A Quantitative Evaluation of Tow Plane Let Down Procedures

by Scott McMaster and Mark Janoska

One of the major concerns of any glider towing operation is the thermal stress cracking of engine cylinders. At the SOSA Gliding Club (based in Rockton, Ontario, Canada), we experienced premature cracking in our Bellanca 7-GCBC Citabria tow planes. These aircraft have had the original 150 hp engines replaced by 180 hp engines (installed using Bellanca Scout engine mounts and cowlings. Although they proved to be very capable tow planes, out climbing our 235 hp Pawnee, we rarely got more than 1000 hours on an engine without experiencing cracked cylinders. The type and location of the cylinder cracking indicated that the cause was thermal shock, but isolating the specific part of the towing procedure that was to blame (and developing a procedure to avoid it while still maintaining high utilization rates) proved impossible without quantitative data. To obtain the required data, a flight data monitoring system (FMS) was designed and constructed for installation in a Citabria.

The FMS system, shown schematically in Figure I, allowed us to collect and analyze airspeed, altitude, cylinder head temperatures (Chats), and RPM Information. To avoid possible flight safety concerns, the FMS has its own separate pitot static system, thermo-couples, and RPM sensor, the only use of aircraft systems being the 12 V main power. Airspeed and altitude are deter-mined using pressure transducers calibrated against the aircraft instruments and the CHT information comes from Chromel-Alumel thermocouples mounted in the standard engine CJHT probe locations. The RPM is obtained in one of two ways: either from a photocell mounted on the engine cowling to detect the propeller blade passes, or by measuring the frequency of the alternator noise on the aircraft 12 V power supply. The FMS itself is a microprocessor-cased data acquisition system. It consists of 16 analog input channels for the various sensors, an analog-to-digital converter, and sufficient battery backed-up memory to record about four hours of data at one record every two seconds. The system is active whenever the aircraft master switch is on. After gathering data, the FMS is removed from the aircraft and the information downloaded to an IBM PC for processing. Processing includes converting individual CHT readings into rates of change for each cylinder, isolating individual tows, checking for letdown procedure adherence, and compiling general statistics such as average turn-around times. The current system uses only seven of the available sixteen data channels (IAS, ALT, RPM, 3xCHT,and temperature) and all data shown in this article were retrieved at a rate of one complete record set every two seconds.

Initial observations of general club towing operations showed that Lycoming's maximum recommended cooling rate of 50°F/min (28°C/min) was exceeded on all letdowns, some-times by as much as 200%. Obviously, this was a good place to start looking for the solution to our cracking problem. The letdown procedure at the time was to slowly throttle back (approximately thirty seconds) to 2000 RPM while accelerating to 110 mph IAS, the larger engine requiring the high speed to achieve a reasonable rate of descent. Analysis of the cooling profiles obtained during these letdowns showed a definite correlation between airspeed and CHT cooling, essentially independent of throttle setting, with the peak rate achieved about thirty seconds after maximum IAS was reached. The independence of peak cooling rates and throttle setting appears to be valid above about 90 mph where the effects of cooling air swamp any heat generated by the engine.

Below 90 mph, the airflow cooling is comparable to the internal heat generated by the engine and there is a definite relationship between IAS, RPM, and cooling rates. In order to establish an optimum letdown procedure, various combinations of throttle setting and IAS were flown under controlled conditions. To make the final procedure robust, the indicated IAS and RPM were established as quickly as practical after glider release (generally about five to ten seconds) and then the peak cooling rate, average cooling rate, and rate of climb or descent were determined for the first minute after release. The rate of descent information is valid only for straight and level un-accelerated flight. The results of these tests are summarized in Figure 2. With the aid of a sharp cold front, we were able to fly some of the data points one day with the outside air temperature (OAT) at 25°C and then repeat the same points the following day with an OAT of 5°C. This minimized any changes in the aircraft and yielded the surprising result that changes in the OAT have no effect on cooling rates. Although this was definitely not what we expected, the data was quite conclusive. Note that the details of Figure 2 are specific to the Scout engine installation in the 7-GCBC Citabria, but the general trends should apply to all similar aircraft.

