

NEARING THE STRATOSPHERE\*  
BY  
D. W. TOMLINSON  
TRANSCONTINENTAL & WESTERN AIR, Inc.

THERE HAS BEEN A GREAT DEAL OF THOUGHT AND STUDY GIVEN TO THE PROBLEM OF HIGH ALTITUDE FLYING. ALONG WITH THE CONSCIENTIOUS EFFORTS OF COMPETENT SCIENTISTS, IMAGINATIVE SOULS HAVE TRANSFERRED THEIR FONDEST DREAMS TO THE STRATOSPHERE AS SORT OF AN AVIATION MILLENNIUM. THESE FANTASIES HAVE MISLED THE LAY PUBLIC UNTIL THE AVERAGE MAN ON THE STREET EXPECTS NEXT YEAR, OR THE YEAR AFTER, TO TRAVEL IN THE STRATOSPHERE AROUND THE WORLD AT 1,000 MILES AN HOUR. THE RESEARCH FLYING CARRIED ON BY TWA HAS BARELY ENTERED A WEDGE INTO AN UNKNOWN REALM, HOWEVER, SUFFICIENT FACTUAL DATA AND POSITIVE EXPERIENCE HAVE BEEN OBTAINED TO CARRY THIS WORK FURTHER WITH A SOUND CONCEPT OF THE ECONOMIC POSSIBILITIES AND TECHNICAL PROBLEMS INVOLVED.

WHEN TWA, IN THE FALL OF 1934, DECIDED TO LOOK INTO THE FUTURE OF HIGH ALTITUDE FLYING, THE PRINCIPAL OBJECTIVES WERE: (1) TO CHOOSE THE BEST METHOD OF SUPERCHARGING TO 20,000 FEET AND ABOVE, AND EQUIP AN ENGINE FOR RATED POWER OPERATION AT 30,000 FEET; (2) DETERMINE THE ACTUAL INCREASE OF SPEED WITH ALTITUDE AS A CHECK AGAINST THEORY; (3) MAKE ACTUAL MEASUREMENTS OF SPEED AT 30,000 FEET TO FURTHER CHECK COMPUTED TRUE AIR SPEEDS; (4) MAKE EXTENDED CROSS COUNTRY FLIGHTS "OVER WEATHER" TO DETERMINE FORCE AND DIRECTION OF WINDS AND METEOROLOGICAL CONDITIONS AT THE BASE OF THE STRATOSPHERE. OBJECTIVES 1, 2 AND 3 HAVE BEEN ACCOMPLISHED; ENOUGH EXPERIENCE HAS BEEN HAD IN THE COURSE OF "OVER WEATHER" FLIGHTS TO SHOW HOW LITTLE IS KNOWN ABOUT CONDITIONS AT HIGH LEVELS ABOUT STORM CONDITIONS BUT OF THIS, MORE LATER.

CHOICE OF A SUPERCHARGING METHOD LAY BETWEEN THE GEAR DRIVEN IMPELLER AND THE EXHAUST TURBINE AS THE MOTIVE POWER FOR THE IMPELLER. ASIDE FROM THE FLYING DONE BY WILEY POST WITH THE "WINNIE MAE", WHICH HAD A WASP ENGINE EQUIPPED WITH A GEAR DRIVEN SUPERCHARGER, NO OTHER HIGH ALTITUDE FLYING OF ANY DURATION HAD BEEN ACCOMPLISHED IN THE COUNTRY WITH THIS TYPE OF SUPERCHARGER. UNFORTUNATELY, THERE WAS NO DATA RECORDED BY WILEY POST WHICH WOULD PERMIT AN ANALYTIC EVALUATION OF THE POWER PLANT OPERATION. ON THE OTHER HAND, THE U. S. ARMY AIR CORPS HAD BEEN CARRYING ON THE EXHAUST TURBINE SUPERCHARGER DEVELOPMENT ALMOST SINCE THE WAR. NUMEROUS HIGH ALTITUDE FLIGHTS HAD BEEN MADE ABOVE 30,000 FEET AND THE DEVELOPMENT OF THE TURBINE UNIT HAD REACHED A POINT WHERE THE ARMY HAD PLACED AN ORDER FOR SERVICE AIRPLANES HAVING ENGINES EQUIPPED WITH EXHAUST DRIVEN TURBINE SUPERCHARGERS.

THEORETICALLY AND PRACTICALLY, THE EXHAUST TURBINE SUPERCHARGER OFFERS ADVANTAGES OVER THE GEAR DRIVEN TYPE. WHEREAS THE GEAR DRIVEN SUPERCHARGER REACHES MAXIMUM EFFICIENCY AT ONLY ONE CRUISING ALTITUDE THE FLEXIBILITY OF THE TURBINE SUPERCHARGER ENABLES A PILOT FLYING ABOVE THE CRITICAL CRUISING ALTITUDE OF THE UNSUPERCHARGED ENGINE AT FULL THROTTLE TO UTILIZE THE TURBINE SUPERCHARGER AS DESIRED, ALWAYS CRUISING AT FULL ENGINE THROTTLE. IN THIS CASE THE ENGINE POWER DIVERTED TO SUPERCHARGING IS LIMITED TO THAT ACTUALLY REQUIRED ABOVE THE ENERGY RECAPTURED FROM THE EXHAUST GAS. THE PRINCIPLE DISADVANTAGES OF THE GEARED SUPERCHARGER ARE THE LOW POWER AVAILABLE FOR TAKEOFF AT SEA LEVEL AND THE EVER PRESENT FRICTIONAL LOSSES IN THE MECHANICAL GEARING REGARDLESS OF THE REQUIRED DEGREE OF SUPERCHARGING.

STRATOSPHERE TESTS WERE MADE POSSIBLE THROUGH THE COLLABORATION OF THE UNITED STATES ARMY AIR CORPS AND THE GENERAL ELECTRIC COMPANY.

