NO	NO	MINOR	YES

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Program Risk Assessment

A primary goal during the predesign study was to assess the RSRA program risk. This is important because the RSRA does include various new and unique features not normally included in conventional rotary wing aircraft. To do this, the unusual features of the final RSRA configuration were identified and a risk assessment performed on each one. Five specific areas were investigated:

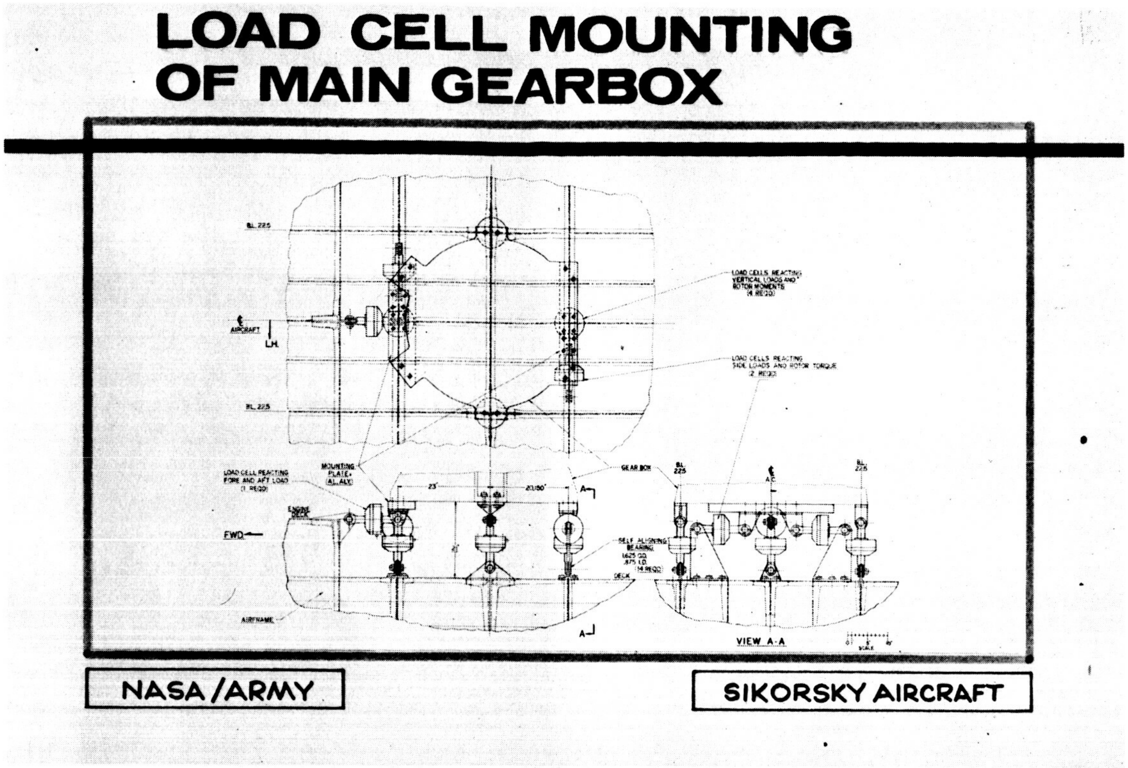
- The load cell mounting of the main gearbox
- Rotor/Airframe Dynamic compatibility when many different rotors are installed on one airframe
- The basic flight control system
- The need for, and feasibility of, a rotor feedback control system
- The crew escape system

Although all of these areas involve development, it is concluded that none has sufficiently high risk to warrant postponement of the RSRA aircraft development program. Based upon past experience and present knowledge, each can be incorporated into the RSRA without unduly adding to the program risk.