As can be seen by comparing Figures 3 and 4, careful aircraft handling in the first sixty seconds after glider release is critical to avoiding high peak cooling rates. Also, it appears that once the CHTs are below about 315°F, the pilot can fly a let down that is relatively unrestricted by cooling considerations. With these results in mind, our letdown procedure was modified so that upon glider re-lease, the tow pilot; 1) applies full flap, 2) reduces power to 2100 RPM, 3) accelerates to 80 mph(69 kts), 4) maintains until the CHT drops below 315°F, and then 5) accelerates to 90 mph (78 kts) and reduces power to 1600 RPM. This letdown procedure has reduced our peak cooling rates dramatically (Figure 4) while slightly ex-tending the time to do an average 2000' tow (from start of the take off roll to finish of landing roll) from 7.34 minutes to 7.43 minutes. The times for 3000' and 4000' tows are actually less than with the original letdown procedure.

In addition to the definition of a new letdown procedure, we were able to make assessments of other parameters that affect the letdown. First, we examined the effect of steep turns (commonly used to help increase the descent rates of tow planes). Letdowns were done using various angles of bank (up to 85°) and various amounts of g loading (up to 3 g's) and in all cases we observed reduced cooling rates (mainly attributable to the higher power and lower airspeed that were maintained in the steep turns), and reduced turnaround times (due to the higher descent rates in the steep turns.) Most of our tow pilots currently make use of steep turns at some point in the letdown. One potential problem with steep turns is that the cooling rate can be so reduced that the cylinders are still hot when the pilot levels out and speeds up. In many of our more aggressive steep turn trials, high peak cooling rates were seen as airspeed was increased after leaving the turn. Proper airspeed control until the CHT is reduced eliminates this problem.

We also examined the effect of descent rate and side slip on cooling. As might be expected, there appears to be no correlation between cooling and rate of descent. It is harder to be definitive about the effects of sideslips, due to airspeed and altitude instrument fluctuations that occur in aggressive sideslips, but slipping appears to have little impact on cooling rates with little evidence of any significant differential cylinder cooling.

To summarize; the first minute or so after glider release is the most critical part of the letdown for prevention of shock cooling due to the high cylinder head temperatures after the long climb. During this time, no amount of power can overcome the shock cooling imposed airspeeds in excess of 90mph, so we have put a restriction of 80 mph on our tow plane until the temperatures have dropped. Once the cylinder temperatures are down (to 315°F in our case) it appears that excessive restrictions are unnecessary and only waste time.

The information gathered with the FMS has allowed SOSA to modify its Citabria towing procedures so that peak engine cooling rates have been reduced by almost 50% with no detrimental impact on tow turnaround times. It is our intention to evaluate the club's Piper Pawnee later this summer and, if there is any interest, these results will be made available. Although the results we have obtained are necessarily specific to our aircraft, we hope the general trends indicated could be useful to others in the soaring community that is experiencing cylinder cracking problems.

Biographies:

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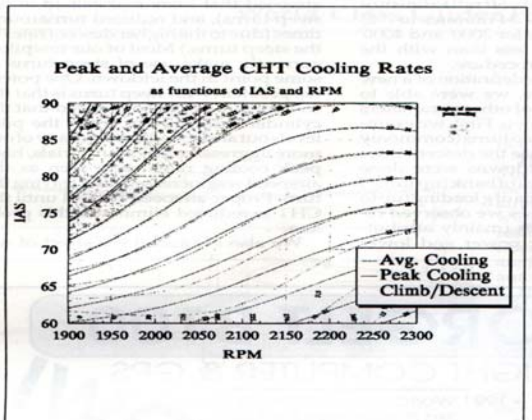

FIGURE 2. 180 hp Citabria flight envelope data, during first minute after glider release. Rate of descent information valid for straight and level flight only.

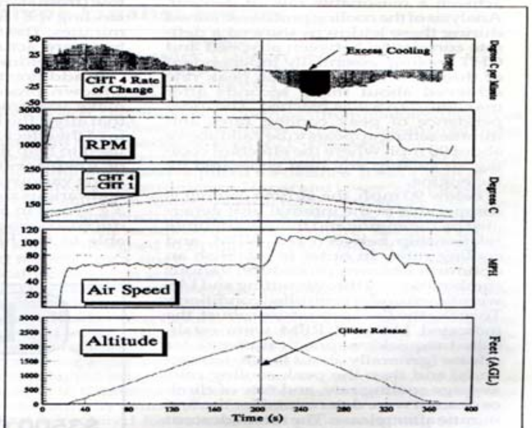

FIGURE 3. Original letdown, throttling back to 2000 rpm while accelerating to 110 mph after glider release.