THE FIRST TURBINE UNIT WAS RECEIVED BY TWA EARLY IN 1936, AND INSTALLED IN A NORTHROP GAMMA AIRPLANE POWERED WITH A SPECIAL DIRECT DRIVE CYCLONE "H" ENGINE. A THREE-BLADED HAMILTON STANDARD CONSTANT SPEED PROPELLER WAS USED. THE USUAL INSTALLATION AND MECHANICAL DIFFICULTIES OF ANY NEW PROJECT PROLONGED THE TEST PERIOD WHICH CONTINUED UNTIL THE STRATOSPHERE FLIGHT FROM KANSAS CITY TO NEW YORK ON JANUARY 24, 1937, AFTER WHICH THE TURBINE SUPERCHARGER WAS TEMPORARILY REMOVED TO MAKE THE NORTHROP GAMMA AVAILABLE FOR OTHER ENGINE TESTS.

SIGNIFICANT PHASES AND RESULTS OF THE TEST PROGRAM FOLLOW:

#### OXYGEN SYSTEM

THE OXYGEN EQUIPMENT CONSISTED OF A FIFTEEN LITER LIQUID OXYGEN BOTTLE AND TWO LIGHT-WEIGHT GASEOUS OXYGEN BOTTLES OF 39 CU. FT. CAPACITY EACH. THE LIQUID OXYGEN CONTAINER WAS LOCATED IN THE OBSERVER'S COCKPIT WITH A HOT AIR BLAST DIRECTED AGAINST THE EVAPORATING COILS. THIS HOT AIR, ALSO THE COCKPIT HEAT, CAME FROM THE INTENSIFIER TUBES IN THE EXHAUST MANIFOLD FORMERLY USED FOR CARBURETOR HEAT, NOW UNNECESSARY BECAUSE OF THE TURBINE SUPERCHARGER. COLD OXYGEN GAS FROM THE EVAPORATOR COULD EITHER BE ROUTED THROUGH AN OXYGEN HEATING COIL LOCATED IN THE HOT AIR DISCHARGE FROM THE INTENSIFIER TUBES, OR BYPASSED DIRECTLY TO THE CREW. IN PRACTICE, THE VALVES TO THE HEATER AND THE BYPASS WERE ADJUSTED SO THAT THE RESULTING MIXTURE OF HEATED AND COLD OXYGEN PRODUCED A TEMPERATURE AT THE BREATHING OUTLETS OF ABOUT 60 DEGREES F.

ALL THE OXYGEN CONTROLS WERE HANDLED BY THE PILOT, EXCEPT THE MASTER VALVES AT THE OXYGEN BOTTLES AND THE REDUCING VALVES WHICH CONTROLLED THE LINE PRESSURE FROM THE BOTTLES; THESE VALVES WERE OPERATED BY THE OBSERVER. FOUR VALVES AND A PRESSURE GAUGE, CONVENIENTLY GROUPED IN THE PILOT'S COCKPIT, COMPRISED THE MAIN CONTROLS. THESE VALVES WERE:

- (1) PRIMER VALVE, USED TO EMPLOY BOTTLE PRESSURE TO QUICKLY BOOST THE PRESSURE IN THE LIQUID OXYGEN FLASK AND ACCELERATE FLOW OF LIQUID OXYGEN INTO THE EVAPORATING COILS.
- (2) BOTTLE OXYGEN VALVE WHICH PUT BOTTLE OXYGEN INTO THE BREATHING SYSTEM.
- (3) LIQUID OXYGEN VALVE WHICH PUT OXYGEN GAS FROM EVAPORATING COILS INTO THE BREATHING SYSTEM.
- (4) RELIEF VALVE WHICH CONTROLLED THE PRESSURE IN THE LIQUID OXYGEN FLASK, THUS DETERMINING THE RATE OF FLOW OF LIQUID OXYGEN INTO THE EVAPORATING COILS AND HENCE THE VOLUME AND PRESSURE OF OXYGEN AVAILABLE AT THE BREATHING OUTLETS.

THE PRACTICE WAS TO USE BOTTLE OXYGEN FOR FLIGHTS OF LESS THAN TWO HOURS' DURATION, AND, AS AN EMERGENCY SUPPLY TO SUPPLEMENT THE LIQUID OXYGEN; FOR LONGER FLIGHTS THE LIQUID OXYGEN FLASK WAS PRIMED TO 15 LBS. PRESSURE PRIOR TO TAKEOFF, WHICH INSURED ADEQUATE EVAPORATED OXYGEN WOULD BE AVAILABLE IN TEN MINUTES. ON SEVERAL OCCASIONS WHEN CRUISING ABOVE 35,000 FEET IT WAS NECESSARY TO CUT IN THE BOTTLE OXYGEN FROM TIME TO TIME TO INSURE AN ADEQUATE SUPPLY, INASMUCH AS AT THESE LEVELS THE CREW HAD TO BREATHE PURE OXYGEN. ALSO DURING RAPID DESCENTS FROM HIGH LEVELS, BOTTLE OXYGEN WAS USED WHEN, DUE TO INCREASE IN ATMOSPHERIC PRESSURE, THE EVAPORATION RATE OF THE LIQUID OXYGEN MARKEDLY DECREASED AND THE OUTPUT OF THE VAPORIZING COILS WAS NO LONGER SUFFICIENT TO SUPPLY THE NEEDS OF THE PILOT AND OBSERVER.

THIS OXYGEN EQUIPMENT WAS CAPABLE OF MAINTAINING NORMAL HUMAN EFFICIENCY TO ALTITUDES OF 35,000 FEET ONLY UNDER CONDITIONS OF ALMOST COMPLETE INACTIVITY. EVEN WHEN BREATHING PURE OXYGEN A MARKED DEGREE OF OXYGEN WANT EXISTED ABOVE



30,000 FEET SUCH THAT A SLIGHT DECREASE IN OXYGEN PRESSURE OR MODERATE ACTIVITY PRODUCED A COMATOSE CONDITION. ALTHOUGH FAIRLY SATISFACTORY FOR TEST PURPOSES THIS OXYGEN INSTALLATION WOULD NOT BE SATISFACTORY FOR ROUTINE OPERATIONS ABOVE 30,000 FT.

