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INTEGRAL TRANSFORMS OF H-FUNCTION OF TWO VARIABLES INVOLVING GENERALIZED M-SERIES

B. SATYANARAYANA[1], ALEM MEBRAHTU[2], Y. PRAGATHI KUMAR*[3]

[1]Department of Mathematics,
Acharya Nagarjuna University, Nagarjuna Nagar-522 510, India.

[2]Department of Physics, Adigrat University, Adigrat, Ethiopia

[3]Department of Mathematics, Adigrat university, Adigrat, Ethiopia.

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ABSTRACT

The object of this paper is to establish some integral transforms involving product of generalized M-series and H-function of two variables. Some special cases have also been derived.

Key words: *H-function of two variables, Mellin transform, Laplace transform and Generalized M-series.*

1. INTRODUCTION

Recently, the Mellin-Barnes type contour integral of H-function of two variables evaluated by P.C.Srinivas [9]. In the present paper we establish the Mellin transform and Laplace transform of H-function of two variables with generalized M-series.

We shall utilized following formulae in present investigation. The H-function of one variable given by Charles Fox [2]

$$H[x] = H_{p,q}^{m,n}[x] = H_{p,q}^{m,n}\left[x\left|\begin{matrix}(a_j, A_j)_{1,p}\\(b_j, B_j)_{1,q}\end{matrix}\right.\right]$$

$$= \frac{1}{2\pi \mathrm{i}}\int_{\mathrm{L}} \mathrm{F(s)x^s}\, ds, \quad \mathrm{i} = \sqrt{-1}, \mathrm{x} \neq 0 \tag{1.1}$$

Where

$$\mathrm{F(s)} = \frac{\prod_{j=1}^{m}\Gamma(b_j - B_j s)\prod_{j=1}^{n}\Gamma(1-a_j + A_j s)}{\prod_{j=m+1}^{q}\Gamma(1-b_j + B_j s)\prod_{j=n+1}^{p}\Gamma(a_j - A_j s)}$$

An empty product is interpreted as unity; m,n,p and q are integers satistying $0 \le m \le q$, $0 \le n \le p$; $A_j(j = 1,\ldots,p)$, $B_j(j = 1,\ldots,q)$ are positive numbers and $a_j(j = 1,..,p)$, $b_j(j = 1,\ldots,q)$ are complex numbers such that no poles of $\Gamma(b_j-B_js)$, $j = 1,\ldots,m$ coincide with any pole of $\Gamma(1-a_j+A_js)$, $j = 1,\ldots,n$ i.e $A_j(b_k+N) \neq B_k(a_j-M-1)$, where $k= 1,\ldots,m$; $j = 1,\ldots,n$; $M = 0, 1, 2, \ldots$

Corresponding Author: Y. Pragathi Kumar[3]*
[3]Department of Mathematics, Adigrat university, Adigrat, Ethiopia.

The contour L runs from σ-i∞ to σ+i∞, σ be a positive constant such that the points $s=\frac{b_h+N}{B_h}, h=1,...,m;\ N=1,...,n;$ which are the poles of $\Gamma(b_j\text{-}B_j s)$, j = 1,…..,m lie to the right and the points $s=\frac{a_j-M-1}{a_j}, j=1,.....,mn;\ M=0,1,.....$ which are the poles of $\Gamma(1\text{-}a_j+A_j s)$, j = 1,…..,n lie to the left of L.