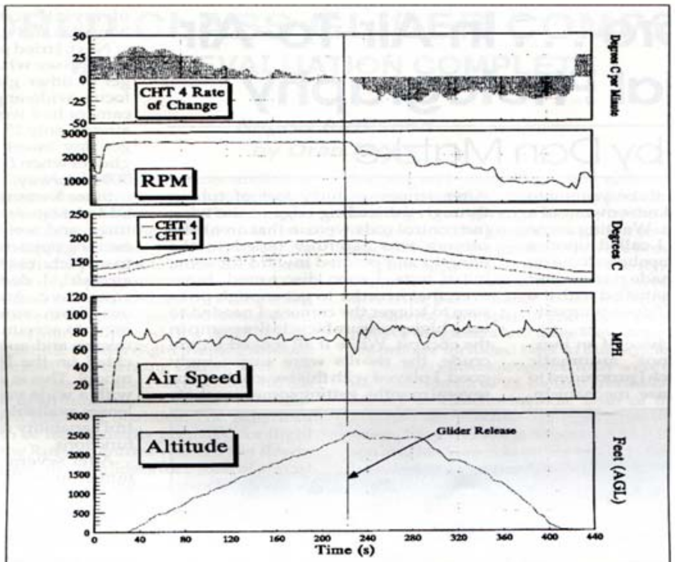

FIGURE 4. New two stage letdown with initial throttle back to 2100 rpm while accelerating to 80 mph, then 1600 rpm and 90 mph after aircraft CHT is below 315° F.

Piper Pawnee:

There were no indications of operational problems with the Pawnee at the time of this study, so very little initial observation of general club operations was undertaken. The standard Pawnee letdown at SOSA is 100 mph IAS, 2000 RPM, and full flap until in the landing circuit. A flight data record of a typical letdown profile is shown in Fig 25. Note the very low cooling rates for all cylinders compared to the Citabria, this was anticipated, given the Pawnee's robust reputation, but the magnitude of the difference lead to a complete recalibration of the PMS to verify the numbers. Recalibration established that aircraft IAS was significantly different between the Citabria and Pawnee but the cooling rates were real. To allow direct comparison all data in this report is calibrated to the Citabria IAS. For those readers wishing to directly apply these results to a Pawnee, please refer to the IAS calibration data in Appendix I.

After 1 weekend of calibration and observation, a flight test schedule was begun to establish a letdown envelope using the same procedure as the Citabria. To cater to the differences in the Pawnee's performance, the IAS was varied between 110 and 70 mph and the RPM ranged from 1900 to 2300. Data was collected and processed as described in the Citabria section, the standard deviations for the peak, and average cooling envelopes being 1.8 and 1.6 C/min respectively, while the RoD standard deviation was 112 *fpm.* A complete review of the statistics is in Appendix HI. The Pawnee letdown envelope that was derived is shown in Fig 26. It was apparent that the Pawnee was well served by the original, one step letdown procedure and no changes were recommended or implemented. The only potential problem seen was a periodic event we described as the "double bump". This was a secondary cooling peak well after the glider released, generally occurring at throttle back in the landing circuit. Peak cooling rates as high as 35C°/min were seen during these events, an example of which is shown in Fig 27. Although the double bump event occurred infrequently (due to the potential for damage to the aircraft no attempt was made to force it to occur) it was noted that when observed, it was generally after a letdown that had not been very aggressive (ie, a long time elapsed between release and the establishing of the letdown RPM and IAS), or when the RPM was abruptly lowered in the landing circuit. To attempt to combat this, the following recommendations were implemented: 1) 105 mph / 2000 RPM should be established without undue delay after glider release, 2) a gradual throttle back should be started in the downwind leg of the circuit to maintain the engine cooling at a gradual pace until touchdown, 3) abrupt throttle backs should be avoided at high IAS at all times during the letdown.

In general, the peak and average cooling rates for the Pawnee are well below the Citabria's at any IAS/RPM setting while at the same time the rate of descent is far higher, making the Pawnee far easier to operate. Unfortunately, the Pawnee is also more sensitive to RPM and IAS variation than the Citabria (d(dT/dt)/d(RPM) being -.03 vs. -.015 C/RPM and d(dT/dt)/d(IAS) being .5 vs .23 C"/mph) and the combination of high descent rates and sensitivity to pilot error requires a more accurate and aggressive flying style very different from the more relaxed letdown used in the Citabria. This difference in required technique has lead to some operational difficulties (none insurmountable) as most towpilots fly both aircraft. A direct comparison of the Citabria and Pawnee letdown envelopes is shown in Fig 28.