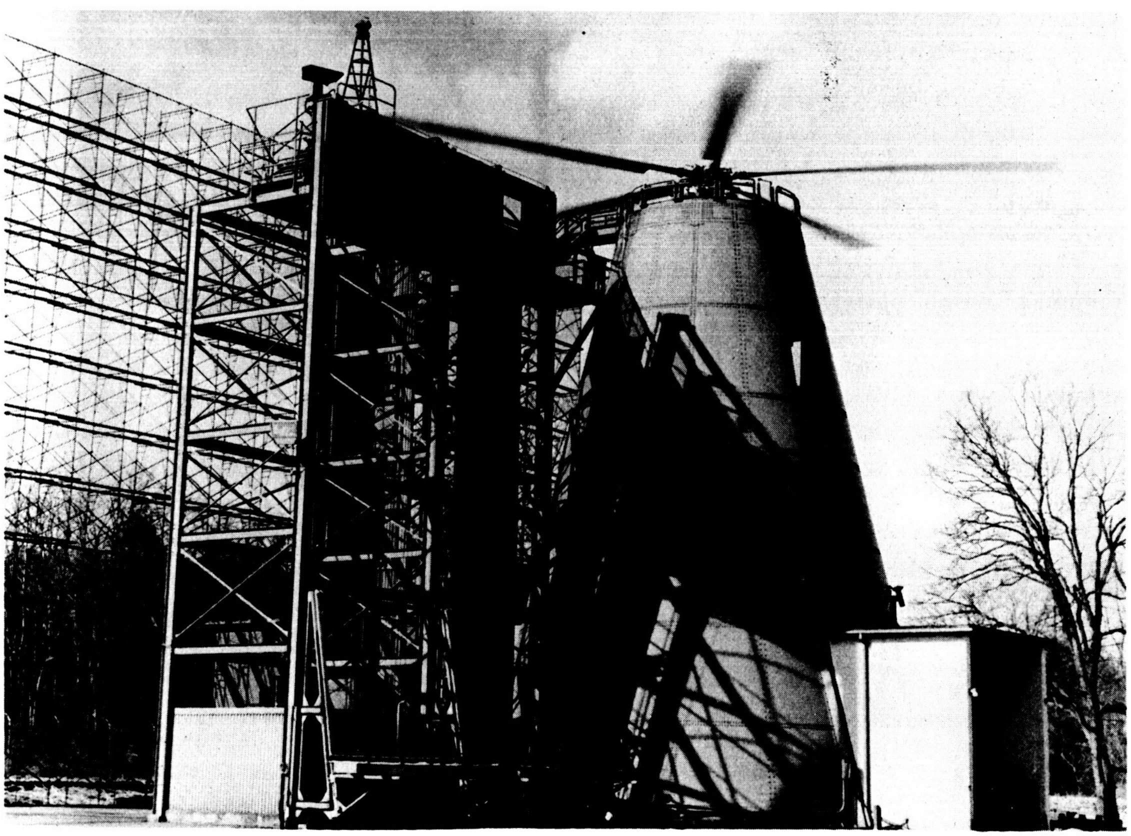
Load Cell Mounting of the Main Gearbox

The rotor load cell force measuring system uses four vertical and three horizontal load cells to measure all rotor forces and moments. These cover all load paths between the gearbox and the airframe, so that all loads can be measured. The load cells are mounted through spherical bearings so that only axial loads will be transferred through each load cell. The units selected are commercially available, and are designed to operate in fatigue applications. They can withstand more than 10^8 fully reversed cycles without failure.

Although RSRA will probably be the first aircraft to mount the complete rotor transmission system on load cells, this is not because of any technical problems or risks associated with the concept. RSRA is the first aircraft that is specifically being designed to measure forces and moments in flight to the high accuracy levels that require this type of hardware. Sikorsky has long used similar load cell rotor force and moment measuring systems on ground test stands. The Sikorsky main rotor Whirlstand can test rotors with over 100,000 pounds of lift. It has been in operation for over fifteen years, using load cells to measure rotor thrust, horizontal force, and torque.



Sikorsky Main Rotor Whirlstand



Rotor/Airframe Dynamic Compatibility

Six advanced rotor systems were considered as representative of the types of rotors which might be tested on the RSRA. These were in addition to conventional helicopter and compound rotors, and included a six-bladed variable geometry rotor, the variable diameter rotor, rigid coaxial, jet flap, variable twist, and slowed rotors. Considering the large variations possible in blade number, radius, and tip speed, they cover a wide band of principle blade passage frequencies. It would be impossible to design an airframe so that all modes of vibration will never be resonant with all possible vibratory excitation frequencies from these rotors.