COMPLETE LOSS OF THE OXYGEN SUPPLY AT 30,000 FEET PRODUCES GROSS MENTAL AND PHYSICAL INEFFICIENCY IN FROM 30 TO 60 SECONDS. PROLONGED MODERATE OXYGEN WANT OR SEVERE OXYGEN WANT FOR A RELATIVELY SHORT PERIOD CAUSES MENTAL RETARDATION AND CONFUSION FOR 30 MINUTES OR LONGER AFTER THE OXYGEN WANT HAS BEEN RELIEVED. THIS LATTER EFFECT IS INSIDIOUS AND VERY HAZARDOUS; BECAUSE OF IT, A PILOT CAN UNWITTINGLY GET INTO SERIOUS DIFFICULTY. THIS CONDITION IS ALMOST INVARIABLY CRITICAL TOWARD THE END OF FLIGHTS AT HIGH ALTITUDES AND IT IS AT THE END OF A FLIGHT WHEN APPROACHING A DESTINATION ON INSTRUMENTS INVOLVING RADIO ORIENTATION AND DESCENT THROUGH THOUSANDS OF FEET OF CLOUDS THAT A PILOT NEEDS HIS FACULTIES TO BE KEEN AND RELIABLE.

IN CONNECTION WITH THE OBSERVED FACT OF OXYGEN WANT THE WRITER EXPERIENCED SEVERAL INSTANCES DURING INSTRUMENT APPROACH TO DESTINATION IN WHICH INCREASED SENSITIVITY OF HEARING DURING DESCENT, COMBINED WITH MENTAL RETARDATION, RESULTED IN COMPLETE MISINTERPRETATION OF RADIO BEAM SIGNALS. CLEARING OF EARS BY SWALLOWING DURING DESCENT, PLUS IMPROVING SENSE OF HEARING DUE TO RECOVERY FROM OXYGEN WANT, MAKES A FADING RADIO SIGNAL SOUND AS THOUGH IT WERE ACTUALLY INCREASING. THIS IS A CONDITION TO BE GUARDED AGAINST WHEN DESCENDING FROM HIGH ALTITUDE AT ANY TIME IF USING A RADIO RANGE STATION FOR ORIENTATION AND APPROACH.

#### FUEL PRESSURE

THE EARLY FLIGHTS WERE DEVOTED TO SMOOTHING OUT THE TURBO OPERATION AND FINDING MEANS OF MAINTAINING ADEQUATE FUEL PRESSURE AT LEVELS ABOVE 20,000 FEET. THE STEPS TAKEN TO PROVIDE FUEL PRESSURE UP TO 35,000 FEET WERE.

- (1) THE 1/2" AND 5/8" DIAMETER FUEL LINES FROM THE TANKS TO THE FUEL PUMP, WERE CHANGED TO 3/4" DIAMETER.
- (2) THE FUEL PUMP WAS PLACED OUTSIDE AND BELOW THE BOTTOM OF THE FUSELAGE TO INCREASE THE HEAD TO THE PUMP.
- (3) THE THREE LEFT WING TANKS WERE CONNECTED TO THE VACUUM PUMP DISCHARGE WITH APPROPRIATE RELIEF VALVE, VALVES FOR CONTROLLING THE PRESSURE AND TWO MANIFOLD PRESSURE GAUGES, ONE TO ATMOSPHERE AND THE OTHER TO THE TANKS IN ORDER THAT DESIRED DIFFERENTIAL PRESSURE COULD BE MAINTAINED BY OBSERVATION OF THESE GAUGES.
- (4) TWO ROMIC F-4 FUEL PUMPS CONNECTED IN PARALLEL.

THUS EQUIPPED, IT WAS NECESSARY TO USE AIR PRESSURE ON THE FUEL TANKS ABOVE 22,000 FEET WHEN USING FULL POWER. ON TAKEOFF THE FUEL PRESSURE WAS 4 POUNDS; AT 22,000 FEET, IT HAD DECREASED TO  $1\frac{1}{2}$  POUNDS. THE APPLICATION OF AIR PRESSURE TO THE TANKS CAUSED THE FUEL PRESSURE TO RISE TO  $2\frac{1}{2}$  POUNDS (FULL POWER OPERATION) AND MAINTAIN THIS PRESSURE TO 35,000 FEET. CRUISING AT 500 HORSEPOWER AT 35,000 FEET, THE FUEL PRESSURE, WITH BOOST ON THE TANKS, WAS  $4\frac{1}{2}$  POUNDS. WITHOUT THE BOOST ON THE TANKS, THE FUEL PRESSURE WAS  $2\frac{1}{2}$  POUNDS AT WHICH THE ENGINE OPERATED SATISFACTORILY.

IT IS APPARENT THAT FUEL SUPPLY IS A SERIOUS PROBLEM IN THE STRATOSPHERE. NOT ONLY IS THE MATTER OF FUEL PRESSURE DIFFICULT BUT ALSO THE MATTER OF EVAPORATION IS A QUESTION OF UNKNOWN PROPORTIONS. WE KNOW DEFINITELY THAT FUEL PUMPS MUST BE COMPLETELY DROWNED, PREFERABLY ELECTRICALLY OR HYDRAULICALLY DRIVEN AND LOCATED IN THE BOTTOM OF THE TANKS. EVAPORATION LOSSES ARE NOT KNOWN. HOWEVER, AS SUCH LOSS IS INESCAPABLE WITH PRESENT FUELS, IT WILL BE NECESSARY BEFORE EXTENSIVE OPERATING IS DONE AT STRATOSPHERE LEVELS, TO DEVELOP A LESS VOLATILE FUEL, OR TO PRESSURIZE THE FUEL TANKS ALONG WITH THE CABIN EVEN THOUGH PRESSURE IN FUEL TANKS IS DEFINITELY UNDESIRABLE.