The H-function of two variables given by Prasad and Gupta[6]

$$H[x,y]=H^{M,N:m,n;g,h}_{P,Q:p,q;u,v}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\middle|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p};(e_j,E_j)_{1,u}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q};(f_j,F_j)_{1,v}\end{matrix}\right]$$

$$=\frac{1}{(2\pi i)^2}\int_{L_1}\int_{L_2}\varphi_1(s)\varphi_2(t)\psi(s,t)x^s y^t\,ds\,dt\quad ,i=\sqrt{-1} \tag{1.2}$$

where x , y ≠ 0,

$$\phi_1(s)=\frac{\prod_{j=1}^{m}\Gamma(d_j-D_j s)\prod_{j=1}^{n}\Gamma(1-c_j+C_j s)}{\prod_{j=m+1}^{q}\Gamma(1-d_j+D_j s)\prod_{j=n+1}^{p}\Gamma(c_j-C_j s)}$$

$$\phi_2(t)=\frac{\prod_{j=1}^{g}\Gamma\left(f_j-F_j t\right)\prod_{j=1}^{h}\Gamma\left(1-e_j+E_j t\right)}{\prod_{j=g+1}^{v}\Gamma\left(1-f_j+F_j t\right)\prod_{j=h+1}^{u}\Gamma\left(e_j-E_j t\right)}$$

$$\psi(s,t)=\frac{\prod_{j=1}^{M}\Gamma\left(b_j-\beta_j s-B_j t\right)\prod_{j=1}^{N}\Gamma\left(1-a_j+\alpha_j s+A_j t\right)}{\prod_{j=M+1}^{Q}\Gamma\left(1-b_j+\beta_j s+B_j t\right)\prod_{j=N+1}^{P}\Gamma\left(a_j-\alpha_j s-A_j t\right)},$$

where *M, N, P, Q, m, n, p, q, g, h, u, v* are all non negative integers such that $0\le N\le P,\ Q\ge 0,\ 0\le m\le q,\ 0\le n\le q,\ 0\le g\le v,\ 0\le h\le u$ and $\alpha_j, \beta_j, A_j, B_j, C_j, D_j, E_j, F_j$ are all positive. The sequence of parameters (a_P), (b_Q), (c_p), (d_q), (e_u) and (f_v) are so restricted that none of the poles of the integrand coincide.

The contour L_1 lies in the complex s-plane and runs from -i∞ to +i∞ with loops, if necessary, to ensure that the poles of $\Gamma(d_j - D_j s)$, (j = 1, 2, ….. , m), lie to the right of the path; and those of $\Gamma(1 - c_j + C_j s)$, (j = 1, 2,….., n) and $\Gamma(1 - a_j + \alpha_j s + A_j t)$, ($j$ = 1, 2,….., N) lie to the left of the path.

Also the contour L_2 lies in the complex t-plane running from -i∞ to +i∞ with loops, if necessary, to ensure that the poles of $\Gamma(f_j - F_j t)$, (j = 1, 2,….., g), lie to the right of the path; and those of $\Gamma(1 - e_j + E_j t)$, (j = 1, 2,….., h) and $\Gamma(1 - a_j + \alpha_j s + A_j t)$, ($j$ = 1, 2,….., N) lie to the left of the path. All poles of the integrand are simple poles.

The Mellin transform of the function f(x) is defined as

$$M\left\{f(x);s\right\}=\int_0^{\infty}x^{s-1}f(x)\,d\,x\quad \mathrm{Re}(s)>0 \tag{1.3}$$

If Laplce transform of f(t) is F(p) and G(s) is Mellin transform of f(t), then

$$F(p)=\sum_{s=0}^{\infty}\frac{(-p)^s}{s!}G(s+1) \tag{1.4}$$

According Erdelyi [1, p.307]

$$\int_0^\infty x^{s-1}\left[\frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} g(s)x^{-s}ds\right]dx = g(s) \tag{1.5}$$

The Generalized M-Series is defined by Sharma and Renu[8] as

$$\underset{p\ q}{\overset{\alpha,\beta}{M}} = \underset{p\ q}{\overset{\alpha,\beta}{M}}(a_1,....,a_p;b_1,....,b_q;z)$$

$$= \sum_{k=0}^{\infty} \frac{(a_1)_k....(a_p)_k}{(b_1)_k....(b_q)_k}\frac{z^k}{\Gamma(\alpha k+\beta)} \qquad z,\alpha,\beta \in \mathbb{C},\ \Re(\alpha) > 0 \tag{1.6}$$

Series is convergent for all z if $q \geq p$, it is convergent for $|z| < 1$ if $p = q+1$ and divergent if $p > q+1$. Where $p = q+1$ and $|z| = 1$, the series convergent in some case. Let $\beta = \sum_{j=1}^{p} a_j - \sum_{j=1}^{q} b_j$

It can be shown that when $p = q+1$ the series is absolutely convergent for $|z| = 1$ if $\Re(\beta) < 0$. Conditionally convergent for $z = -1$ if $0 \leq \Re(\beta) \leq 1$ and divergent for $|z|=1$ if $1 \leq \Re(\beta)$.