General Results:

Some data obtained during the course of this study is of interest to the operators of glider towing aircraft, but does not fit conveniently into any specific category. The purpose of this section is to list these results in as coherent a manner as possible.

General Observations:

During the data collection for the Citabria letdown envelope, a sharp cold front allowed data points to be flown one day with an outside air temperature (OAT) of 25°C and then repeated the following day with an OAT of 5°C. This yielded the somewhat surprising result that OAT does not have a measurable effect on the observed cooling rates, at least within the range 25 to 5^DC.

A number of "wives tales" had evolved in glider towing operations and some of these were investigated. First, it appears that steep turns during letdown slightly reduce cooling rates for a given IAS/RPM combination. This is as would be expected due to the higher angle of attack carried by the aircraft when subject to increased "g" loading. Second, the application of continuous slip and skid, up to 1/2 ball deflection, resulted in no measurable differential cooling between me two sides of the engine. Third, there is no correlation between rate of descent and cooling rates.

Finally, the differences between aircraft types was startling. Small variation in the cowling and internal baffling arrangements of different aircraft lead to radically different cooling profiles. This was somewhat unexpected as the general arrangement of the engine compartments of all aircraft was similar.

Average turnaround times for sampled tows:

The average time taken for each tow used in this study was recorded as a side benefit to the general data collection required for the letdown cooling profiles. This information is summarized below.

Citabria:

1000'(6 tows)	tow: 3.7 min; variation: very small
2000'(67 tows)	tow: 7.3 min; variation: low 6.1 min., high 10.2 min
3000'(27 tows)	tow: 10.2 min; variation: low 8.2 min, high 11.3 min
4000'(7 tows)	tow: 13.7 min; variation low 12.8 min, high 14.5 min

Pawnee:
2000'(26 tows) tow: 5.6 min; variation: low 4.5 min., high 8.0 min
3000'(14 tows) tow: 9.8 min; variation: low 6.8 min, high 11.9 min
L-19:
2000'(15 tows) tow: 8.2 min; variation: low 6.4 min, high 12.4 min
3000'(14 tows) tow: 12.2 min; variation: low 9.5 min, high 14.4 min

These times are from the beginning of the takeoff roll to the end of the landing roll to eliminate any effect of flight-line efficiency.

Rates of Climb:

A detailed examination of the climb performance of the Pawnee was undertaken to verify the performance of the Hauffman 4 blade propeller fitted to this aircraft (this is believed to be the only Pawnee in North America so equipped). The Pawnee data was normalized to a takeoff weight of 851,9 kg (equivalent of full fuel and a 91 kg pilot), ICAO standard atmosphere at sea level, and glider type. Limited information for the L-19 is also presented but it is of a more general nature as no detailed records of pressure altitude or temperature were kept. Climb rates were found by averaging a reasonably smooth section of the climb between 500' and 1500' AGL

Pawnee:

Schweizer 2-33 (2 people);	617 ± 40 fpm
Grob G103 Twin Astir (2 people):	573 ± 24 fpm
Schweizer 1-26 (1 person):	801 ± 55 fpm
Single seat high performance:	750 ± 66 fpm
L-13 Blanik: (2 people):	685 ± 100 fpm

L-19:

Schweizer 2-33 (1 or 2 people):	474 fpm ± 63 fpm
L-13 Blanik (1 or 2 people):	517 fpm ± 88 fpm
Grob G103 Twin Astir (2 people):	416 fpm
Single seat high performance:	571 fpm ± 51 fpm

Pawnee Cooling and Descent Rate Data Statistics

Peak Cooling Rate

RPM / IAS	1900				2000				2100				2200				2300			
	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ
80	5	16.6	17.3	1.14	4	14.8	13.6	1.14	4	9.25	10.0	0.96	4	5.5	6.5	1.73	5	3.8	3.1	.83
90	4	20.5	20.4	1.29	4	18.25	17.0	1.29	4	14.0	13.6	1.63	4	11.5	10.4	1.29	4	6.5	7.1	3.32
100	5	24.8	24.2	1.30	4	19.0	21.3	1.30	4	17.3	18.2	1.71	4	15.5	14.8	1.91	5	11	11.2	1.58
110	4	28.5	28.6	2.08	4	27.5	26.6	2.08	4	23.3	23.7	1.5	4	20.5	19.9	1.29	4	15	15.2	1.83