## POWER PLANT OPERATION

THE CONTROL OF THE TURBINE SUPERCHARGER WAS BY MEANS OF AN AUTOMATIC PRESSURE REGULATOR. THIS DEVICE UTILIZES A SYLPHON AND A DIFFERENTIAL OIL PISTON EMPLOYING ENGINE OIL PRESSURE TO CONTROL THE EXHAUST WASTE GATE, WHICH IN TURN CONTROLS THE AMOUNT OF EXHAUST GASES PASSING THROUGH THE TURBINE, HENCE THE SPEED OF THE TURBINE WHEEL AND THE IMPELLER WHICH IS ON THE SAME SHAFT. THE SYLPHON IS CONNECTED TO THE CARBURETOR INLET (INTERCOOLER DISCHARGE PRESSURE) AND TO ATMOSPHERIC PRESSURE. IT WAS SET AT THE BEGINNING OF THE TESTS TO MAINTAIN AT THE CARBURETOR EITHER A PRESSURE OF 30 INCHES HG. OR 26 INCHES HG., THE LATTER FOR CRUISING. EITHER PRESSURE COULD BE SELECTED BY THE PILOT USING A CONTROL IN THE REAR COCKPIT. EARLY FLIGHTS PROVED THAT THE OPERATION OF THE AUTOMATIC CONTROL WAS GOOD AT 30 INCHES HG., BUT UNSATISFACTORY WHEN OPERATING IN THE CRUISING POSITION, AS THE CARBURETOR PRESSURE WOULD SURGE TWO TO FOUR INCHES WITH A CORRESPONDING SURGE IN ENGINE MANIFOLD PRESSURE.

THE BLOWER SPEED OF THE ENGINE WAS SUCH THAT AT FULL THROTTLE AT SEA LEVEL WITHOUT TURBINE BOOST, THE ENGINE DEVELOPED FULL RATED POWER. EXPERIENCE THUS FAR INDICATES SUCH BLOWER SPEED TO BE DESIRABLE FOR TURBINE SUPERCHARGED INSTALLATIONS AS IT PERMITS USE OF AN ENGINE MANIFOLD PRESSURE ALWAYS HIGHER THAN THE CARBURETOR PRESSURE. INASMUCH AS THE EXHAUST BACK PRESSURE, AT RATED POWER, VARIES FROM ABOUT 2 INCHES HG. ABOVE CARBURETOR PRESSURE AT SEA LEVEL, TO TWO INCHES BELOW CARBURETOR PRESSURE AT 35,000 FEET IT IS DESIRABLE TO MAINTAIN THE ENGINE MANIFOLD PRESSURE AT LEAST 2 INCHES HG. HIGHER THAN THE EXHAUST BACK PRESSURE TO INSURE GOOD SCAVENGING. USE OF LOWER BLOWER SPEEDS INVOLVING EMPLOYMENT OF TURBINE BOOST TO SECURE RATED POWER REVERSES THIS CONDITION AND RESULTS IN A HIGHER EXHAUST BACK PRESSURE THAN ENGINE MANIFOLD PRESSURE.

IN ORDER TO CORRECT THE CARBURETOR PRESSURE SURGING DURING HIGH ALTITUDE CRUISING, THE AUTOMATIC PRESSURE REGULATOR WAS MODIFIED TO PERMIT THE PILOT TO SELECT ANY DESIRED CARBURETOR PRESSURE FROM 20 INCHES HG. TO 30 INCHES HG. POWER CONTROL WITH THIS CHANGE WAS SATISFACTORY AND WAS ACCOMPLISHED AS FOLLOWS: ON TAKE-OFF, THE AUTOMATIC REGULATOR CONTROL WAS SET FOR "WASTE GATE OPEN" AND CLIMB WAS MADE USING THE THROTTLE ONLY TO MAINTAIN DESIRED CRUISING CLIMB POWER. WHEN FULL THROTTLE WAS REACHED, CRITICAL ALTITUDE FOR THE DESIRED CLIMBING POWER, THE AUTOMATIC REGULATOR CONTROL WAS SET SO THAT THE RESULTING CARBURETOR PRESSURE WAS SUFFICIENT TO JUST MAINTAIN THE DESIRED ENGINE MANIFOLD PRESSURE. WITH CONTROLS SO SET, AND THE MIXTURE SET ACCORDING TO CAMBRIDGE INDICATOR, NO FURTHER ADJUSTMENT WAS NECESSARY UNTIL CRUISING ALTITUDE WAS REACHED WHEN THE AUTOMATIC CONTROL WAS READJUSTED TO GIVE THE DESIRED ENGINE MANIFOLD PRESSURE, SLIGHT MIXTURE CHANGE WAS THEN NECESSARY. THUS, ABOVE CRITICAL ALTITUDE OF THE ENGINE FOR ALLOWABLE CRUISING CLIMB POWER (FULL THROTTLE), ENGINE CONTROL WAS WHOLLY ACCOMPLISHED BY MEANS OF THE AUTOMATIC REGULATOR, THE CONTROL OF WHICH BECAME VIRTUALLY A SECONDARY THROTTLE ABOVE CRITICAL ALTITUDE.

IT APPEARS, FROM EXPERIENCE, TO BE A SOUND PRINCIPLE IN TURBINE SUPERCHARGER OPERATION TO EMPLOY ONLY THE AMOUNT OF TURBINE BOOST NECESSARY TO CAUSE THE DESIRED ENGINE MANIFOLD PRESSURE. THUS, THE EXHAUST TURBINE OPERATES WITH A MAXIMUM WASTE GATE OPENING AND THEREFORE MINIMUM EXHAUST BACK PRESSURE. IT IS THIS DEGREE OF CONTROL WHICH CONSTITUTES ONE OF THE PRIME ADVANTAGES OF THE TURBINE SUPERCHARGER, ITS FLEXIBLE COUPLING TO THE ENGINE PERMITTING UNDER ALL CONDITIONS THE MINIMUM EXPENDITURE OF AVAILABLE POWER FOR SUPERCHARGING.