It is possible to dynamically tune the airframe to accept three, four, five, and six bladed rotors if their RPM bands are within reasonable limits. This will permit testing of these rotors without the use of either active or passive vibration suppression systems. Other rotors, such as two bladed rotors, slowed rotors which operate over a wide band of rotational speeds, and rotors with unusual RPM operations, will require some type of vibration suppression system.

Because the airframe can be dynamically tuned, it is suggested that the RSRA be developed without an isolation system. If a full universal capability is indeed required, an active vibration system could be developed as a parallel effort. During the predesign study a full active system has been conceptually designed which will accept all types of rotors operating over an extensive RPM range. This system would replace the main gearbox to airframe load cell mounting hardware and can be used to also serve as a rotor force and moment measuring system.

Airframe Dynamic Tuning - Consider the five-bladed compound rotor operating at forward speeds up to 300 knots, the six-bladed variable geometry rotor, and the four-bladed variable diameter rotor. These can be accomodated on the RSRA without the need for vibration suppression devices through structural tuning of the airframe. This will also permit the testing of other three, four, five, or six bladed rotors operating at similar rotational speeds.

Two tuned airframe configurations are recommended. The first will accomodate the compound and variable diameter rotors. The second will accommodate the variable geometry rotor. To tune the airframe, the transmission pitch, transmission roll, second lateral, and second vertical bending modes must be controlled. Experience indicates that these modes are uncoupled, and their locations are controlled by the stiffness of different portions of the airframe. The transmission pitch mode is controlled by the stiffness of the top of transmission support frames. The transmission roll mode is controlled by the stiffness of the sides of these frames. The second lateral and second vertical bending modes are controlled by the lateral and vertical bending stiffness of the aft fuselage and tail cone, respectively. The basic vehicle will be designed to locate the modes at the lower of the two required positions. The frequencies of these modes can then be increased as required through the addition of material.

The feasibility of shifting the location of fuselage modes has been demonstrated during full-scale ground tests at Sikorsky Aircraft. In addition, three-, five-, and six-bladed rotors have been successfully flight tested on a single aircraft, the S-61F (NH-3A) high speed research aircraft.

Active Transmission Isolation - Airframe tuning provides the capability of testing the compound rotor, variable diameter rotor, variable geometry rotor, and any other rotor system whose primary excitation frequencies fall within the bands produced by these rotors. Tuning for other rotor systems whose frequencies fall beyond these bands, particularly slowed rotors, can be expedited through use of a variable tuning device.

Active transmission isolation can provide full wide band tuning for RSRA. Static and transient displacements are actively controlled. Spring rates can be made as low as required to provide wide band isolation. The proposed configuration of the Sikorsky active rotor balance vibration suppression system uses seven self-contained hydropneumatic actuators (isolators) to decouple the pitch and roll modes and thus provide independent focusing of the isolation system. Circular tracks are provided so that focusing can be varied easily. This variation can be accomplished independently in pitch and roll.

Analyses have substantiated the ability of this system to isolate the airframe from all rotor forces and moments simultaneously while providing accurate measurement of principal rotor forces.

Basic technology required for development of the active rotor balance/ vibration suppression system has been demonstrated. Full-scale laboratory experiment of the hardware acting also as a rotor balance is scheduled.

A full-scale active transmission isolation system has been fabricated and ground tested under contract to the U.S. Army. It has the ability to provide an overall 70% reduction in vibration to vertical and inplane forces at the particular blade passage frequency of interest. Of greatest significance to RSRA is the wide band characteristic achieveable with this system.

The feasibility of using active isolator units as load sensing devices was also demonstrated successfully during a recent NASA-supported effort. The accuracy of measuring steady loads was found to be within a band of ±1 percent of applied load about a linear bias that can be removed through calibration.

Calibration of the total system as a rotor balance will take place later this year under a NASA/Army-supported program that is currently under way. The system, which contains three active hydropneumatic units, will be instrumented and installed on a CH-53A aircraft. Instrumentation will include hydraulic pressure transducers, inplane drag strut load cells, and transmission-mounted accelerometers required for transient and vibratory measurement.

The Basic Flight Control Systems

A combination electrical and mechanical flight control system has been selected for RSRA to provide testing versatility with low cost and risk. The test pilot's controls are electrical and are separated from the safety pilot's mechanical controls. With this system the test pilot's controls can be shaped and varied as required, yet the safety pilot has a completely mechanical system which can override pilot's system. The safety pilot is therefore responsible for monitoring aircraft status and returning the aircraft to normal flight from any test condition.