2. MAIN RESULTS

Theorem 1: Prove that

$$M\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\middle|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right];s\right\}$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m} b_j}{\prod_{j=1}^{l} a_j}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k)}{\delta}}H^{M+m_1+n_2,N+n_1+m_2}_{P+p_1+q_2,Q+q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma\middle|\begin{matrix}(a_j+(\frac{s+\lambda k}{\delta})A_j,\alpha_j-(\sigma/\delta)A_j)_{1,P},\\ (b_j+(\frac{s+\lambda k}{\delta})B_j,\beta_j-(\sigma/\delta)B_j)_{1,Q},\end{matrix}\right.$$

$$\left.\begin{matrix}(1-f_j-(\frac{s+\lambda k}{\delta})F_j,(\sigma/\delta)F_j)_{1,n_2},(c_j,C_j)_{1,n_1},(1-f_j-(\frac{s+\lambda k}{\delta})F_j,(\sigma/\delta)F_j)_{n_2+1,p_2},(c_j,C_j)_{n_1+1,p_1}\\ (1-e_j-(\frac{s+\lambda k}{\delta})E_j,(\sigma/\delta)E_j)_{1,m_2},(d_j,D_j)_{1,m_1},(1-e_j-(\frac{s+\lambda k}{\delta})E_j,(\sigma/\delta)E_j)_{m_2+1,q_2},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

Provided $\sigma > 0$, $\delta > 0$, λ is complex number

$\alpha_j - (\sigma/\delta) A_j > 0$ for j = 1, 2, - - -, P

$\beta_j - (\sigma/\delta) B_j > 0$ for j = 1, 2, - - -, Q

$|\arg\gamma| < (1/2)\pi\Delta_1$, $|\arg\eta| < (1/2)\pi\Delta_2$

where $\Delta_1 = \sum_{j=1}^{N}\alpha_j - \sum_{j=N+1}^{P}\alpha_j + \sum_{j=1}^{M}\beta_j - \sum_{j=M+1}^{Q}\beta_j + \sum_{j=1}^{m_1}D_j - \sum_{j=m_1+1}^{q_1}D_j + \sum_{j=1}^{n_1}C_j - \sum_{j=n_1+1}^{p_1}C_j$

and $\Delta_2 = \sum_{j=1}^{N}A_j - \sum_{j=N+1}^{P}A_j + \sum_{j=1}^{M}B_j - \sum_{j=M+1}^{Q}B_j + \sum_{j=1}^{m_2}F_j - \sum_{j=m_2+1}^{q_2}F_j + \sum_{j=1}^{n_2}E_j - \sum_{j=n_2+1}^{p_2}E_j$

and $\mathrm{Re}\left\{s+\frac{\delta(a_j-1)}{A_j}\right\} < 0$ for j = 1, 2,….., N

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$\mathrm{Re}\left\{s+\frac{\delta b_j}{B_j}\right\}>0$ for j = 1, 2,….., M

$\mathrm{Re}\left\{s+\frac{\delta b_j}{B_j}+\frac{\sigma d_i}{D_i}\right\}>0$ for i = 1, 2,….., m_1; for j = 1, 2,….., m_2

$\mathrm{Re}\left\{s+\frac{\delta(e_j-1)}{E_j}+\frac{\sigma(c_i-1)}{C_i}\right\}>0$ for i = 1, 2,….., n_1; for j = 1, 2,….., n_2