σ using smoothed data as mean: 1.823 Average σ: 1.647

Average Cooling Rate

RPM / IAS	1900				2000				2100				2200				2300			
	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ
80	5	14.2	14.6	0.93	4	11.2	10.7	2.43	4	7.18	7.01	1.02	4	2.27	3.64	1.22	5	1.27	.57	.79
90	4	16.8	17.2	1.41	4	15.3	14.0	0.56	4	10.6	10.8	1.61	4	8.23	7.37	0.94	4	3.33	3.89	2.55
100	5	21.2	20.5	1.53	4	16.8	17.9	2.06	4	14.0	15.0	0.75	4	12.4	11.5	1.79	5	7.48	7.6	0.98
110	4	24.2	24.3	2.16	4	23.0	22.4	1.23	4	18.9	19.6	1.79	4	17.1	16.0	1.31	4	11.2	11.7	1.73

σ using smoothed data as mean : 1.567 Average σ : 1.441

Rate of Descent (+ indicates climb)

RPM / IAS	1900				2000				2100				2200				2300			
	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ	n	Mean	Smth	σ
80	5	252	245	115.2	4	+14	19	137.7	4	+179	+181	76.0	4	+334	+356	83.7	5	+519	+506	77.9
90	4	613	569	122.6	4	357	374	86.0	4	156	186	105.6	4	92	7	58.8	4	+197	+163	108.7
100	5	1049	1042	81.6	4	814	887	92.0	4	709	708	86.1	4	552	506	50.1	5	253	280	83.4
110	4	1676	1664	88.5	4	1574	1560	132.0	4	1337	1385	104.2	4	1199	1139	91.4	4	802	823	340.7