This type of control system for RSRA is a relatively low risk approach that has counterparts in several current experimental and production aircraft. The major programs that use an electrical/mechanical system are the Cornell TIFS, CH-54B, and NASA V107.

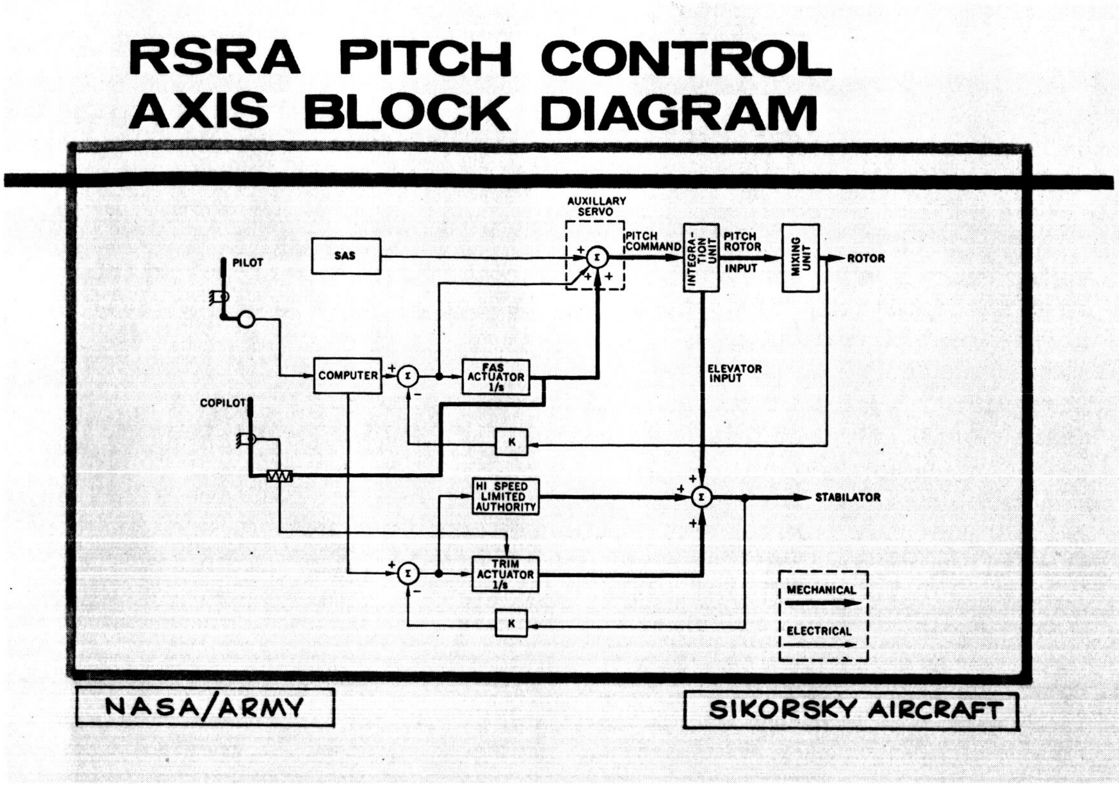
The two types of electrical control systems currently employed are the mechanical following system and the mechanical reversion system. The primary advantage of the mechanical following system, such as that in the RSRA, is its set of mechanical controls, which are linked to the control surface at all times. The U.S. Army/Sikorsky CH-54 has an electric stick at the rear-facing seat configured in much the same fashion.

Many of the control system components of the RSRA already exist on other Sikorsky helicopters and are adapted to the RSRA. The development risk for the remaining components is low due to the conventional design. The primary servos, auxilliary servo, and mixing unit of the RSRA are the Sikorsky S-61/S-67 components. They are installed in the Navy SH-3, the Air Force CH-3, the commercial S-61L and N, and the S-67 Blackhawk. No additional development is required to adapt these components to the RSRA. The mixing unit will have to be modified to allow control of rotors with different control phasing, but the technology exists and is well developed.