A FACTOR WHICH CAUSED SOME CONCERN DURING THE EARLIER TEST FLIGHTS WAS THAT OF CARBURETOR ICE. IT HAD BEEN SUPPOSED THAT THE TEMPERATURE RISE THROUGH THE COMPRESSOR WOULD BE ADEQUATE TO ELIMINATE THIS TROUBLE. DURING DESCENT FROM HIGH LEVELS INDICATIONS OF CARBURETOR ICE WERE OBSERVED. IN THIS CONNECTION IT WAS NOTED THAT THROTTLING BACK OF THE ENGINE RESULTED IN RAPID DROP OF CARBURETOR PRESSURE DUE TO THE INADEQUACY OF EXHAUST GAS TO MAINTAIN THE TURBINE SPEED. IN FACT, IF THE ENGINE IS COMPLETELY THROTTLED AT ABOUT 30,000 FEET, IT IS DIFFICULT TO BRING THE ENGINE BACK. THE CAUSE OF THIS IS OBVIOUS. WITHOUT TURBINE BOOST THE ENGINE POWER AVAILABLE IS NEGLIGIBLE AND THE AMOUNT OF EXHAUST GAS RESULTING AT FULL THROTTLE TAKES SEVERAL MINUTES TO BRING THE TURBINE UP TO SPEED. ALSO, IT MUST BE BORNE IN MIND THAT LOSS OF TURBINE BOOST CAUSES THE CARBURETOR TO BECOME EXCESSIVELY RICH AND CONSIDERABLE LEANING IS NECESSARY TO EVEN MAKE THE ENGINE RUN UNTIL THE CARBURETOR PRESSURE BEGINS TO BUILD UP. IF THE ENGINE IS LEFT THROTTLED LONG ENOUGH TO ALLOW THE TURBINE WHEEL TO NEARLY STOP ROTATING, IT MAY BE IMPOSSIBLE TO START IT UNTIL THE PLANE HAS DESCENDED TO AROUND 20,000 FEET. THEREFORE, IN MAKING DESCENTS, SUFFICIENT POWER SHOULD BE MAINTAINED TO KEEP THE TURBINE WHEEL TURNING FAST ENOUGH TO PRODUCE A CONSTANT CARBURETOR PRESSURE.

CONSIDERABLE FLYING WAS DONE ON INSTRUMENTS IN IDEAL ICE FORMING CONDITIONS ALTHOUGH NO INDICATIONS OF CARBURETOR ICE WERE OBSERVED DURING TAKE-OFF AND CLIMBS, THE CARBURETOR ADAPTER TEMPERATURES WERE FREQUENTLY BELOW 32 DEGREES F. THEREFORE, SHUTTERS CONTROLLABLE FROM THE COCKPIT WERE PLACED AT THE COOLING AIR ENTRANCE TO THE INTERCOOLER. WITH THESE SHUTTERS CLOSED, IT WAS POSSIBLE TO KEEP ADAPTER TEMPERATURE OVER 32 DEGREES F. AND TO PERMIT A 40 DEGREE F. RANGE OF CONTROL OVER THE INTERCOOLER DISCHARGE TEMPERATURE. IT IS POSSIBLE THAT IN ADDITION TO THE SHUTTERS, IT MAY BE DESIRABLE IN SOME INSTALLATIONS TO PROVIDE MEANS FOR TAKING THE AIR INTO THE COMPRESSOR FROM EITHER OUTSIDE OR FROM THE ENGINE SECTION AT THE CONTROL OF THE PILOT.

SPARK PLUG TROUBLE, EVIDENCED BY ENGINE ROUGHNESS, WAS OBSERVED ABOVE 25,000 FEET. DURING A SERIES OF TEST FLIGHTS MADE IN COLLABORATION WITH THE ARMY AT WRIGHT FIELD, PLUGS WERE REMOVED, TESTED, AND NEW ONES INSTALLED PRIOR TO FLIGHTS. IT WAS CONCLUSIVELY DETERMINED THAT PLUGS WERE BREAKING DOWN BETWEEN 25,000 AND 30,000 FEET UNDER FULL POWER OPERATION. SEVERAL SETS OF PLUGS OPERATED SATISFACTORILY FOR EXTENDED PERIODS AT CRUISING POWER ABOVE 30,000 FEET. HOWEVER, BETTER SPARK PLUGS THAN ANY THEN AVAILABLE WILL BE REQUIRED TO INSURE SATISFACTORY OPERATION AND LIFE AT ALTITUDES ABOVE 25,000 FEET.

THE RIGHT MAGNETO WAS FOUND TO BE DEAD AFTER A CLIMB TO 35,000 FEET. THIS FAILURE WAS CAUSED BY THE HIGH TENSION CIRCUIT ARCING ACROSS FROM THE HIGH TENSION OUTLET TO THE GROUND. THE ARCING HAD BURNED A GROOVE INTO THE COIL INSULATOR. THIS WAS THE ONLY MAGNETO FAILURE.

NO DIFFICULTY OF ANY KIND WAS ENCOUNTERED FROM THE SHIELDED IGNITION HARNESS.

A SHEET OF CURVES WAS PREPARED BASED ON A PLOT OF ALL DATA RECORDED DURING THE SERIES OF THIRTY-THREE FLIGHTS. ABOVE 30,000 FEET, THE DATA IS NOT CONCLUSIVE. HOWEVER, THE CURVES AS EXTROPOLATED CHECK REASONABLY WELL WITH THE DATA OBTAINED. DUE TO THE LARGE NUMBER OF INSTRUMENTS TO BE OBSERVED AND READINGS TAKEN, THE ONLY PRACTICAL MEANS OF RECORDING SIMULTANEOUS DATA WAS THROUGH THE USE OF A LEICA CAMERA. THE CAMERA WAS MOUNTED JUST AHEAD OF THE PILOT'S INSTRUMENT BOARD AND AT A DISTANCE FROM THE OBSERVER'S BOARD, SO THAT THE FIELD OF THE LENSE JUST COVERED ALL INSTRUMENTS. A LANDING LIGHT BULB WAS INSTALLED ON EACH SIDE OF THE OBSERVER'S COCKPIT.