Proof: To prove this theorem, take f(x) as

$$\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\middle|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right]$$ in (1.3),

then expression becomes

$$M\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\middle|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right]\right\} \tag{2.2}$$

$$=\int_0^{\infty}x^{s-1}M\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\middle|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right]\right\}dx$$

By using (1.2) and (1.6) represent H-function in integral form and M-series as series form. Put δt_2 = -u, we get

$$\sum_{k=0}^{\infty}\frac{(a_1)_k.....(a_l)_k}{(b_1)_k.....(b_m)_k}\frac{a^k}{\Gamma(\alpha k+\beta)}\frac{1}{(2\pi i)^2}\int_{L_1}\int_{L_2}\phi_1(t_1)\phi_2\left(\frac{-u}{\delta}\right)\psi\left(t_1,\frac{-u}{\delta}\right)\gamma^{t_1}\eta^{\frac{-u}{\delta}}x^{-u}x^{\sigma t_1+\lambda k+s-1}\left(\frac{du}{\delta}\right)dt_1\,dx$$

Interchange the order of integration, we get

$$=\sum_{k=0}^{\infty}\frac{(a_1)_k.....(a_l)_k}{(b_1)_k.....(b_m)_k}\frac{a^k}{\Gamma(\alpha k+\beta)}\frac{1}{\delta}\frac{1}{2\pi i}\int_{L_1}\phi_1(t_1)\gamma^{t_1}\left\{\int_0^{\infty}x^{\sigma t_1+\lambda k+s-1}\left[\frac{1}{2\pi i}\int_{L_2}\phi_2\left(\frac{-u}{\delta}\right)\psi\left(t_1,\frac{-u}{\delta}\right)\eta^{\frac{-u}{\delta}}x^{-u}\,du\right]dx\right\}dt_1$$

Use result (1.5) and (1.1) to get the result. Change of order of integration is justifiable due to convergence of integrals.

Theorem 2:

$$L\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\middle|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right];s\right\}$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m}b_j}{\prod_{j=1}^{l}a_j}\sum_{s=0}^{\infty}\frac{(-p)^s}{s!}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k+1)}{\delta}}H^{M+m_1+n_2,N+n_1+m_2}_{P+p_1+q_2,Q+q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma\middle|\begin{matrix}(a_j+(\frac{s+\lambda k+1}{\delta})A_j,\alpha_j-(\sigma/\delta)A_j)_{1,P},\\ (b_j+(\frac{s+\lambda k+1}{\delta})B_j,\beta_j-(\sigma/\delta)B_j)_{1,Q},\end{matrix}\right.$$

$$\left.\begin{matrix}(1-f_j-(\frac{s+\lambda k+1}{\delta})F_j,(\sigma/\delta)F_j)_{1,n_2},(c_j,C_j)_{1,n_1},(1-f_j-(\frac{s+\lambda k+1}{\delta})F_j,(\sigma/\delta)F_j)_{n_2+1,p_2},(c_j,C_j)_{n_1+1,p_1}\\ (1-e_j-(\frac{s+\lambda k+1}{\delta})E_j,(\sigma/\delta)E_j)_{1,m_2},(d_j,D_j)_{1,m_1},(1-e_j-(\frac{s+\lambda k+1}{\delta})E_j,(\sigma/\delta)E_j)_{m_2+1,q_2},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

Proof: To prove this theorem use (1.4) to get the result

3. SPECIAL CASES

(i) Take

$$(\alpha_P)=(A_P)=(B_Q)=(b_Q)=(C_{p_1})=(D_{q_1})=(E_{p_2})=(F_{q_2})=1$$

We get Mellin and Laplace transforms of G-function of two variables with Generalized M-series