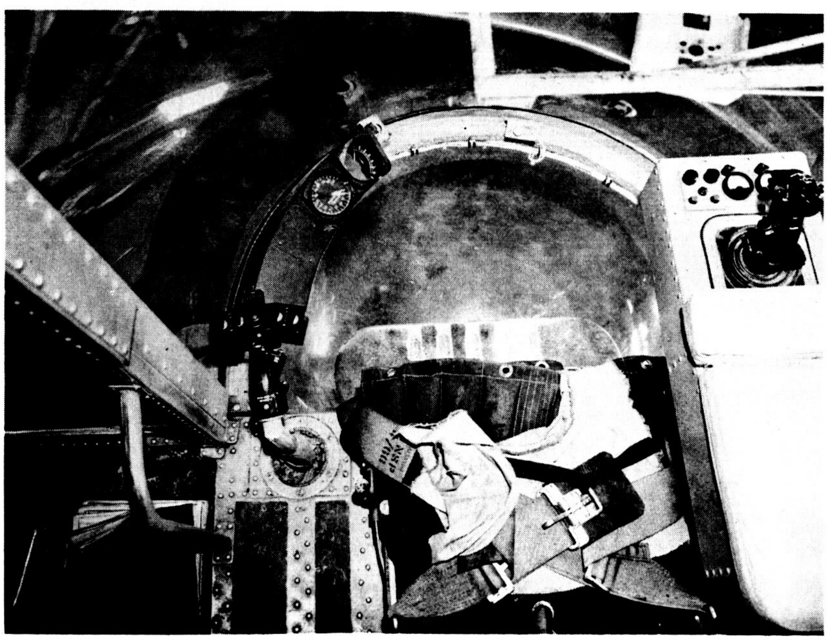
RSRA uses control integration units of new design. Success in building similar units for the XC-142, F-111 and other variable geometry aircraft makes the development of these units a low technical risk.

The control surface actuators are similar in concept to the actuators currently in use on many aircraft of variable types. They consist of a high speed, limited authority series servo and two low speed, full authority, series servos. The high speed servo is similar to the SAS input of the auxilliary servo and the low speed servo is similar to the trim actuator of the H-53 and H-54B. The development of these actuators is therefore low risk.

A prototype FAS (Force Augmentation System) system has been developed and flown on the CH-53 and S-67 Blackhawk. A production version will be developed for the RSRA. This development will involve only a repackaging effort and will be a low risk effort.



CH-54 Rear Facing Seat Controls



Rotor Feedback Control System

Rotor feedback control is not required for the RSRA to perform its basic research function. It would, however, add to the testing capability of the aircraft because it could provide:

- An automatic trim feature to expedite testing at a predetermined loading condition, independent of the normal trim characteristics of the test aircraft.
- The ability to dynamically simulate the fuselage/ wing characteristics associated with the rotor design being tested.
- A flexible system that can provide any of the test rotors with the ability to test various control and feedback schemes. Some of these that might be desired for the next generation high speed helicopter include gust alleviation, adaptive control configurations, and modal suppression.

State feedback to accomplish model-following is not new in terms of helicopter technology. Several helicopters are currently being used as variable stability systems. Rotor feedback has not been done as extensively, and Sikorsky currently has a NASA/Army contract to begin to investigate this area.

The objective of this separate rotor/vehicle state feedback contract is to:

(1) Establish, using a CH-53, the feasible bandwidth of rotor state control by means of high gain feedback of several possible rotor and vehicle state variables.

(2) Quantify on the CH-53 the gust suppression capabilities of various possible rotor and vehicle state feedback loops.

The first portion of the study will be analytic, with the computer techniques and the system stability being investigated using both linear and nonlinear dynamic programs. The second part of the study involves flight testing. Feedback will be introduced into the helicopter control system through the existing limited authority AFCS. An airborne computer will be used to condition and shape the feedback information before it is routed to the AFCS servos.