BOTH LIGHTS WERE OPERATED TOGETHER BY A PUSH BUTTON SWITCH. THE OBSERVER TO TAKE A READING LEANED TO ONE SIDE, OUT OF THE WAY OF THE FIELD OF THE CAMERA, TURNED ON THE LIGHTS AND OPERATED THE CAMERA SHUTTER BY MEANS OF AN EXTENSION DEVICE. READINGS WERE THUS TAKEN AT EVEN THOUSAND FOOT ALTITUDES DURING CLIMBS AND PERIODICALLY WHILE CRUISING. THE DEVELOPED FILMS WERE EITHER READ WITH A MAGNIFYING GLASS OR PROJECTED ON A SCREEN.

#### LEVEL SPEEDS AT ALTITUDE

THE AIR SPEED METER WAS CALIBRATED OVER A SPEED COURSE 4.8862 MILES IN LENGTH WHICH RESULTED IN AN ACCURATE CALIBRATION. TWO FLIGHTS WERE MADE TO 30,000 FEET USING FULL POWER TO OBTAIN MAXIMUM CLIMB PERFORMANCE. LEVEL SPEEDS WERE THEN OBSERVED AT 30-25-20-15-10 AND 5,000 FEET. AT EACH ALTITUDE THE PLANE WAS FLOWN LEVEL AT RATED POWER EXCEPT AT 30,000 FEET WHICH IS APPROXIMATELY 2,000 FEET ABOVE THE CRITICAL ALTITUDE OF THE TURBINE SUPERCHARGER INSTALLATION. THE POWER WAS THEN REDUCED TO 500 HORSEPOWER ESTIMATED, 26 HG. ENGINE MANIFOLD PRESSURE AND 1,000 RPM. THE EXACTNESS OF THIS POWER DETERMINATION IS ONLY APPROXIMATE, AS NO ONE HAS YET FIGURED A WAY TO DETERMINE THE HORSEPOWER AT ALTITUDE OF AN ENGINE EQUIPPED WITH A TURBINE SUPERCHARGER ON ACCOUNT OF THE UNKNOWN QUANTITATIVE EFFECT OF EXHAUST BACK PRESSURE ON POWER. IT IS HOPED THAT TORQUE METER READING HORSEPOWER DIRECT WILL SOON BE AVAILABLE FOR USE WITH GEARED ENGINES. UNTIL SUCH AN INSTRUMENT IS AVAILABLE, THE APPROXIMATION OF POWER USING MANIFOLD PRESSURE, CARBURETOR AIR TEMPERATURE AND RPM WILL HAVE TO SUFFICE. THE AIRPLANE WAS MAINTAINED ON STEADY LEVEL FLIGHT FOR THREE TO FIVE MINUTES BEFORE EACH SPEED READING.

A QUESTION HAD BEEN RAISED REGARDING THE RELIABILITY OF AIR SPEED METER READINGS AT HIGH ALTITUDES. IN ORDER TO PROVE THE ACCURACY OF TRUE AIR SPEEDS REDUCED FROM INDICATED AIR SPEEDS OBSERVED AT 30,000 FEET, THE GAMMA WAS FLOWN AROUND A TRIANGULAR COURSE. IN ORDER TO NAVIGATE SUCH A COURSE WITH ANY DEGREE OF ACCURACY, IT WAS NECESSARY TO CHOOSE TURNING POINTS HAVING DEPARTMENT OF COMMERCE RADIO RANGE STATIONS. FORTUNATELY, THE RADIO RANGE STATIONS AT KANSAS CITY, KIRK VILLE AND COLUMBIA, MO., PROVIDED AN EXCELLENT COURSE, THE LENGTH OF THE LEGS BEING 120, 78 $\frac{1}{2}$  AND 120 $\frac{1}{2}$  MILES RESPECTIVELY. IN FLYING THIS COURSE NEARLY SIX MILES ABOVE THE GROUND IT WAS NOT POSSIBLE TO MAINTAIN A CONSTANT HEADING WITH ALLOWANCE FOR DRIFT SO AS TO MAINTAIN AN ABSOLUTELY STRAIGHT TRACK. HOWEVER, THE OCCASIONAL INACCURACIES OF NOT OVER 10 DEGREES IN COMPASS HEADING WERE NOT ENOUGH TO VITIATE THE RESULTS. THE PILOT'S VISIBILITY FROM THE COCKPIT OF THE GAMMA IS EXTREMELY POOR THAT FLYING AT HIGH ALTITUDES IS LARGELY DONE BY INSTRUMENTS. THE KANSAS CITY RADIO RANGE WAS USED AS A POINT OF DEPARTURE AND FINISH, WITH TURNS BEING MADE AT KIRK VILLE AND COLUMBIA WHEN OVER THE RESPECTIVE CONES OF SILENCE. REDUCING THE AVERAGE INDICATED AIR SPEED GAVE A TRUE AIR SPEED FOR THE CIRCUIT OF 224 MILES PER HOUR. THE TIMED GROUND SPEED FOR THE THREE LEGS WAS 208, 215 AND 171 MILES PER HOUR, RESPECTIVELY. GRAPHIC SOLUTION, USING THE GROUND SPEEDS, GIVES A TRUE AIR SPEED 222 MILES PER HOUR AND WIND 52 MILES PER HOUR FROM 268 DEGREES. IT IS CONSIDERED THAT THIS FIGURE SUBSTANTIATES THE REDUCED TRUE AIR SPEED REASONABLY WELL, THE DIFFERENCE OF 2 MILES PER HOUR MAY BE EASILY ACCOUNTED FOR BY INACCURATE FLYING. THE APPROXIMATE POWER USED WAS 500 HORSEPOWER.

THE LEVEL SPEED CURVE OF TRUE AIR SPEEDS AT 500 HORSEPOWER SHOWS 135 MILES PER HOUR AT SEA LEVEL AND 225 MILES PER HOUR AT 30,000 FEET. THIS IS AN INCREASE OF 36.4 PERCENT WHICH COMPARES WITH A THEORETICAL MAXIMUM OF 30 PERCENT.