σ using smoothed data as mean : 112.5 Average σ : 106.1

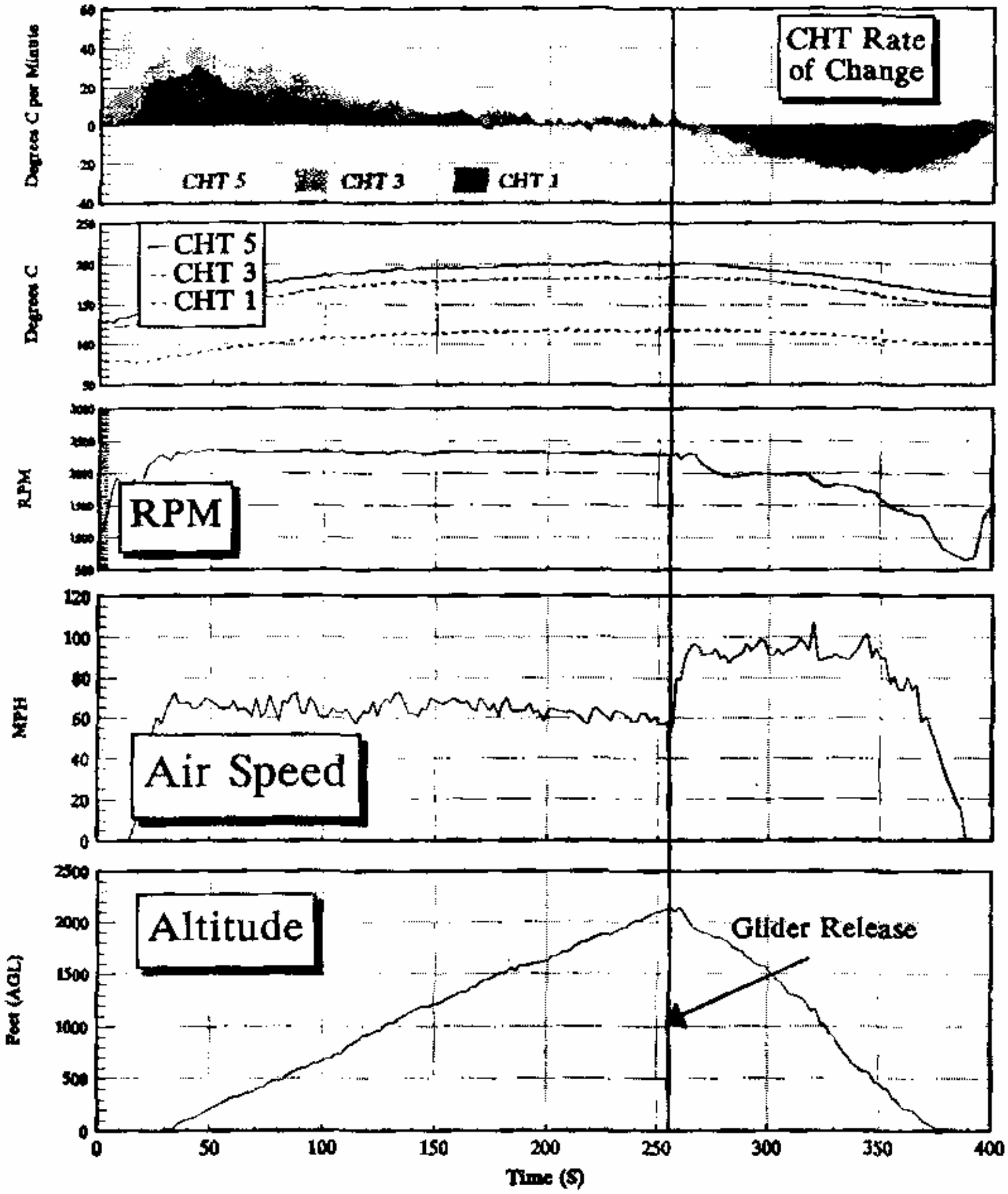

Figure 25 *Standard Pawnee 105/2000 RPM letdown.*