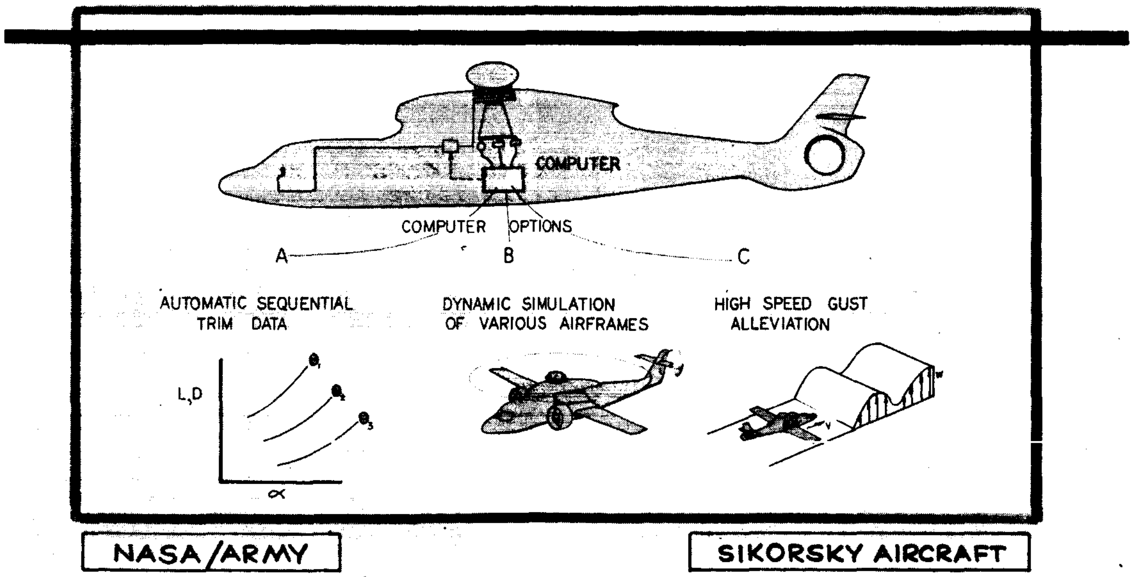
The question of concern in regard to rotor feedback is one of degree of tracking accuracy required rather than one of whether or not the job can be accomplished. This test program will help to answer these questions.

The RSRA will algebraically resolve rotor load cell data into the six rotor forces and moments. These force and moment signals can be fed back into the control system to provide automatic control inputs to trim the rotor or to actuate the vehicle fixed wing controls.

The predesign study has shown that good response characteristics can be obtained with the proposed aircraft and control system. Analytic studies performed on a PDP-10 hybrid computer with the full RSRA aircraft characteristics have shown that tight response can be obtained for a standard articulated rotor. The hybrid analysis has a rotor blade element solution and uses fuselage aerodynamic data extrapolated from previous compound helicopter wind tunnel data. The full control shaping and feedback network has been programmed on the hybrid in order to fully assess the stability situation. The tight response available from the system can be achieved with practical gains and will operate within nominal authority limits.

To summarize, rotor feedback control is not required for the RSRA but it would add to its testing versatility. With the preliminary results from the predesign study, and after the separately contracted flight tests of a similar system are completed, it should be possible to include a feedback capability in the RSRA without undue risk.

FEEDBACK CAN MEAN BETTER DATA FOR RSRA AND CAN IMPROVE THE TESTING RANGE



Crew Escape System

The RSRA uses a crew escape system which combines rotor blade severance, canopy separation, and upward crew extraction. It is not considered to be a high risk area since it is the combination of well proven fixed wing type crew escape systems with the Sikorsky demonstrated rotor blade severance system.

Since early in 1970, Sikorsky has been actively involved in a program to develop a reliable aircrew escape system for helicopters. The upward extraction was desired to provide operation near the ground and to avoid the design complexity of a downward extraction system. Upward extraction requires removal of the main rotor blades prior to crew extraction, and this can be accomplished by using linear shaped charges around the blade spar. However, two major factors constrained further development of such a system: how to reliably propagate the initiating signal onto the rotating rotor, and how to protect any adjacent aircraft from randomly scattered rotor blades.