## WEATHER AT HIGH LEVELS

IN THE COURSE OF FLYING THE GAMMA LOCALLY AT KANSAS CITY AND CROSS-COUNTRY FLIGHTS, VARIOUS TYPES OF CLOUD FORMATIONS WERE ENCOUNTERED AT LEVELS BETWEEN 25,000 FEET AND 35,000 FEET.

THE COMMON VARIETY OF HIGH CIRRUS CLOUDS WHICH WAS OBSERVED ON CLEAR DAYS WERE FOUND TO LIE AT ALTITUDES FROM 28,000 FEET TO 30,000 FEET. THE TEMPERATURE AT THESE LEVELS VARIED FROM 20 TO 30 DEGREES BELOW ZERO. THE CLOUDS WERE ALWAYS VERY THIN, NEVER EXCEEDING 200 TO 300 FEET IN THICKNESS. FLYING THROUGH THESE CLOUDS WAS LIKE FLYING THROUGH A MODERATE HAZE. ONLY VERY SLIGHT TURBULENCE NOTICED IN FLYING THROUGH CIRRUS CLOUDS OF THIS TYPE.

DURING STORM CONDITIONS WHEN CLIMBS WERE MADE TO ABOVE 30,000 FEET, AS MANY AS FIVE WELL-DEFINED LAYERS OF CLOUDS HAVE BEEN TRAVERSED. THESE LAYERS VARIED IN THICKNESS FROM FOUR TO FIVE THOUSAND FEET AT LOWER LEVELS - TO 500 FEET AT AROUND 30,000 FEET. ONLY DURING APPROACH OF WARM FRONT CONDITIONS HAVE CLOUD LAYERS OF ANY THICKNESS BEEN ENCOUNTERED AT HIGH LEVELS. UNDER THESE CONDITIONS, HOWEVER, CLOUD LAYERS OF ALMOST UNBELIEVABLE DEPTH HAVE BEEN ENCOUNTERED IN THE UPPER AIR. FOR EXAMPLE: ON ONE FLIGHT, SOLID CLOUD CONDITION WAS ENCOUNTERED FROM 30,000 FEET DOWN TO 8,000 FEET, 22,000 FEET THICK. THESE CLOUDS WERE NOT DENSE CLOUDS IN RESPECT TO VISIBILITY. AS IS WELL KNOWN, ORDINARY CLOUDS AT LOWER LEVELS CUT VISIBILITY TO ZERO, OR A MATTER OF A FEW FEET. IN THESE CLOUDS AND IN OTHER SIMILAR ONES, VISIBILITY WITHIN THE CLOUD WAS NEARLY CONSTANT FROM THE BASE TO THE TOP. IT IS ESTIMATED THAT A PLANE COULD HAVE BEEN SEEN A QUARTER OF A MILE AWAY. VIEWED FROM ABOVE AND BELOW, THE APPEARANCE OF THE CLOUD GAVE NO INDICATION OF THIS PHENOMENON AND LOOKED THE SAME AS ANY ORDINARY CLOUD DOES AT LOW LEVELS. NO TURBULENCE WHATEVER WAS ENCOUNTERED WHILE FLYING THROUGH CLOUDS OF THIS NATURE. UPON ENTERING THESE CLOUDS AT THEIR TOPS, ONLY A VERY SLIGHT BUMP IS NOTICEABLE, JUST ENOUGH TO INDICATE A SLIGHT RELATIVE MOVEMENT OF AIR MASSES.

CONTINUOUS OVERCAST CONDITIONS EXISTING FOR OVER 500 MILES WITH THE TOP OF THE CLOUD LEVELS AT 30,000 FEET, HAVE BEEN OBSERVED SEVERAL TIMES. THESE CONDITIONS EXISTED IN CONNECTION WITH AN ADVANCING WARM FRONT.

TOPS OF THUNDERSTORMS HAVE BEEN OBSERVED TO EXTEND ABOVE 35,000 FEET AND ANVIL HEADS OF THUNDERSTORMS APPEARED TO RISE UNTIL THEY ENCOUNTERED THE BASE OF THE STRATOSPHERE, WHICH IS THE POINT WHERE THEY FLATTEN OUT. THESE ANVIL HEADS HAVE BEEN FLOWN THROUGH AT ALTITUDES AROUND 30,000 FEET WITHOUT ENCOUNTERING ANY TURBULENCE OTHER THAN A SLIGHT BUMP UPON ENTERING THE CLOUD AND UPON LEAVING IT. FLYING THROUGH THESE CLOUDS, A CONSTANT RATE OF ASCENT FROM 200 TO 300 FEET PER MINUTE, WAS SHOWN ON THE RATE OF CLIMB INDICATOR. THESE ANVIL CLOUDS HAVE THEIR ORIGIN IN HEAVY DARK CLOUDS OF EXTREMELY TURBULENT APPEARANCE AT ALTITUDES OF AROUND 25,000 FEET. NO ATTEMPT WAS MADE TO FLY INTO THESE CLOUDS BECAUSE OF THE EXTREME TURBULENCE EVIDENCED BY THE BOILING AND TRANSITIONAL APPEARANCE OF THE CLOUDS THEMSELVES.

IT IS BELIEVED THAT AT 30,000 FEET, COMFORTABLE INSTRUMENT FLIGHT MAY BE MAINTAINED THROUGH ANY CLOUDS ENCOUNTERED.

## RADIO

RADIO RECEPTION IN CLEAR AIR AT ALTITUDES ABOVE 30,000 FEET WAS EXCELLENT, BOTH IN RESPECT TO RADIO BEAMS AND TWO-WAY COMMUNICATIONS WITH THE GROUND BY EMPLOYING NORMAL WAVE LENGTHS USED FOR AIRLINE COMMUNICATION.