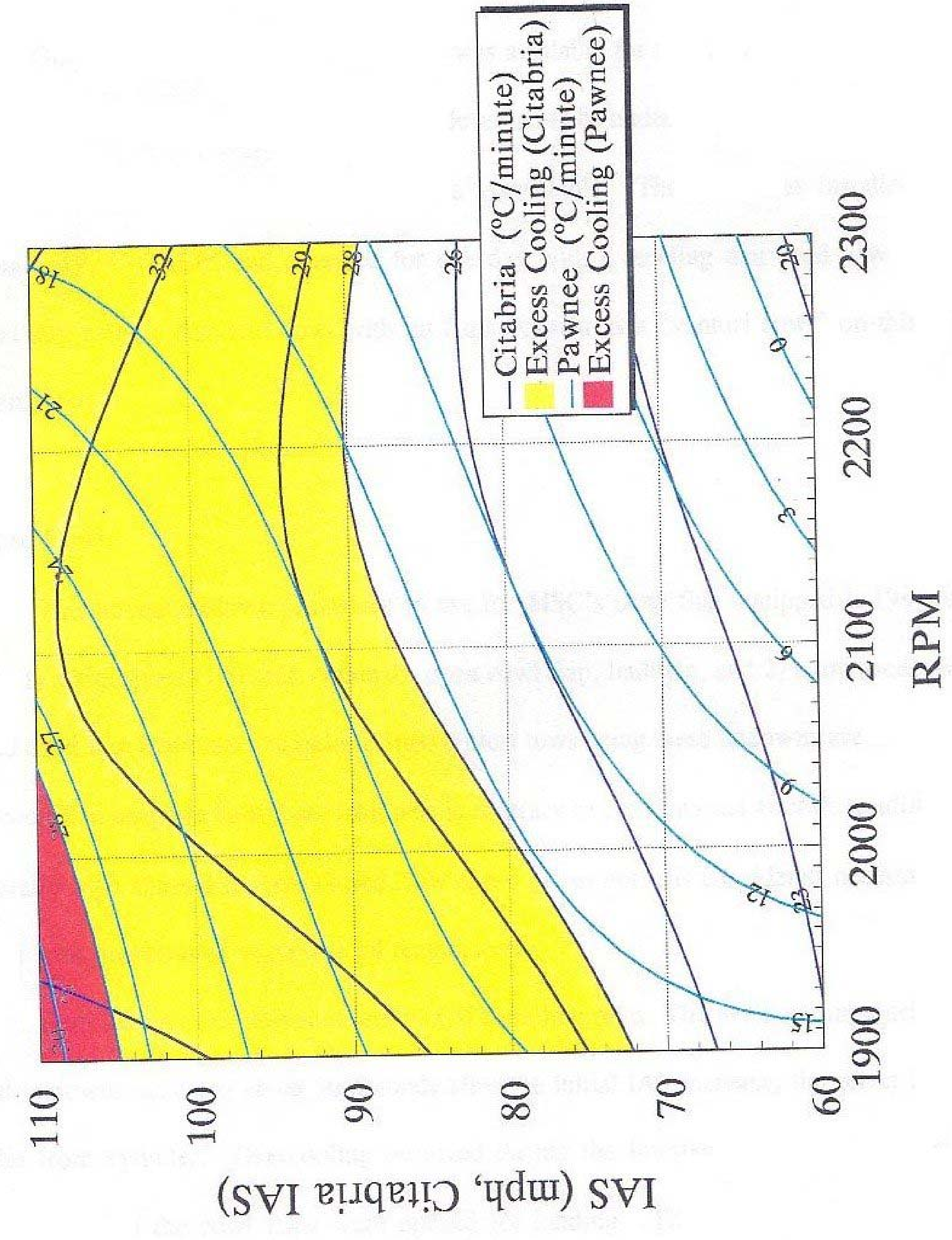

Figure 28 *Direct comparison of Citabria and Pawnee letdown envelopes.*

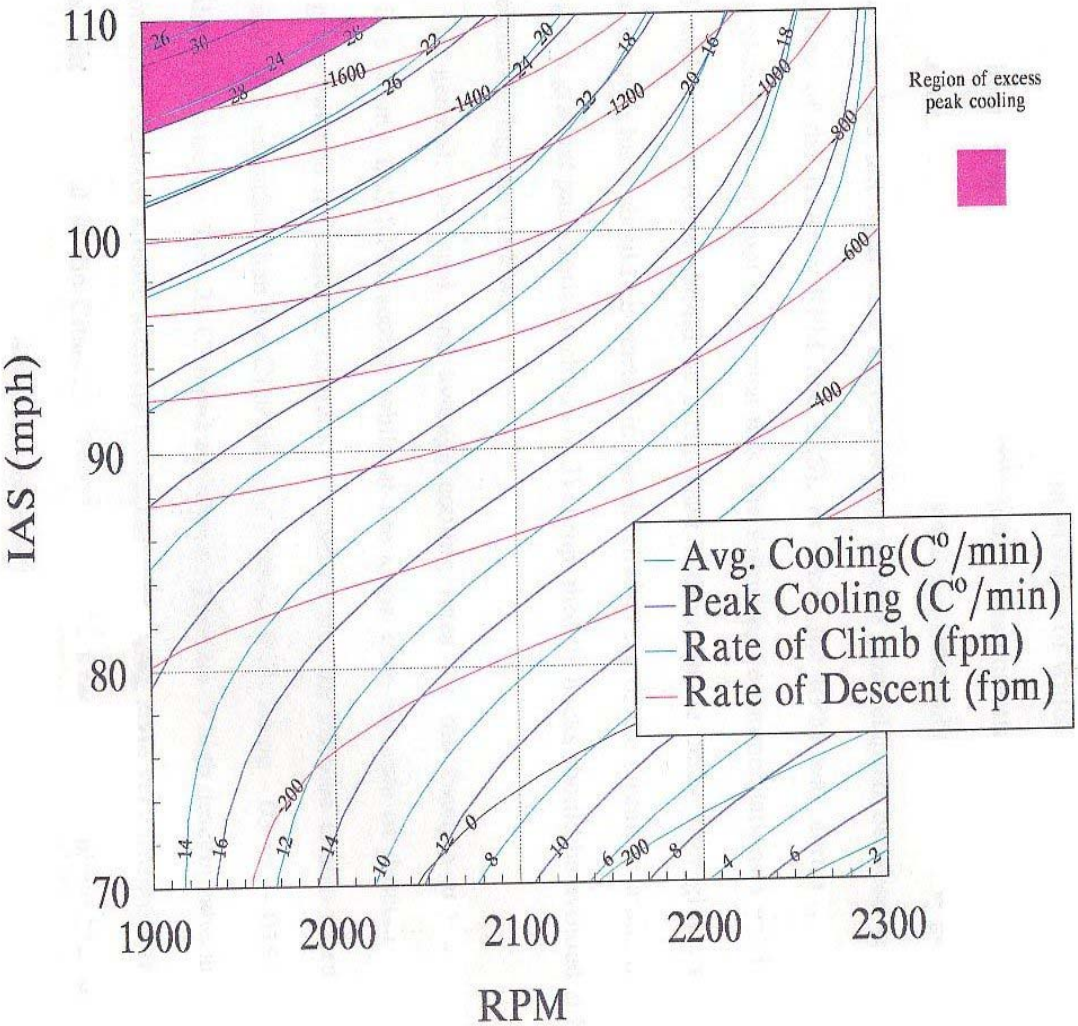