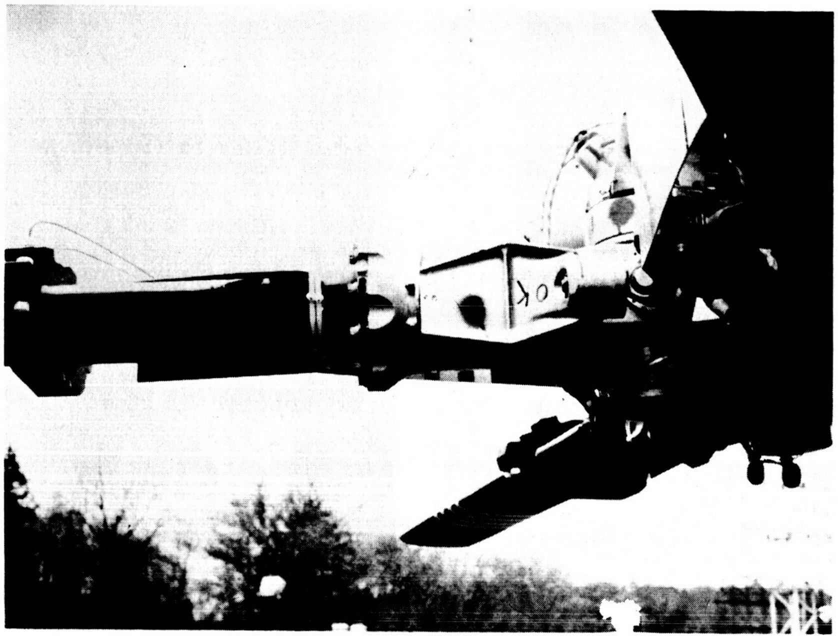
The solution to these difficulties has been achieved through the highly successful demonstration of main rotor blade shedding using the sequential main rotor blade severing system. Two demonstrations in December 1971 used a tied-down SH-3 test vehicle. The main rotor blades were sequentially separated in a predetermined direction, three forward and two aft along the longitudinal axis of the vehicle with the main rotor head turning at 203 rpm.

A photo taken from a hand-held camera caught all five blades in flight. The three blade stubs forward hit the road 80 feet ahead of the vehicle within a 5-foot circle. The key to precision of this system is the versatility of the blade sequencing device. It permits any number of blades to be separated singly or in any combination, in any direction. When applied to the RSRA vehicle, this will allow the option of simultaneous separation of all blades at once, or sequentially and laterally as proposed for an optional two-stage escape system approach in which the pilot sheds blades only to continue flight as a fixed wing.

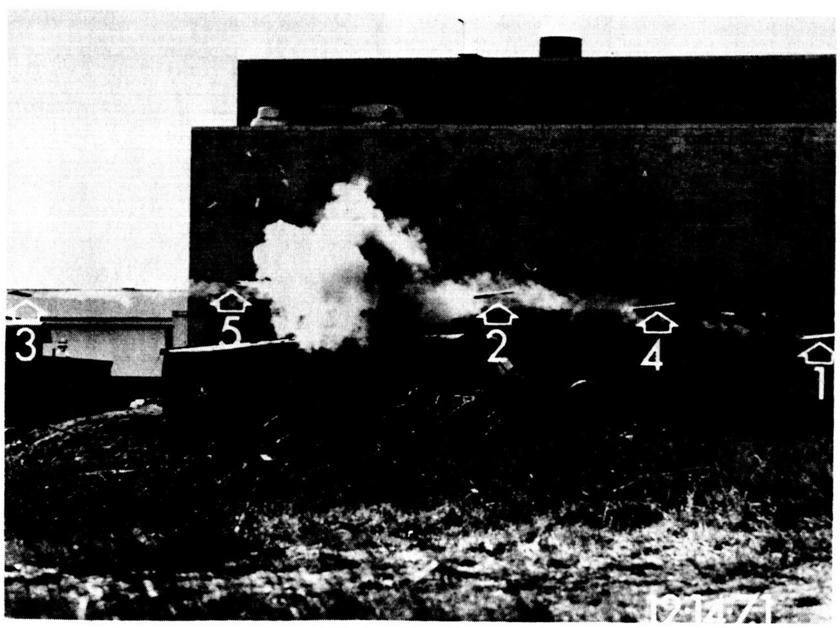
The only modification required to adopt this system to any new rotor is the addition of the linear shaped charges clamped around the blade spar, and provisions for the detonating chord.