(ii) Put M = N = P = Q = 0 in (2.1) and (2.3), we get

$$M\left\{ \overset{\alpha,\beta}{\underset{l\ \ m}{M}}(a_1,....,a_l;b_1,....,b_m;ax^\lambda) H^{m_1,n_1}_{p_1,q_1}\left[\gamma x^\sigma \middle| \begin{matrix}(c_j,C_j)_{1,p_1}\\(d_j,D_j)_{1,q_1}\end{matrix}\right] H^{m_2,n_2}_{p_2,q_2}\left[\eta x^\delta \middle| \begin{matrix}(e_j,E_j)_{1,p_2}\\(f_j,F_j)_{1,q_2}\end{matrix}\right];s\right\} \quad (3.1)$$

$$M\left\{ \overset{\alpha,\beta}{\underset{l\ \ m}{M}}(a_1,....,a_l;b_1,....,b_m;ax^\lambda) H^{m_1,n_1}_{p_1,q_1}\left[\gamma x^\sigma \middle| \begin{matrix}(c_j,C_j)_{1,p_1}\\(d_j,D_j)_{1,q_1}\end{matrix}\right] H^{m_2,n_2}_{p_2,q_2}\left[\eta x^\delta \middle| \begin{matrix}(e_j,E_j)_{1,p_2}\\(f_j,F_j)_{1,q_2}\end{matrix}\right];s\right\}$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m} b_j}{\prod_{j=1}^{l} a_j}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k)}{\delta}} H^{m_1+n_2,n_1+m_2}_{p_1+q_2,q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma \middle| \begin{matrix}(1-f_j-(\frac{s+\lambda k}{\delta})F_j,(\sigma/\delta)F_j)_{1,p_2},(c_j,C_j)_{1,n_1},(c_j,C_j)_{n_1+1,p_1}\\(1-e_j-(\frac{s+\lambda k}{\delta})E_j,(\sigma/\delta)E_j)_{1,q_2},(d_j,D_j)_{1,m_1},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

$$L\left\{ \overset{\alpha,\beta}{\underset{l\ \ m}{M}}(a_1,....,a_l;b_1,....,b_m;ax^\lambda) H^{m_1,n_1}_{p_1,q_1}\left[\gamma x^\sigma \middle| \begin{matrix}(c_j,C_j)_{1,p_1}\\(d_j,D_j)_{1,q_1}\end{matrix}\right] H^{m_2,n_2}_{p_2,q_2}\left[\eta x^\delta \middle| \begin{matrix}(e_j,E_j)_{1,p_2}\\(f_j,F_j)_{1,q_2}\end{matrix}\right]\right\} \quad (3.2)$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m} b_j}{\prod_{j=1}^{l} a_j}\sum_{s=0}^{\infty}\frac{(-p)^s}{s!}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k+1)}{\delta}} H^{m_1+n_2,n_1+m_2}_{p_1+q_2,q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma \middle| \begin{matrix}(1-f_j-(\frac{s+\lambda k+1}{\delta})F_j,(\sigma/\delta)F_j)_{1,p_2},(c_j,C_j)_{1,n_1},(c_j,C_j)_{n_1+1,p_1}\\(1-e_j-(\frac{s+\lambda k+1}{\delta})E_j,(\sigma/\delta)E_j)_{1,q_2},(d_j,D_j)_{1,m_1},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

(iii) For β = 1 in (2.1) and (2.3), we get Mellin and Laplace transform of H-function of two variables with generalized M-series by M. Sharma [7]

(iv) For l = m = 0 in (2.1) and (2.3), we get Mellin and Laplace transform of H-function of two variables involving Mittag-Leffler function $E_{\alpha,\beta}(ax^\lambda)$ [4]

(v) Take α = β = 1 in (2.1) and (2.3), we get Mellin the Laplace transform of H-function of two variables involving generalized hypergeometric function [3]

(vi) Put l = 0, m = 1 and $b_1 = 1$ in (2.1) and (2.3), we get Mellin and Laplace transform of H-function of two variables involving Wright function $W(ax^\lambda;\alpha,\beta)$ [5].

CONCLUSION

Thus we proved Mellin and Laplace transforms of H-function of two variables involving generalized M-series and special cases, which gives some interesting applications in fractional calculus.

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