Figure 26 *Complete Pawnee letdown envelope.*

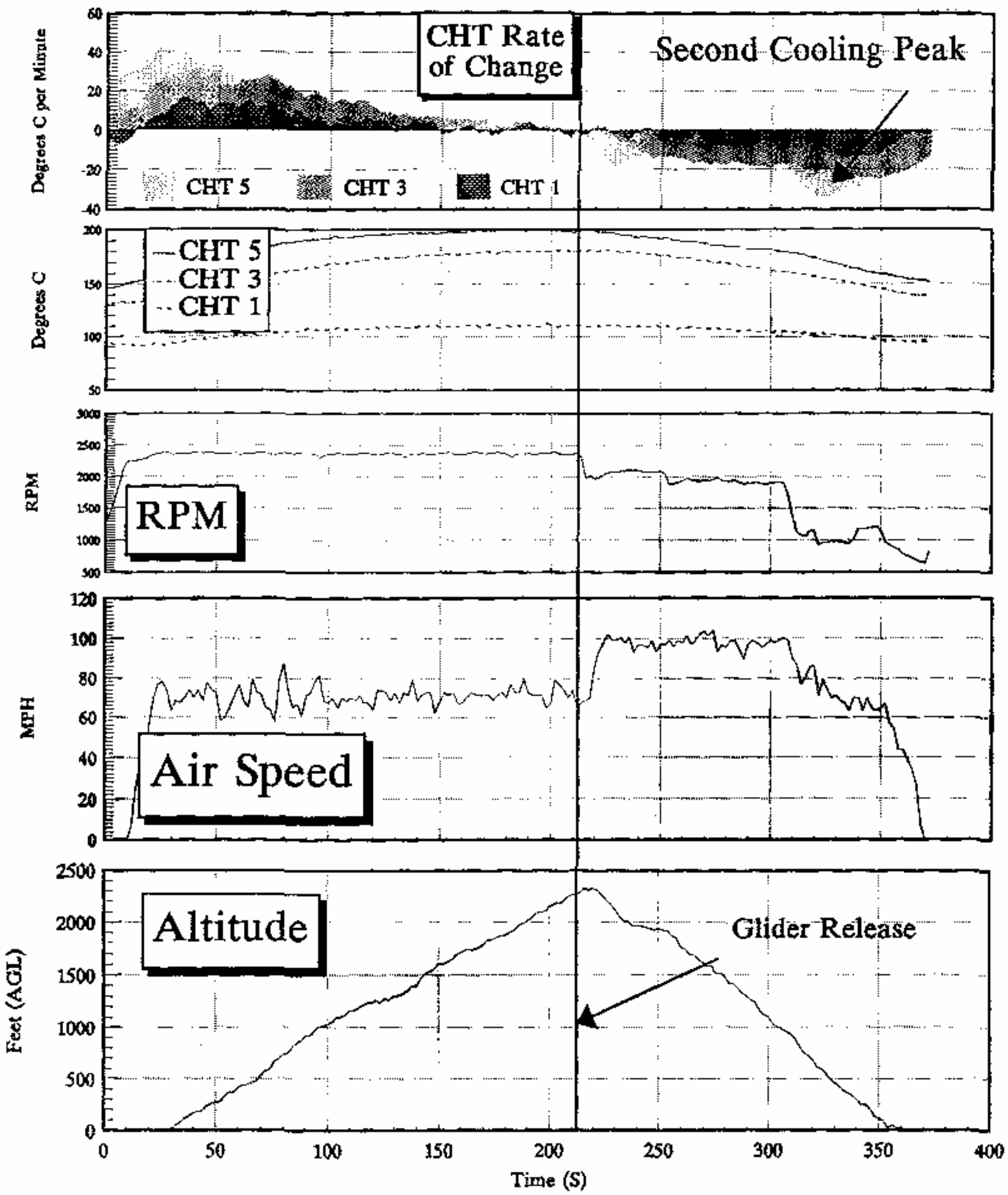

Figure 27 *Flight data for a Pawnee "double bump" event.*