The blade shedding system is a fully independent system, having no connection with the aircraft's electrical or hydraulic systems. It propagates initiation from the cockpit to the rotor blades through SMDC (Shielded Mild Detonating Chord) with a chemical deflagration rate of approximately 20,000 feet per second. This pyrotechnic system was selected in order to achieve maximum reliability. It is impervious to RF, lightning, and stray voltage. Even gunfire tests with high explosive 20 mm rounds will not cause premature initiation. Deflagration is begun by pilot or copilot activation of percussion primers in the D-rings in the cockpit. Initiation continues through to a sequencing device at the main gearbox, is transferred to the main rotor shaft, and travels out to linear-shaped charges on the rotor blades.

Blade Severance Hardware



Blade Stubs Being Shed



Conclusions

The following conclusions were drawn from this Predesign Study:

I. The concept of developing a single aircraft to test many different advanced rotor systems is sound. It is possible to design the aircraft to accept these rotors with reasonable modifications to the basic vehicle.

II. Because RSRA is a single vehicle designed specifically as a rotor test aircraft, testing versatility is maximized. RSRA includes:

- An accurate system to measure rotor forces and moments in flight
- Auxiliary devices to offload and overload the rotor in both the horizontal and vertical direction for testing at extreme rotor operating conditions
- Complete fixed wing capability and a crew escape system for increased safety during tests of new and unproven rotor systems
- A 300 knot speed capability for testing rotors in high speed flight
- A combination electrical/mechanical control system to provide maximum testing versatility at minimum program risk and cost.

These features give the RSRA a capability substantially beyond that achievable with any existing rotary wing test aircraft. To try to incorporate these features into an existing airframe requires modifications so extensive as to not be cost effective.

III. The most capable RSRA vehicle, to provide maximum testing versatility at minimum cost, combines existing dynamic components and an all new airframe. The use of existing dynamic components frees the program from the need to develop what is historically the most complex part of a rotary wing vehicle. The use of a new airframe is required to provide those features considered necessary for testing versatility. A 26,392 pound gross weight aircraft meets the design goals and includes:

- A 3700 horsepower main gearbox and Sikorsky S-67 rotor system.
- A fan anti-torque system buried within the vertical tail.
- An airframe designed for a 360 knot dive speed, a design limit load factor of 4.0, and side-by-side cockpit seating.
- Separate rotor and auxiliary propulsion systems, with the capability to remove the auxiliary propulsion system for hover tests
- Load cell mounting of the rotor system, wing, auxiliary propulsion system, and anti-torque system for accurate inflight measurement of forces and moments.
- Two wings; a large wing for unloading the rotor at low speeds and a smaller wing for high speed testing of compound rotors.
- A ballast system and drag device to simulate unusual rotor operating conditicns.

IV. RSRA is a technically feasible concept that can be designed and developed with present day technology. No new subsystems need be developed before development of the aircraft is initiated.

- The dynamic components include an existing rotor head, and a gearbox and anti-torque fan which are presently undergoing separate U.S. Army funded development programs.
- The airframe is of conventional design and constructed of conventional materials.
- The load cell instrumentation system is similar to that used for many years in rotor test stands and is within the state-of-the-art.
- Active vibration suppression is not a requirement for RSRA. If it is desired for testing of unusual rotor concepts, such as the slowed rotor, it can be developed in parallel to the basic aircraft.
- The electrical/mechanical control system provides the versatility desired with a system which is similar to that now flying on the NASA V-107 and the U.S. Army CH-54.
- Rotor feedback control is not a requirement for the RSRA to perform its test mission. It would be desirable to extend the aircraft test capability and should be ready for incorporation into the RSRA at the conclusion of a presently funded program.
- RSRA crew safety is improved by a system which combines conventional canopy and crew extraction systems with a Sikorsky demonstrated rotor blade severance system. All components of the system have been demonstrated; they now only need integration.

V. RSRA will be an important research aircraft for both government and industry.

- It will test the hovering performance of many advanced rotors with differing aerodynamic characteristics and disc loadings.
- It will perform as a "flying wind tunnel", measuring rotor performance over the full range of lifting capability and speed during actual flight conditions.
- It will test rotors to 300 knot speeds with excellent endurance and instrumentation payload capabilities.
- It will continue to advance the technical leadership of the United States in the rotary wing field. The basic aircraft itself will have capabilities beyond those of present vehicles. In addition, RSRA will ease the development of advanced rotor systems, reducing their development time.