THE CONES OF SILENCE OF OUR RADIO RANGE STATIONS WERE FOUND TO GIVE NULLS ESTIMATED TEN TO FIFTEEN MILES IN DIAMETER. ON CLEAR DAYS IT WAS OBSERVED THAT THE CONES OF SILENCE LEANED AS MUCH AS 5 MILES TO ONE SIDE OR THE OTHER FROM THE STATIONS. UPON PASSING THROUGH THE CONES OF SILENCE, THE CHARACTERISTIC SURGE WAS HEARD THE SAME AS AT LOWER LEVELS. INASMUCH AS EXTREME ACCURACY OF POSITION REPORTED AT THESE HIGH ALTITUDES DURING CRUISING IS UNIMPORTANT, THESE FACTS ARE NOT SERIOUS.

UNUSUALLY SEVERE STATIC WAS ENCOUNTERED WHEN FLYING ON INSTRUMENTS IN ALL CLOUDS AT 30,000 FEET AND ABOVE. THIS IS BELIEVED TO BE DUE TO THE FACT THAT THESE CLOUDS ARE COMPOSED OF MINUTE ICE CRYSTALS, HEAVILY CHARGED WITH STATIC ELECTRICITY. THIS STATIC INVARIABLY OBLITERATED RADIO RANGE RECEPTION COMPLETELY, AND IN EXTREME CASES, ALSO TOTALLY OBLITERATED TWO-WAY COMMUNICATION. DURING THESE EXTREME CONDITIONS, HOWEVER, THE GROUND STATIONS RECEIVED THE MESSAGES FROM THE AIRPLANE PERFECTLY. THE ELIMINATION OF THIS STATIC IS PURELY A MATTER OF INSTALLING AN ADEQUATE ANTI-STATIC SHIELDED ANTENNA. AT THE TIME THESE FLIGHTS WERE MADE, THE GAMMA WAS NOT EQUIPPED WITH ONE OF THE ANTI-STATIC SHIELDED LOOP ANTENNAS WHICH ARE STANDARD EQUIPMENT ON ALL TWA DOUGLAS AIRPLANES. THERE WAS NO EXTRA ANTENNA AVAILABLE FOR THIS USE OR IT WOULD HAVE BEEN INSTALLED. BECAUSE OF THE EFFECTIVENESS OF THIS ANTENNA UNDER STATIC CONDITIONS AT PRESENT FLIGHT LEVELS, IT IS BELIEVED THAT IT WILL FUNCTION AS EFFECTIVELY AT HIGHER ALTITUDES. THEREFORE, AN AIRPLANE PROPERLY EQUIPPED WITH A SHIELDED ANTENNA, SHOULD EXPERIENCE NO DIFFICULTY WITH RADIO RECEPTION FLYING AT HIGH ALTITUDES.

#### RECOMMENDATIONS:

IT IS PROPOSED THAT OUR MEAGER KNOWLEDGE OF CONDITIONS AT THE BASE OF THE STRATOSPHERE BE EXPANDED BY THE FOLLOWING MEANS:

1. AIRPLANE WEATHER OBSERVATION FLIGHTS BE TAKEN OVER BY THE GOVERNMENT. THE U. S. ARMY AIR CORPS HAS EQUIPMENT SUITABLE FOR REGULAR FLIGHTS TO 30,000 FEET. THERE ARE NOW IN SERVICE ABOUT FIFTY SUITABLE AIRPLANES EQUIPPED WITH TURBINE SUPERCHARGERS. THESE PLANES WILL SOON BE OBSOLETE FROM THE MILITARY STANDPOINT, BUT ARE SUITABLE AND SATISFACTORY FOR USE IN MAKING HIGH ALTITUDE WEATHER FLIGHTS. THESE PLANES SHOULD BE MADE AVAILABLE FOR THIS PURPOSE EQUIPPED WITH DEICERS AND OPERATED EITHER BY THE ARMY OR TURNED OVER TO A SPECIAL DEPARTMENT OF THE WEATHER BUREAU TO BE CHARGED WITH THIS PARTICULAR MISSION, WHICH WOULD ORGANIZE A GOVERNMENT UNIT INCLUDING PILOTS AND MECHANICS TO PERFORM THE FLYING.
2. ESTABLISH A LARGE NUMBER OF METEOROGRAPH STATIONS TO AUGMENT THE DATA OBTAINED FROM AIRPLANE OBSERVATIONS AND TO EXTEND OUR KNOWLEDGE OF CONDITIONS INTO THE STRATOSPHERE, SAY TO 50,000 FEET.
3. SECURE CONGRESSIONAL APPROPRIATION FOR THE DEVELOPMENT OF AN EXPERIMENTAL HIGH ALTITUDE, HIGH SPEED TRANSCONTINENTAL AIR MAIL SERVICE USING AIRCRAFT CAPABLE OF CRUISING AT 30,000 FEET AND MAKING NOT MORE THAN ONE STOP. THIS SCHEDULED OPERATION WILL PROVIDE A PROVING GROUND FOR ALL THE MECHANICAL DEVICES ESSENTIAL FOR HIGH ALTITUDE FLYING, INCLUDING PRESSURE CABINS, AND WILL PAVE THE WAY FOR THE PASSENGER TRANSPORTS.

REGULAR TRANSPORT OPERATION AT 30,000 TO 35,000 FOOT LEVELS WILL COME WITHIN THE NEXT TEN YEARS. IT WILL PLAY AN IMPORTANT PART IN LONG RANGE, NON-STOP TRANSCONTINENTAL AND OCEANIC FLYING. THE SURFACE, SO TO SPEAK, HAS HARDLY BEEN TICKLED, LET ALONE SCRATCHED. ENOUGH HAS BEEN DONE TO CLEARLY SHOW HOW MUCH WE HAVE TO LEARN. GOVERNMENT HELP IS NECESSARY TO OBTAIN VITAL DATA AND TO ESTABLISH AN EXPERIMENTAL STRATOSPHERE SERVICE WHICH WILL LEAD TO THE ANNIHILATION OF GREAT DISTANCES AND MAKE THE WORLD IN FACT A GROUP OF NEIGHBORLY NATIONS.

